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**Pacific Southwest
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General Technical Report
PSW-GTR-160

Proceedings of a Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues

March 19–22, 1996 **San Luis Obispo, California**

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Abstract

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Oak woodlands, the predominant vegetation type in the most inhabitable areas of California, comprise 10 million acres in the State and have been used primarily for livestock production. Today, residential intrusion into oak woodlands results in habitat fragmentation and degradation of economic, esthetic, and ecological values. Decision makers must face up to the population pressures caused by the increasing human population in California and its shift from coastal metropolitan areas into formerly rural areas—especially oak woodlands. Newcomers want roads, schools, housing, shopping centers, and water. How can oak trees compete with these needs and demands?

Retrieval Terms: oaks, oak management, range management, regeneration, wildlife, urban interface, restoration, economics, policy

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Proceedings of a Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues

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Preface

These proceedings concern California's 10 million acres of oak woodlands—the predominant vegetation type in the most inhabitable areas of the most populous and fastest-growing state in the nation. Oak woodlands encircle the Central Valley and extend southward along the coast to our border with Mexico. They occur in 54 of California's 58 counties, and 22 counties include at least 100,000 acres of oak woodlands. Since European settlement, the oak woodlands have been managed primarily for livestock production. Currently, about 80 percent are privately owned, and their primary use remains livestock production. But this enterprise is being threatened because greatly increased value has been placed on the woodlands within the past 20 years for esthetics, wildlife habitat, watershed functioning, maintenance of water quality, erosion and sediment control, outdoor recreation, and production of wood and specialty products.

During the first three quarters of this century, the primary change in extent and composition of oak woodlands was a result of conversion to rangeland and agricultural production. More than one million acres were thinned or cleared of oaks to enhance areas for grass production for livestock or to increase water yield. These practices may have been misguided. In the mid-1980's, residential development, which may fragment formerly contiguous woodlands, replaced rangeland conversion as the primary cause for loss of oak woodlands. Recent concern in coastal California has focused people's attention on the conversion of oak woodlands to vineyards. During the past several years, increased demand for wine grapes has driven up their value, resulting in unprecedented vineyard development. Demands on the oak-covered valleys and foothills are expected to continue—even to accelerate—as a result of demographic pressure and the social and economic needs of more than 30 million Californians. Population and economic expansion will continue to fuel concern for the well-being of the woodlands.

This is the fourth in a series of statewide symposia to focus attention on oak woodlands. The first was held at Claremont, California, in 1979. Each symposium has attempted to synthesize the state of our knowledge at the time. The second symposium, convened in San Luis Obispo in 1986, focused on issues of oak regeneration and the potential effects of land use on the oak resource. That symposium served as a springboard for the newly formed University of California's Integrated Hardwood Range Management Program (IHRMP), charged with the mission of maintaining California's oak woodlands through applied research and public outreach and education. The third symposium, held in Davis in 1990, provided the latest knowledge on the inventory, ecology, uses, and management of oak woodlands. The potential effects of habitat fragmentation and the role of local policy and planning efforts in maintaining oak woodlands were new research and education directions emphasized at that symposium. Building on the past three symposia and continued development of research information and education programs, this—the 1996 symposium—hosted nearly twice the attendance as the first symposium and was held once again on the campus of California Polytechnic State University in San Luis Obispo.

Since the first symposium, we have made great advances in our understanding of the functioning of the woodland ecosystems and in developing sound management strategies for woodland owners and managers. But this important work is not done. California added 6 million people to its population during the 1980's. Further increases of 6 million per decade are projected well into the next century. Accompanying this phenomenal growth has been a substantial movement of the state's population from large metropolitan centers to formerly rural areas. As a result, challenges at the urban-wildland interface have been accelerating for years; these promise to be among the toughest issues that we must address in our future management of the woodlands.

Statewide, many groups and agencies are seeking solutions to the issues associated with oak woodlands. They face the challenge of maintaining the ecological values of the woodlands while maintaining the livelihood of the present owners and a way of life for California's residents. Several partnerships have developed in this process. The **Integrated Hardwood Range Management Program (IHRMP)** has worked directly with the California Department of Forestry and Fire Protection and the California Department of Fish and Game on research and education programs. Research funded by this partnership has produced more than 150 technical papers and 50 extension education leaflets. **California Polytechnic State University, San Luis Obispo,** has a long and productive history of work on oak woodlands, especially on oak distribution, growth, and yield. Its Natural Resources Management Department teaches the only course devoted to the ecology and management of oak woodlands in the western United States. **Humboldt State University (Arcata, Calif.)** has given attention to wildlife issues in oak woodlands and, recently, **Chico State University (Chico, Calif.)** began a geographic information systems (GIS) program on detecting change in oak woodlands. The **California Oak Foundation** assists people working to improve oak conservation policies; enables youth to become responsible stewards of California's oak woodlands; and has reported on financial burdens, such as estate taxes, that landowners and their heirs face in keeping rural land in the family through the generations. The **USDA Forest Service's Pacific Southwest Research Station (PSW)** has increased its emphasis on research into ecological relations in oak woodlands. Recently, the **Station's Forest Fire Laboratory in Riverside, California,** began a program to address the effects of wildfire and prescribed burning in oak woodland. All of these organizations have worked in partnership to produce workshops, symposia, meetings, and one-on-one contacts to increase the awareness of oak woodland values among landowners, land managers, and city and county planners. Continued attempts are needed to develop other partnerships that seek amicable solutions to issues arising over oak woodlands.

This symposium attempted through the plenary presentations to educate the public about the diverse views on oak woodlands that are represented by different groups and management agencies. Themes of the plenary papers emphasized the need for (1) developing partnerships to address common goals, rather than creating obstacles that lead to divisive viewpoints, (2) financial relief for woodland owners to protect their way of life and the public's interest, in return for assurances of long-term land use and stewardship, and (3) better science and education to demonstrate to the public the multiple values of the State's oak woodlands.

Technical sessions provided a forum for researchers, land managers, and land-use planners to share their latest research about oak woodland ecosystems in California. The technical papers, all critiqued by peers, are presented here in eight topical sections. In addition, 15 poster presentations are presented as summary papers and 11 others are presented in abstract form.

Section I—Ecology and Regeneration. The 17 technical papers in this section deal with the role of oaks and associated plant species in nutrient cycling and factors that affect regeneration, including soil characteristics, shade, and herbivores. Several new lines of research are included.

Section II—Restoration. This section emphasizes efforts to restore stands of oaks in areas from which they have been eliminated. It is clear that restoration has gone beyond research and experimentation to direct implementation. Information is included on restoration of Engelmann, blue, valley, black, and Oregon white oaks.

Section III—Range and Livestock Relations. Seven papers discuss the influence of livestock grazing on ground squirrels, water quality in oak woodland riparian habitats, and the effects of season and intensity of grazing on erosion in intermittent streams.

Section IV—Wildlife Habitat Relations and Habitat Fragmentation. Presenters of nine papers report results of studies on the ecology and management of oak woodland amphibians, reptiles, birds, and mammals. Some papers show that we are now entering a phase of controlled experiments on the effects of management practices on wildlife in the oak woodlands. Habitat fragmentation is a new and emerging research area in the oak woodlands, an area that will be markedly enhanced by advances in geographic information systems (GIS) and spatial statistics.

Section V—Wood Products and Utilization. Four papers focus attention on the many uses of oak wood and oak woodlands: firewood, lumber, and specialty forest products, including cork from the introduced cork oak. Papers do not advocate the harvesting of large numbers of trees from the oak woodlands nor the need to investigate all woody materials as potential sources for wood products. The ultimate goal is to encourage sustainable use of the oak woodlands.

Section VI—Urban Forestry Interface Issues. Five papers provide information on the effects of development on oak trees and oak woodlands and highlight the need for long-term monitoring to evaluate the success of mitigation efforts. Several spatial scales of planning are needed to preserve oaks and associated habitats at the urban-wildland interface.

Section VII—Damaging Agents and Protection. Three technical papers provide information on wildfire, oak tree infection and disease, and the California Oak Disease and Arthropod (CODA) database. Since the last symposium, research has not emphasized the role of damaging agents, diseases, and insects on oaks, although this should not be interpreted as a lack of importance of these agents. Diseases are a major source of natural mortality among mature oaks. Insects, important as damaging agents, constitute the largest component of biological diversity in oak woodlands.

Section VIII—Economics, Policy, and Planning. Five papers represent the diversity of planning, legislation, and value approaches to managing oak woodlands. One important message that emerged: through research and education, we can help our elected officials conserve oak woodlands. Work is under way to provide policy makers a tool to understand the effectiveness of policy decisions on the economic forces that are affecting oak woodlands.

Information presented at this symposium indicates that concerns about the status of oak woodlands and solutions to the challenges are not static. Instead, they have been and will continue to be driven by California's demographic, economic, social, and political events, and by our understanding of the ecology of oak woodland ecosystems. We are presently less concerned about regeneration of blue oaks than we were in 1979, at the first oak symposium. We have developed regeneration techniques to apply where human intervention is needed. We also have realized that the apparently low level of regeneration by blue oaks in some areas may be in accord with nature's strategy to maintain this species. The same cannot be said about the state of valley oak regeneration, however. We now know much about what constitutes good habitat for wildlife species that use oak woodlands, but we know less about where and how much of that habitat is needed to sustain the ecological system and maintain its full spectrum of biological diversity. We are more concerned today about residential intrusion into oak woodlands and associated habitat fragmentation, and the degradation of economic, esthetic, and ecological values. The recent increase in conversion of oak rangelands to vineyards, driven by the increasing value of wine grapes, brings new challenges for the maintenance of wildlife populations, soil stability, riparian integrity, and watershed functioning. This shift in the use of oak woodlands again calls for developing new partnerships, information, and applications for minimizing and mitigating environmental degradation.

What does the future hold for California's oak woodlands? To paraphrase the views of Dan Walters, who presented the closing address for the symposium: The great story of California today is the explosion of the state's population, accompanied by the shift of population from coastal metropolitan areas into formerly rural areas—especially oak woodlands. Newcomers want roads, schools, housing, shopping centers, and water. Ironically, the impetus for this movement is to escape the crush of metropolitan life, but the newcomers then want to reestablish in their new surroundings the selfsame conditions they sought to escape. How can oak trees compete with these needs and demands? And will decision makers ever face up to the population pressures that created the threats to California's ancient oaks in the first place?

One fact seems abundantly clear to us. The economic, social, political, and natural resource issues addressed in this symposium, and the three that preceded it, will not disappear soon. We are making progress, but much remains to be done.

Norman H. Pillsbury
Jared Verner
William D. Tietje

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Student Symposium Team

Students from the Forestry and Natural Resources Leadership class (Norman H. Pillsbury, instructor) and the Recreation Administrative Events Planning and Management class (Carolyn B. Shank, instructor) at Cal Poly served as on-campus organizers and liaisons for the transportation, dining, advertisement, facilities, multi-media, agenda publications, session chair correspondents, student volunteer organizers, and a myriad of responsibilities associated with the production of a symposium of this magnitude. We thank these dedicated students for their hundreds of hours of class and volunteer time.

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Eleven scientists were responsible for technical review and editing of the papers presented at the Symposium (and subsequently published in these proceedings) and for following up with authors. These Consulting Editors moderated the sessions at the Symposium.

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Norman H. Pillsbury
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PLENARY ADDRESSES

California's Oak Woodlands: Where We Have Been, Where We Are, Where We Need to Go[1]

Jack Ward Thomas[2]

Oak woodlands comprise about 25 percent of California's forests and woodlands and include about 10 tree species, eight shrub species, and many hybrids. Three quarters of this resource is privately owned, mostly in large ownerships for agricultural and grazing purposes. This information comes from the latest available inventory of oak woodlands in the state, completed in 1985 by the USDA Forest Service, Forest Inventory and Assessment (FIA) Unit, located in Portland, Oregon. A new USDA Forest Service inventory has been done in California, but results are not yet available because of technical problems. They should be available early in 1997. The California Department of Forestry and Fire Protection has also inventoried oak woodlands using satellite imagery, and this information is available from that agency.

Oak woodlands yield important benefits to Californians. Water and watershed protection are probably the most important outputs of these woodlands, though most of the water in California originates at higher elevations. Other values include grazing, recreation, and wood products, in about that order of importance. Grazing occurs on about 75 percent of the oak woodlands, and these ecosystems produce about a third of the state's total forage. They are especially important as winter range for ranchers with access to higher-elevation summer range. Oak woodlands are extremely important for open-space and recreation uses because of their proximity to urban and suburban populations. Wood products include firewood and specialty products, such as furniture stock, flooring, and barrels.

Some other aspects of oak woodlands, such as their wildlife habitat and esthetics, have little or no direct economic value but are nonetheless important to California. For example, more than 300 vertebrate species use oak-dominated woodlands for reproduction, and many more spend some time in these woodlands. These include some threatened, endangered, and sensitive species, such as the California spotted owl and the willow flycatcher.

In recognition of these benefits to Californians, in 1986 the state initiated a 10-year program designated as the "Integrated Hardwood Range Management Program," which was designed to produce new information on oak management and transfer that information to managers of oak woodland resources. In 1988, the California Oak Foundation was chartered to foster the wise management of oaks. The California Legislature designated 1990 as the "Year of the Oak." And before this week's symposium (19-22 March 1996) in San Luis Obispo, California, previous symposia on oak woodlands were held in 1979, 1986, and 1990. Truly, considerable attention has been focused on California's oaks in recent years.

Before I issue the challenges that I was asked to provide in this address, I would like to review the past and present situations concerning oaks in California, as I see them.

[1]This was an invited, plenary paper for the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif. In the absence of the author, the paper was presented by Ronald E. Stewart, Associate Deputy Chief for Research, USDA Forest Service. None of the plenary papers presented at this symposium was subjected to technical peer review.

[2]Chief, USDA Forest Service, Box 96090, Washington, DC 20090-6090.

Where We Have Been

Oaks have been a part of California for at least 10 million years. For most of that period, impacts on the oak ecosystem were natural and dominated by periodic, climatic fluctuations and by natural fires. An important perspective to understanding the earlier impacts of humans is that the resource was extensive and the population small. Many of California's Native Americans depended upon the abundant oak resource. Within the past 3,000 years, Native Americans practiced localized and intensive land management, including hunting, forest burning, seed harvesting, pruning, irrigation, and thinning. Effects were probably significant locally but generally near natural conditions at the rangewide scale of the oak woodlands.

Immigration of non-Indian settlers in the early 1800's began a period of increasingly intense resource use and development. Europeans introduced cattle in the 1770's and, in so doing, they introduced non-native grasses and forbs. These introductions brought about major and probably irreversible changes. For example, California's native perennial grasses were largely replaced by European annual grasses, which adapted well to the Mediterranean climate. Changes in vegetation were reinforced by grazing.

Much of the gold rush of 1849, and other gold mining activities throughout the latter part of the 1800's, occurred in the foothill oak and oak-pine woodlands of the central Sierra Nevada. Placer, hard-rock, and hydraulic mining, combined with the associated settlements, brought about significant changes, readily visible today. Other long-term changes were introduced with the advent of fire prevention and aggressive fire control in the early part of this century.

Where We Are

In contrast to the abundant oak woodlands available to Native Americans and Europeans in the past, today the resource is limited in relation to the expanding population. At least 90 percent of California's 31 million people are living in urban and suburban communities. They increasingly look to the oak woodlands for open space, recreation, and community expansion.

Through conversion to agriculture and other uses, the state's original 10-12 million acres of oak woodlands have been reduced to about 7 million acres today. At the same time, riparian areas, which were hardest hit by conversion, were reduced from about 700,000 acres to about 20,000 acres today.

The California Native Plant Society considers the Valley oak and Engelmann oak to be threatened. Only about 4 percent of the state's woodlands and grasslands are protected. The human population has more than doubled in the oak woodlands since 1970, causing considerable conflict. Some of the fastest growth rates in the state are occurring in areas dominated by oak woodlands. As the population grows and the demographics of rural communities change, conflicts between agrarian and urban lifestyles increase. This brings increasing pressure to regulate historical land uses that conflict with environmental concerns and values of the new emigrants.

Conversion by development (both urbanization and agriculture) and the resulting fire and fragmentation of ecosystems foster concerns. The population boom in oak woodlands has resulted in the development of sizable communities there, in what were once sleepy hamlets that are now rapidly growing suburban centers, such as Oakhurst in Madera County. Because the woodlands in these areas have burned periodically, concern is growing that much property and many lives will be lost as a result of wildfire. More people also mean an increased chance of ignition. Conversion to agricultural uses such as open pastures and vineyards will likely continue. More houses, roads, vineyards, and so on mean more change, fragmentation, and actual loss of habitat. This can result in a continuing decline of wildlife species associated with the oak woodlands. Interactions between people and mountain lions are particularly volatile, and mountain lion management will again be on the state's ballot in March 1996.

Oaks have low survival rates in many areas of the state. Regeneration and survival are spotty and periodic. Thus, many stands have trees that regenerated around the turn of the century but have not regenerated since then. Considerable research in recent years has been devoted to the regeneration issue, and several organizations have spent much effort and money on planting oaks.

Changing lifestyles and values, together with public appropriation of private property rights, cause further concern. Ranchers in particular are seeing their way of life change as rural communities expand with urbanites. The freedom the ranchers once had to manage their lands is increasingly being curtailed by state and local rules and regulations. Obviously, the ranchers are not happy! On the other hand, many of the conservation groups are not happy about the changing character of the oak woodland ecosystem, and the urbanites who move into these areas are unhappy with the limited public services in more rural communities, the threat of wildfire, the smells of agriculture, and so on. This can result in very interesting mixtures of coalitions, depending upon the particular issue being addressed.

Where We Need to Go

California is fortunate. All the proper ingredients are here to solve these problems with the usual far-sightedness that distinguishes the State: (1) California is blessed with some very clear-thinking people from all sides of the oak woodland issue. It is my impression that many leaders from the agricultural, governmental, environmental, and conservationist perspectives are looking for working solutions, rather than for new battlegrounds to fight old wars. (2) California is blessed with some very innovative mechanisms, such as the Biodiversity Memorandum of Understanding, Conservation Reserves, and the Cooperative Resource Management Planning (CRMP) process as championed by the Natural Resource Conservation Service (formerly Soil Conservation Service). If these live up to their potential, they can provide some excellent solutions. The recent effort in southern California to take an ecosystem approach for the California gnatcatcher to provide sufficient habitat, while allowing development, shows promise for long-term answers to other problems. (3) We are beginning to understand how ecosystems work, and an ecosystem approach to management of oak woodlands is critical.

Although people may disagree about the concept of "ecosystem management" and what it means, clearly we are beyond attempting to solve our natural resource problems one species at a time. I appreciate the simple definition of ecosystem management implied by Aldo Leopold when he wrote, "The intelligent tinkerer saves all the parts." Simply stated, ecosystem management means the integration of ecological, economical, and social factors to maintain and enhance the quality of the environment to best meet current and future needs.

Ecosystems can be described at different scales in a hierarchy. These ecosystems are coupled to one another: changes in the structure or function of one ecosystem can have consequences in many contiguous and some noncontiguous ecosystems. For example, late successional and riparian forests in the Sierra Nevada are important habitats for wildlife, as are the low-elevation foothill oak woodlands and pine-oak forests. In the latter case, conversion of habitat and loss of ecological function in this zone have dramatically altered the grouping of species that once used these communities. A common and important pattern for many Sierra Nevadan birds is their seasonal migration up- and downslope. When specific habitats needed to complete critical life-history stages (for example, foothill zones for breeding) are disrupted, then species can be put at risk even if they are able to use other habitats for other needs.

We know that all ecosystems are dynamic, that they undergo change naturally, with or without human interference. Consequently, why should we worry about retaining natural diversity and function at any specific place or time? We worry because the rate and direction of change in natural systems are extremely important to ecosystem sustainability. Natural change tends to occur slowly over long periods of time, allowing structural elements and populations to adapt. By contrast, in some places in California over the past 150 years, humans have brought about ecological changes on a scale that, under natural conditions, would have required millions of years.

Healthy ecosystems in the future will require that managers act within natural ranges of change so that biota can adapt to them. We need to avoid changes within decades or centuries that are of such magnitude that they would occur naturally only over periods along a geologic time scale.

Because funds will always be limited, I suggest that we prioritize our ecosystem management efforts. First, we need to protect what we have while we learn to use it wisely. A priority must be placed on preventing further deterioration of key ecosystems. We know that it is far less expensive to protect ecosystems than it is to restore them. Second, we need to identify deteriorated ecosystems and together undertake efforts to restore them to a sustainable, productive state. Third, we need to learn how to better manage the oak woodlands to provide multiple benefits within the sustainable capability of these ecosystems.

Rather than getting side-tracked on terminology and the debate about the future of the concept for managing complex vegetation types, I will focus on some of its principles. A good starting point for reference is the "Interim Report" from the recent Workshop on Ecosystem Management held last December in Tucson, Arizona (*Interim Report. Toward a Scientific and Social Framework for Ecologically Based Stewardship of Federal Lands and Waters*. December 4-14, 1995). I will briefly discuss four aspects of the principles of ecosystem management, based on that report: (1) science-based management, (2) people as part of the ecosystem, (3) partnerships to make it work, and (4) telling the public the ecosystem management story.

Science-Based Management

Everyone understands that good science is critical to good decision making, but much research is not relevant to the actual decisions that managers must make. In particular, we increasingly need research that looks at structure, composition, and function simultaneously, and at multiple scales. Because this kind of research is the most expensive to undertake, it is also becoming critical to build constituency support for scientific research. Finally, and perhaps most importantly, much of the controversy surrounding resource management questions is not due to a lack of science, or disagreements about the state of nature, but instead involves basic disputes about human values. Scientists and decision makers need to make sure these issues are clearly separated in both the research and decision-making processes.

Good information is required to make good management decisions. Thanks to the state's Integrated Hardwood Range Management Program, started in 1986, as well as other efforts, we now know a great deal more about oak woodlands than we did a decade ago. We still have a ways to go, however, particularly for valley and Engelmann oaks, and for oaks found in forested ecosystems. When the next USDA Forest Service FIA inventory is available, it will add to our understanding of the nature and extent of the hardwood resources in California.

Concerns about low rates of regeneration have stimulated considerable research, particularly on blue oak. Results of this effort have been reported in previous symposia, and our knowledge will be expanded at this symposium.

Profitable areas of research include silviculture, disturbance ecology, wildlife habitat relations, and economic benefits and tradeoffs. It is unlikely that sufficient public funding will be available to protect and restore a significant amount of the oak woodland resource, so I believe that we need to find ecologically sound management techniques that provide a return on investment whenever possible. Research results must be packaged in ways that invite rapid adoption by land managers and policy makers.

We should keep in mind, however, what one participant at the Ecosystem Management Workshop said: "No matter how good and useable the science is, nothing of great value will result without support for, and direct action by, local communities. The trust and confidence required for this may take years. Only then is the science useful/useable."

The challenge is to continue to support the quest for better scientific understanding of the oak woodland ecosystem. More research is needed on oak woodland dynamics, especially on such topics as patterns of natural disturbance, responses to people's activities, and ecosystem processes. More information on silvics of individual oak species and their associates is also important. Finally, we need better information on the occurrence and habitat requirements of plant and animal species dependent upon the oak woodlands.

People As Part of the Ecosystem

Unfortunately, some individuals would argue that people are not part of the ecosystem—that the only acceptable ecosystem is one in which natural processes are allowed to continue without the influence of humans. I disagree. First, with the population of California at more than 31 million, we could not exclude people from the oak woodlands even if we wanted to. As I mentioned earlier, the human population has more than doubled in the oak woodlands since 1970, and the fastest rates of growth in the state are generally occurring in the Sierra Nevadan foothills, where oak woodlands are common. Second, humans have already influenced the oak woodlands significantly, and it would be prohibitively expensive to try to return to "natural conditions" even if we could define what those conditions are. For example, some would advocate allowing wildfires to burn. Given that decades of fire prevention and aggressive fire suppression have allowed fuels to accumulate to unnatural levels, and that expensive homes and new communities are interspersed within the oak woodland, return to natural fire regimes is not acceptable.

As another participant at the Ecosystem Management Workshop said: "Ecosystem management is about people and for people. It is a tool for meeting people's needs for a sustainable natural system. It is a device to help us realize our very human goal of passing on to our children and theirs a world that will sustain them." What are the criteria for sustainable, forested ecosystems? Ecosystems are sustained when they maintain native biological diversity, when they are resilient to stress, when they adapt to major environmental changes, and when they support human needs and desires.

People living in and using the oak woodlands now expect many things:

- *Products*—clean water, meat, firewood, wood for specialty products.

At the same time, the demand exceeds what is available.

- *Recreational opportunities*—sightseeing, off-road vehicle trails, hunting, camping, hiking, picnicking, and so on. Yet, the supply of public areas is limited.
- *Biological diversity and ecosystem integrity*—People want to know that oak woodlands will continue to be part of California's landscape. Yet, more houses, roads, and so on mean change, fragmentation, and loss of habitat. This, in turn, can result in the loss of species.
- *Property and associated values*—home sites, ranching, community values. Yet, these values are changing with the influx of urbanites and the public appropriation of private property rights.
- *Safety*—fires controlled quickly without property damage or loss of life. Yet, fuels and ignitions are increasing, fire fighting resources are being reduced or stretched to their limit, and values at risk are increasing.

The challenge is to find the mix of oak woodland outputs that best meets human needs, both public and private, within the sustainable capability of the ecosystem. This implies some continued active management, based on better scientific information.

Partnerships to Make Ecosystem Management Work

Ecosystem management absolutely will not work without partnerships. Most of the oak woodlands are owned by private parties, yet many of the services of the woodlands accrue to the public at large. These include scenic vistas, recreational opportunities, biological diversity, clear air, open space, and wildlife. Partnerships can counter fragmentation effects on biodiversity, resource management, fire protection, economies of scale, and so on. The problems cross boundaries; so must the solutions.

As another participant at the Ecological Stewardship Workshop said, "Ecosystem management is not about 'us' or 'them,' but rather it transcends ownership boundaries and should be recognized as 'we' resource management. All parties can contribute, and all groups need to recognize each other's contributions. The expectation should not be maps of specific ecosystems or specific prescriptions for ecosystems, but rather we should look for tools and frameworks that all land managers, regardless of ownership objectives, can use to integrate scientifically based ecosystem approaches into their programs."

The challenge is to continue production of public goods and services while maintaining private property rights. CRMP, Conservation Reserves, and tax relief are especially useful for cooperative planning and mitigation (the former) and providing incentives to private owners to provide public benefits (the latter).

Telling the Public

A well-informed public will likely make better decisions. The "public" includes woodland owners, woodland users, community leaders, consumers of woodland products, the press, and the voting public in general. We must communicate research results in ways that people can understand. We must also communicate the reasoning behind our management decisions.

Social commitment exists for environmental protection, but social support for ecological stewardship must be improved. Somewhere along the way, ecosystem management got a bad name. One reason is the perceived negative effect of ecological stewardship on natural resource jobs—right or wrong, that is the perception. To gain legitimacy, ecosystem managers must tap into core public values and build social support for science and management dedicated to sustaining healthy, productive ecosystems. This effort is not about "big government." Rather, it is about looking for collaborative approaches among all landowners who desire health and productivity for the lands, waters, and resources they manage.

Successful approaches to ecosystem management are increasingly community-based—initiated by local people and motivated by a "love of place." In such cases, ecosystem management is in the local interest and is a means to achieve the beneficial use of its "natural capital." There is a growing realization that a long-term approach to land use and management is generally better ecologically and economically for developing harmonious and sustainable relationships between people and the land. Ecosystem management is also a means to build trusting relationships, often among former antagonists, to gain political power in furthering envisioned ends.

The challenge is to have both woodland managers and the public making informed decisions.

The Challenges Ahead

By way of summary, I challenge you to incorporate ecosystem management into California's oak woodlands by

- Providing new information for management decisions. This information must be readily available and user-friendly. Science-based knowledge that provides better explanations of how oak woodland ecosystems function is especially needed. An important tool is a continuously updated, statewide geographic information system accessible to local planners and the public.
- Finding the mix of oak woodland outputs that best meets human needs, both public and private, within the capabilities of the ecosystem.
- Continuing production of public goods and services while maintaining private property rights through partnerships.
- Making better woodland management decisions through efforts to keep the woodland manager and the public better informed.

I believe that you are up to these challenges.

A California Cattleman's Perspective on the Oak Hardwood Issue[1]

Richard O'Sullivan[2]

Webster's definition of ecology is "that branch of biology that deals with the relationship between living organisms and their environment," and the definition of an ecosystem is "a community of animals and plants and the environment with which they are inter-related." We as human beings are part of these definitions, even though we are not animals of the four-legged kind. We most certainly are living organisms, and we are definitely inter-related with the environment. Like it or not, we must realize this and understand our relationships with the environments within which we live and with which we interact. The question then arises, and rightly so, "Do we as human beings truly understand this relationship?" Do ranchers truly understand the concerns of an urban society? Not really, although we are certainly trying to do so.

Most ranchers live out of town, and many of us spend every day in either the oak woodlands or conifer forests. We primarily graze cattle. We live in and work on the land that urban society is so concerned about. Such terms as ecology, ecosystem, and biodiversity are new to us. But this does not mean that these terms represent new concepts. Quite the contrary. We have been dealing with the ecology of living organisms within rangeland ecosystems and the biodiversity that this represents for generations. We live in this type of environment because that is the lifestyle we have chosen, and we are just as much a part of the range as the animals that live upon it. It is not for financial gain that we ranch in such environments as oak woodlands because not many individuals in ranching will tell you that the economics of this business are favorable. We certainly do not wish to live within a sterile environment devoid of trees and wildlife. Ranchers for generations have understood that, if they are to live life within environments such as oak woodlands, they must be conservationists.

We must protect and care for the natural resources on our ranges, where cattle have become a part of the ecology, a part of the ecosystem, along with the deer, quail, wild turkeys, squirrels, rabbits, and many other creatures. Indeed, no one is more concerned about rangeland wildlife than the typical rancher. When he builds a reservoir in a normally dry area, he gets much satisfaction from observing wildlife using his pond along with cattle. When he puts out salt or other feed supplement for his cattle and he sees wildlife using it, he does not complain. He takes pride in the fact that he is helping other animal life. For example, our eastern Tehama County ranges are deficient in selenium, an important mineral for livestock and wildlife. Ranchers in the County place selenium salt and supplement on the range, knowing full well that not only the cattle benefit but also the deer will benefit.

I know of no rancher who is not concerned with the deer herd. Quite frankly, most ranchers in our area have a great deal of difficulty understanding the public policy toward deer. We see the deer herd declining, not because the forage is unavailable but because of increased hunting pressure, the mountain lion, and the public highways that cross rangelands. Of course, how can we expect public policy to take care of the deer herd when it appears that public policy cannot take care of the people?

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[1]This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif. None of the plenary papers presented at this symposium was subjected to technical peer review; the views expressed and the mode of expression are those of the presenters, in behalf of the organizations they represented.

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Public policy has changed throughout the years with regard to conservation issues. The early conservation movement in this country was characterized by great debates between preservationists, who believed in little or no utilization of natural resources, and conservationists, who believed in a certain degree of utility. That same debate rages on today. A rancher's viewpoint of conservation, for the most part, combines a degree of preservation along with the utilization of natural resources. We look at many natural resources on our lands as renewable.

For example, consider rangeland grasses, the primary resource for sustaining our livestock. Without the grass, our enterprise cannot survive. We must return to the same range year after year. Consequently we treat it as a renewable natural resource and devise grazing programs and range improvement programs that benefit the resource. One strategy uses rotational grazing programs, within the confines of winter grazing and, in a broader sense, rotational programs from winter ranges to spring ranges to summer ranges. Our fall and winter ranges are rested in the spring to allow regrowth of grass for the next year. Spring ranges are usually grazed for a shorter time, and we then move cattle to the mountains for summer grass. This program has been successfully followed for generations.

In addition to rotating livestock, we must follow some basic concepts in range improvement. We know that a range abandoned will ultimately revert to brush and canopy cover that will choke out the grass. For years, ranchers controlled this problem through the judicious use of fire, which was always a natural part of the ecological process of rangeland ecosystems. Old-timers, every year, when moving cattle to the mountains, burned buck brush and live oak thickets behind them. Where rangeland oaks were so thick that grass would not grow, ranges were thinned. In some areas, oaks were removed entirely. The federal government got involved with brush removal programs, including the bulldozing and burning of oaks. As a matter of fact, this federal program is still available, and the government will pay more than half the cost! This program lost popularity when the value of firewood increased.

The cutting of rangeland oaks for firewood became a matter of major concern in many northern counties, reaching its zenith about 4 years ago when the State Board of Forestry was considering regulation. Ranchers became increasingly concerned. Knowing full well that areas of range needed treatment, knowing that they could not survive if the grass were choked off, and understanding the value of oaks to the rangeland, it became clear that they needed to get involved. Involvement came through cattlemen's associations, at both State and local levels. Those of us who happened, by chance, to be on the front lines in the cattlemen's associations caught most of the pressure.

In my mind it was clear. Oaks are a natural part of the landscape. There are geographical differences throughout the State concerning oak species—how rapidly they grow, how thick they grow, and how they regenerate. For more than 100 years, ranchers have been more or less protectors of the open space. What they did on rangelands affected not only livestock grazing but also wildlife, water, air, and any other natural entity on that land. I knew that the majority of ranchers understood this and were practicing sound conservation measures that would preserve the land. They wished to pass this land down to future generations. I also understood that the vast majority of ranchers were not interested in bulldozing and burning oaks. Their thinning programs were just that—thinning. They were very concerned about erosion and understood the importance of maintaining trees along ravines and draws to control it. Oaks are a renewable resource that could, if handled properly, enhance land values. Finally, and of most importance, I understood that this was a private property rights issue.

Ranchers owned not only the land but also what the land grew. I felt that if the regulatory hand of the State fell upon ranchers, it would not improve the situation but would, instead, create an adversarial climate and drive ranchers back to land-clearing programs. Ultimately ranchers would respond by selling more land, resulting in more subdivisions and ranchettes. The way to approach this became obvious. Somehow, individual responsibility had to surface. Because of the geographical differences between counties and because the residents within a county were more in touch with their particular local problems, it was a local issue. Because most of the rangeland within counties was owned by ranchers, they simply had to become actively involved in the process.

Tehama County became directly involved in the oak/hardwood issue when both Tehama and Shasta counties were identified by the California Department of Forestry as being significantly involved in the cutting of oaks for firewood. At a State Board of Forestry meeting, a Tehama County Supervisor and the Tehama County Cattlemen's Association took the position that State regulations were not the answer, that this was a local problem requiring a local solution.

A diverse advisory committee was formed in Tehama County, through appointments by the Board of Supervisors. The committee developed a voluntary set of oak/hardwood management guidelines to aid landowners in managing their oak/hardwood resources. This committee is still active today and has been well-accepted within the county. Later, the California Cattlemen's Association adopted an oak/hardwood policy that followed Tehama County's lead. This policy has three major points: to encourage the landowner to develop his own oak/hardwood management plan, to encourage the landowner to educate himself concerning oak/hardwoods, and to encourage the landowner to establish his own process of review. We believe in individual responsibility, and we believe the landowner has a responsibility toward the land he owns.

We understood that it would be difficult to make the educational material available to the landowner. This is where the University of California came in. The University responded positively through the Integrated Hardwood Range Management Program, as established by the State Board of Forestry. Since then, educational seminars have been directed toward landowners and woodcutters. Rick Standiford and his associates have just finished the draft text on oak woodland management guidelines. To the University's credit, comments were taken from the cattlemen's associations—specifically from ranchers who live and raise cattle within oak woodlands. These guidelines present extensive information that I know will be of great value to landowners planning their own oak/hardwood management programs.

Now it has moved even farther forward. Not only have the northern counties put forth their own criteria in their respective counties, but also a voluntary oak/hardwood plan has been filed with the Tehama County Agricultural Commissioner's Office by woodcutters operating within the county. Things are on the right track, but much work remains to be done. Much of this work is going to be related to the question: Can the rural rancher communicate with the urban city dweller? And vice versa: Can the urbanite communicate and understand the rancher's point of view? This remains to be seen. Both are property owners and both have private property rights related to what they own. Both need to understand the other's point of view.

I would not attempt to tell you here today that I understand how all ranchers look at their ranges and the natural entities upon them. I believe that the spectrum of thought ranges from a few that are preservationists, such as an individual who ranches for wildlife, to those that have a purely utilitarian concept of natural resources. Most ranchers will fall somewhere in between, in many cases having been raised for generations on the same land and having a genuine appreciation for the land and what it produces. They also understand the concept of utility when it comes to renewable natural resources. They are very independent and, in most cases, rugged individuals. They prefer to keep to themselves and not enter into anyone else's business. They believe in the free enterprise system and the right to own private property. These beliefs run deep in this regard. When you analyze this belief, it is fundamental to the concept upon which this country was founded. The right to own private property is one of the basic rights that protects all of us from the concentration of governmental power. When it comes to productive resources that land produces, especially those resources that are renewable, the concept of conservation is based not only upon preservation but also upon the utilization of these productive resources. A resource that is renewable can be productive for generations, which is in the best interest of society and the producer.

It is important that we make a clear distinction between renewable and nonrenewable resources. For example, after the northern Sacramento Valley was settled and riverboats and locomotives became the principal means of shipping goods, thousands of cords of oaks were cut to fuel these methods of transportation. I am sure that if the environmental concerns of today were present at that time, a major conflict would have developed. Here we are, 80 to 90 years later, and many of those same lands that underwent significant cutting in earlier days have been cut and recut and are still growing oaks. I am most certainly not implying by this observation that oaks can be indiscriminately cut or removed without upsetting the balance between preservation and conservation. I am simply noting that oaks do regenerate. With regard to oak regeneration, there are geographical differences throughout the State. Oaks, if looked upon as a resource, are renewable.

So how does a rancher look at rangeland oaks? We certainly cannot presume that each person looks at oak trees in the same manner, but I think it is safe to say that ranchers view oak trees in a manner similar to other people. Ranchers know that oaks most certainly have an esthetic quality to them. People enjoy seeing oaks, they are part of the landscape. We also know that oak woodlands support a wide variety of wildlife that are a natural part of the range. Oaks provide shade, a certain amount of protection for forage, and help to prevent soil erosion. Ranchers have, within the confines of range improvement, thinned oaks out to promote grass production and sold firewood from this thinning. There is a small economic benefit to ranchers, in tough times, to be able to to sell firewood.

One of the most interesting concepts to surface in the past few years is that sustainable grass and forage production is stimulated through maintaining a canopy cover. This concept indicates that grass production over time on properly thinned range will exceed the grass production on clear-cut range. The idea is that if you clear cut a range, making it devoid of canopy cover, you get an initial flush of grass. After a few years this flush of grass recedes, and the longer term effect is that you get less grass over time than if you had maintained some canopy cover. It seems that many different environmental factors, including geography, annual precipitation, and locality, influence the oak canopy/grass relationship. Certainly more research is needed on this issue. Examine both the positive and negative effects of canopy cover and oak mast on grass production, with respect to both quantity and quality. Let us see what nutritive value oak mast and debris have to the soil.

We do understand one of the principal negative effects oaks have and that is the production of tannic acid. I have read a number of times that livestock producers considered acorns as a source of nutrition for cattle. I do not. As a matter of fact, acorns are toxic to cattle. The degree of toxicity depends upon the amount of acorns an animal ingests, the age of the animal, the nutritional state of the animal, and the particular stage of development that the acorn is in. Let me give you my personal experiences with acorn toxicity.

First, we all realize that the production of acorns varies from year to year. It varies to the point that it is not a reliable source of nutrition even for deer in the fall. Indians used to say that a heavy acorn year would precede a hard winter.

The one thing that I could not quite understand about the heavy acorn production and a hard winter was what they meant by "hard winter." When I thought a bit about this, I decided that every winter was a "hard winter" for the Indians. I doubt whether they ever had an easy one! What I did discover was that a heavy acorn year can be especially tough on livestock.

Yearlings seem to be most affected. They can die, full of acorns, with their kidneys destroyed. I did autopsies on several yearlings and sent their kidneys to a laboratory for analysis. The results were clear: acute renal failure caused by an accumulation of tannic acid in the kidney, which resulted in uremic poisoning and death. In adult cows, the situation was not quite so severe, although we had an occasional fatality. Cows were eating acorns in the last trimester of gestation and, when suffering from nutritive deficiencies, as they do in the fall, can produce what we call "acorn calves." Acorn calves are calves that are deformed, with shortening of the long bones, undershot jaws, and an abnormal cranium. The mortality rate is higher than normal, and calves that survive have absolutely no economic value. Another interesting observation was that, after the rains came, acorns soften and open and they did not seem to bother the cattle as much. Knowing that serious harm to the cattle can be associated with their eating large quantities of acorns, ranchers have attempted to control the problem by thinning oaks and finding alternative sources of feed during these tough times. However, it must be understood that, in many situations, ranchers are unable to significantly supplement cattle on the range. In this regard, weather and economics play a major role.

In contrast to cattle, hogs can eat acorns without adverse effects. They will actually fatten up on them. Oldtimers would sack acorns in the fall to feed their hogs during the winter, and I know ranchers today who turn hogs loose to lighten the load of acorns in heavy mast years before livestock are turned out. But whoever came up with the idea that acorns are nutritionally important to cattle obviously was not in the livestock business or, if they were, I doubt whether they were in it for long!

I think it would be worthwhile for the scientific community to study the differences in tannic acid concentration in acorns on the tree, after they fall to the ground, and after they have softened and opened up. A better understanding of this question would certainly help the livestock owner to manage his oak woodlands for grazing. A related question, and a more basic one, is: Why do the oaks produce tannic acid in the first place? For example, what effect does tannic acid have on inhibiting competitive plant growth?

I would not want to leave this subject of toxicity without mentioning oak bud poisoning. About 9 years ago in the northern Sacramento Valley, approximately 800 hundred head of cattle died from this condition, and in the following years the deer count declined. Oak bud poisoning is a peculiar and uncommon event related to oak buds, full of tannic acid, being knocked off trees by late snow and hail storms and being ingested by herbivorous animals. When this happens, it can be devastating.

Nothing is more beautiful in our country than the oak woodlands in the springtime. It is ironic that the very beauty of these woodlands, and the rural setting in which they exist, are the most significant factors that threaten their destruction. People are attracted to these areas and wish to get out of the towns and cities into the open space. But they cannot live without the amenities that they leave behind. We see it happening all the time. Large tracts of land are cleared, pavement is laid down, concrete sidewalks are put in, and the land is changed forever. Fast-food establishments and shopping centers are built and, before you know it, they have brought the city with them. Often these are the same people who have been pointing fingers at the rancher, criticizing range practices that have been going on for more than 100 years. Ranchers find a great deal of hypocrisy in this. The open space exists today in rural agricultural counties because of the enterprises that operate within it. Ranching is the primary agricultural enterprise.

Ranchers at times must sell land. The livestock business is extremely volatile and cyclical. Caught in economic downturns, ranchers many times must sell some land to survive. When ranches are sold for development, it is a land use change, and counties should have policies in place to deal with this. There certainly is no reason that these policies cannot deal with open space and oak trees. Counties need to plan communities and not allow developers to simply roll over them. The biggest challenge facing rural counties is how to deal with the urban/rural interface issue and control urban expansion. Only by answering this challenge will the natural beauty of the land be preserved. And only by answering this challenge in rural California will the rancher be able to survive with his urban neighbor.

Ranchers are also finding other sources of income related to oak woodlands. For example, many ranchers are involved in controlled hunting programs. When game is properly managed and improvements are made on ranches that encourage game production and conservation, it can become a worthwhile endeavor. Recreation and tourism are other activities that can economically benefit ranchers in the oak woodlands. Currently we are investigating the feasibility of taking interested people with us to gather and move cattle on the range. This could provide some additional income for us and a fine recreational experience for others.

Survival: that is what it is all about. Survival for us, for the wildlife, and for the oak trees. Those of us who live in these oak woodlands wish to preserve our way of life. We continue to do this despite adverse economic conditions in the cattle business. We consider ourselves to be environmentalists and conservationists and do not understand how the misconception of environmental issues can drive policy. We believe policy formulated in this manner will simply not work. We question people who are non-ranchers when they tell us how much residual dry matter to leave on a particular range and how many acres it takes to graze a cow and calf. We question this because, too many times in the past, well-meaning, highly educated specialists have given advice that led to economic disaster. We must come back to the same ranges year after year. We must conserve grass to make this work; we must get rid of excessive brush and canopy cover; and we must address toxic material on these ranges. We must do all of this and still make everything work. We cannot gamble on new, untried, and unproven ideas.

When you get into the genuine rural areas of California, conditions have not changed much. Do not make the mistake of comparing a rancher with a land speculator who wears a hat and cowboy boots. We do not wish to be included in the category of individuals who do not really care about the land but simply want to make a dollar. Where is the pride of some county supervisors in those counties that are showing complete disregard for oaks in allowing land conversions to take place? Is the almighty dollar so important that they would sell out their principles? Well, maybe they did not have many principles to begin with!

The genuine ranchers in my acquaintance do have principles. We will continue to practice sound conservation measures when it comes to the range and preserve oak trees along with forage and wildlife. We care about the open space, and we have no intention of selling out, either our principles or our land. We support educational efforts concerning oaks and oak woodlands, we encourage individual responsibility, and we favor open communication between ranchers and urban society. Most of all, we will preserve and protect the land that we steward and the private property rights that we hold so dear.

Resolving Oak Woodland Issues in California[1]

Terry Barlin Gorton[2]

The Resources Agency is the umbrella State agency for many of the departments working with California's natural resources. The Departments of Forestry and Fire Protection, Fish and Game, and Water Resources are a part of the collection of departments within the State's Resources Agency.

One of the most important things we do, especially on resource issues, is pulling together groups of people to discuss, to engage, and to shape policy. Most natural resource issues are resolved by collaborative solutions, and most often, they're compromises. An example of policy development is taking place right here at Cal Poly during this Symposium. This involves concerns about conversion of oak woodlands due to development of a water pipeline right-of-way. There are major issues here today as oaks as threatened to be cleared as part of the construction of a new water pipeline to the Central Coast. We are issuing a stop work order to allow meaningful conversations to proceed in order to reach a compromise on this issue. The more we engage people at the local level, the more we can continue to push local solutions.

Pressure on Oak Woodlands

Since the earliest of times in California, oaks have had value. From our State's Native Americans and their historic values for oaks and acorns, to the whole complement of uses that created new values for the historic people of California, to today's most aggressive home builders, our oaks have maintained a high value. Because they have this high value, oaks are going to continue to be part of the policy discussions that occur in this State. We're not going to destroy the oaks in this state because they are valuable. It is important to appreciate and stress those values, which will allow oaks and oak woodlands to continue to be a part of California's culture in all the myriad of ways they have historically been.

It is important to bring the question of how many oaks there are going to be, and where they will be distributed, to the forefront. To do this, it is necessary to look at all the pressures on oak woodlands. This is certainly a major thrust of this Symposium.

There are differences in the value of oaks from a regional perspective. There is an increasing interest in the use of oaks for commercial purposes, such as sawn wood, and all the value-added products which can be produced from oak trees. In the North Coast, tanoak, although not a true oak species, is receiving a great deal of emphasis as a commercial product. In Southern California, we have all witnessed the pressure and intensity on our oak woodlands that comes from development. In this region, the value of oaks must be placed in the context of overall ecosystem and how those values are balanced with development. This balance will be influenced by the increasingly high values placed on housing and land due to the presence of oaks.

Identifying and describing values of oak woodlands are not enough information to involve the key members of a community or region in determining

[1]This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif. None of the plenary papers at this symposium was subjected to technical peer review; they were the views of the presenters, in behalf of the organizations they represented.

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policies for oak conservation. This important step needs to be tied to research, education, and to outreach efforts, to bring the issues before the people at the local level, and gain their participation in ensuring that their lands are appropriately planned in the context of all the competing needs. This additional step ensures many new perspectives, and a grasp of those "compromises of values." The conversations will be varied in the North Coast discussing tan oak, in the Sierra foothills discussing oak clearing practices on rangelands, or in San Diego County discussing urban development. There is no single statewide approach that would work for this myriad of issues. It is very important to engage as many participants as possible at the local level in collaborative efforts to attain the right type of protection, the right type of conservation, and the right kinds of development that are worthwhile to all future generations.

The Integrated Hardwood Range Management Program (IHRMP) and the California Oak Foundation (COF) are key players in identifying the issues. The COF and IHRMP raised the issue of "values" to the Board of Forestry. Issues such as esthetics, abatement of noise and air pollution, shade, watershed protection, biodiversity of animals and plants that live in oak woodland areas, and agricultural production and values raised by the California Cattleman's Association, the Wool Growers, and Farm Bureau must all be considered in the protection and the utilization of our oak woodlands and rangelands.

Developing collaborative efforts requires evaluation of real threats. Too often, policy making is undertaken without the "real" information being on the table. Certainly, California's oaks are under attack, and they're under attack primarily from conversion to human developments. In fact, from 1945 to 1973, approximately 1.2 million acres of oak woodland were converted to other land uses. By 1986, that loss had escalated to almost 14,000 acres per year. Since 1986, there has been a huge escalation in the conversion of oak woodlands for development purposes. This level of conversion cannot be sustained for much longer. This conversion has fragmented oak woodlands, posing a serious threat, not just to the oaks themselves, but to the biodiversity of oak woodlands. That is of major concern in the state of California. Our concerns must consider the broad landscapes, and how to protect and maintain natural corridors of open space to maintain all species which we wish to preserve for future generations.

As an additional threat, we also need to look at the unregulated use of wildlands for all kinds of recreational uses. Wildlands can sustain only a certain number of feet, so many campfires, and so many little trips, before it has lost its "wild" character, and becomes an area that one no longer wishes to visit. How many people are using the areas, and what is the long-term impact of those people?

Fire represented another threat to oak woodlands. Part of my position with the Resources Agency involves dealing with fire risk and fire risk assessment. As the "edge effect" to our oak rangelands from human encroachment into wildlands comes more into play, these areas become vulnerable to man-caused threats. As these edge areas become even more pronounced, more and more oak woodlands will be subjected to the possibility of catastrophic fire, as we are seeing with softwood forests throughout the Sierra Nevada and North State. Since most of these wildlands and forested areas are experiencing an increase in fuel loading, fire intensities have increased. Therefore, our losses will be higher. In the South State, with dry fuel conditions, a Mediterranean climate, and an increasing "edge" with human developments, fire will continue to be a high risk into the future.

Solutions to Oak Woodland Conservation

With some of the risks and threats to oak woodlands described above, we need to focus on solutions. Unfortunately, we often get caught up in discussing and re-discussing the problems, and then reiterating it so that everybody "really" understands. This inefficient cycle typically takes 80 percent of our time, leaving only 20 percent of our time to focus on the solution. In discussing conservation solutions, I try to use only 20 percent of the time defining the problem, and 80 percent of the time discussing possible solutions. There are a huge number of stakeholders and responsibilities involved in maintaining sustainable oak woodlands in all its forms. It is time to divide many of these responsibilities between the appropriate stakeholders. Although this may have been ill-defined in the past, events like this symposium can redefine areas of need and stakeholders' responsibilities.

Certainly, when discussing fragmentation of landscapes and suitability of habitat over county lines and thousands of acres, one community is not going to resolve all the issues in their action plan. However, a good role for government is to encourage state, regional, and county organizations to work together resolving mutual resource issues. Another appropriate role for government is to provide the "big picture" overview in support of county-wide conservation and development efforts. This "big picture" also provides everyone an opportunity to see how these components are going to work across the state.

At the community level, whether it's overdevelopment or other issues which inhibit the sustainability of local oak woodlands, it is the involvement of locally elected supervisors and council people, planners, educators, research organizations, and groups like the IHRMP and COF that can focus the issues and bring together local resolutions that provide sound management policy that can be integrated with bordering areas and jurisdictions.

Since it is not possible to grow an oak in 5 years, it is imperative to stay engaged in local issues and policies. There is no large umbrella that is covering everything that's happening throughout the state, although this is often our sense of government. Government is like a double-edged sword. Sometimes, it's way too invasive, and at other times, it isn't doing enough. It is difficult to reconcile this mixture of feelings and emotions. Secretary Wheeler has made it a priority of the Resources Agency to find ways to encourage issues to be resolved at the local level. It is very important to him that local communities are involved and assisted in the identification of resolutions to local issues.

With all the people and communities involved with oak woodland issues, it is possible to avoid the problems seen with issues affecting softwoods. However, it is important to keep pressure on all parties on the various aspects of the issues, and to continue to develop possible compromises that may need to be considered in developing successful policy and community guidelines. Many people at this Symposium have brought many of the issues to the forefront and are working toward resolutions that can be supported by all the stakeholders.

The issues and information affecting California's oak woodlands are before us. We can thank former Board of Forestry chair Hal Walt for the information which has brought us to this point. Hal was responsible for the first appropriation to get the Integrated Hardwood Range Management Program started, and funding focused on getting some early solutions. The Cattlemen's Association, Wool Growers, and Farm Bureau also played key roles in these early efforts and remain engaged in these issues at the local levels. Peter Passof and James Bartolome of the University of California (UC) and Bob Ewing of the California Department of Forestry and Fire Protection (CDF) are all early developers of the

Integrated Hardwood Range Management Program and are responsible for a tremendous amount of information that has evolved about oak management, conservation, and preservation. Rick Standiford of UC, Cathy Bleier of CDF, Barry Garrison of the California Department of Fish and Game, and many others have also made substantial contributions to our knowledge and emerging technologies.

It is important to acknowledge once again the California Oak Foundation and its president, Janet Cobb, who has kept the issues in front of us; Norm Pillsbury, of Cal Poly San Luis Obispo, who has developed and maintained support of these great oak symposia; and Director Richard Wilson of CDF and Dave Neff and others who have worked diligently on many issues, especially the fire and "edge" issues. I would also like to recognize Helen Lebieu and others from the conservation community, who have devoted a tremendous amount of time keeping the issues on the center stage.

Conclusions

Our challenge is to take the awareness of the issue and the foundations of information that has evolved, engage your community's leaders, and take some giant steps toward local resolutions. Over the next several days, you will have an opportunity to watch some key oak issues played out here at Cal Poly.

It is often difficult to turn large processes toward a new focus. However, a large process can obtain a new focus with the assistance of only a few key people. But it takes the efforts of key leaders, who are dedicated to making a difference that reflects and incorporates local community's values.

Issues affecting oak woodlands are not simple issues. However, they are issues that can ultimately meet part of everybody's needs. We need to put the awareness of issues and compiled information to work for us in forums in our schools, communities, counties, and regions to attain our short-term goals. This will also allow the issues to mature and information to grow so that goals may be established and accomplished for the next 2 to 5 decades. If we are successful in these endeavors, future generations may not have to resolve the number of critical issues we have faced. You can be assured that the state, through my efforts and those of the Governor and the Secretary of the Resource Agency, will work very hard to keep oak woodlands at the forefront of state policy resulting in progressive kinds of solutions that are important to all Californians.

The Network Solution[1]

Tharon O'Dell[2]

When invited to speak at this symposium, I was asked to discuss corporate timber policies and Board of Forestry perspectives as they relate to oak woodland ecology, management, and planning. I was also asked to comment about hardwoods and the role of Registered Professional Foresters. The topics of timber company policies and Board of Forestry perspectives are rather different, but I think I can use one to reach the other.

Let me begin by sharing my feelings as a resource manager for a timber company that owns 380,000 acres of timberland on the North Coast. I was trained as a forester and a scientist. I came to Simpson Timber Company[3] from a university faculty position, and my qualifications included an understanding of students, a dislike of faculty politics, a healthy skepticism about what is known about forestry, and a strong desire to find answers.

I presently oversee the resource base of a company in California with a focus on long-term asset management. Specifically, my role includes producing seedlings for replanting units after harvest, managing these young forests through cultural treatments to control competition, prescribing treatments to enhance growth, and ultimately estimating the volume of these young stands as they grow into merchantable size classes. These cruise data then serve as a "check point," strengthening our growth and yield modeling efforts, which are anchored to permanent growth plots.

Since the beginning of this decade, the management of noncommodity wildland resources on private lands has risen to assume major importance. To accommodate the need to manage these resources, we have increased our staff to include a wildlife dimension, and more recently a fisheries dimension, to our forestry business. This company is family owned, having been in the timber business for more than 100 years, and it plans to continue in that business. The purpose of the company is to make a profit. It does so by selling logs and other wood products. Hence, the company aggressively manages its land to produce wood fiber. Log prices, harvesting and marketing costs, and interest rates get much attention—and so do governmental regulations.

The company also has a land ethic: Preserve our productive assets—the soil, the watersheds, and the genetic and vegetative bases of the forest. To these ends, we invest hundreds of thousands of dollars annually to maintain a road system, to monitor the impacts of our management on water quality and wildlife, to improve the genetic quality of our growing stock, and to protect and restore streams. We make extensive use of GIS technology and saturate our managers with information.

More importantly, we use science as an asset. Our large land base treats us to many different problems, each an opportunity to learn. Although the existing information base is impressive, it is not yet adequate to address the complexity of forest ecosystems. The company is not timid about trying something new, observing how it works, and then making adjustments. I believe this is called "adaptive management" in current parlance.

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[1]This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif. None of the plenary papers at this symposium was subjected to technical peer review; the views expressed and the mode of expression are those of the presenters, in behalf of the organizations they represented.

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[3]The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

As is so often true in land management, managers are constrained by a past not of their making. Nearly all of the company's lands have had extensive harvesting historically, so many of our current ecological challenges involve vegetation assemblages that developed as a result of past harvesting practices that had little or no regard for regenerating the site with conifers. A common legacy of these practices throughout the north coast is conifer sites covered with hardwoods, principally tanoak/madrone complexes, although alder can dominate sites with ample soil moisture. Timber companies differ in their approach to hardwoods, but what I will describe is pretty much a standard dilemma over whether to harvest hardwoods that are unwanted because they occupy conifer growing space or to retain them for wildlife habitat reasons.

For most timber companies, the standard approach is to discourage hardwoods from growing after conifer stands are harvested, and to try to recapture hardwood-dominated conifer sites if hardwood log or chip prices make it economically feasible to do so. Harvesting and regeneration techniques vary by timber company and by site. No set prescription exists for harvesting method, choice of planting stock, or the use of fire or herbicides. Of course, techniques like fire, and especially herbicides, can raise very different sets of questions and bring in larger social issues with neighbors and surrounding communities. That topic, however, is beyond the scope of this talk.

Foresters also know that hardwoods are critical components of ecosystems for wildlife and fish. In some ways, hardwoods in a forest stand provide the best assurance of habitat diversity. At Simpson, as a part of our obligation to comply with our conservation plan for the northern spotted owl, we leave recovery centers—cores of habitat—as part of our harvesting practices. Our foresters are instructed to make sure that these "Habitat Retention Areas" include both hardwoods and conifers whenever possible. As part of our planning, and to simplify the timber harvesting plan process, company foresters often enlarge the stream protection zone, or design a bulge onto the riparian strip to meet our habitat retention requirements for the owl. As it happens, these riparian corridors are commonly dominated by hardwoods so, as a practical matter, a significant component of hardwoods, especially red alder, is retained low on the slope, where it benefits owls and other wildlife. On drier areas inland from the coast, and on upland locations, the "Habitat Retention Areas" are composed of hardwood and conifer species typical of less mesic sites. Types of hardwoods retained at these locations include tanoak, madrone, pepperwood, black oak, and white oak.

Companies vary in how much time or money they spend trying to understand how hardwoods function on their lands. Most leave hardwood trees or stands in places where they serve critical ecological values, such as in riparian areas or for specialized nesting or denning habitat. Analyses of these opportunities are required in the forest practice rules.

Simpson considers hardwood retention a cost because it promotes lower-valued, slower-growing trees at the expense of conifers, which lowers the productivity of our timberlands. Yet we also consider the retention of hardwoods a necessity for meeting wildlife needs and managing public-trust resources. Nonetheless, from a strictly economic viewpoint, we would generally prefer to have conifers because they presently give a greater economic return.

Next let me turn to a Board of Forestry perspective. It has been broadening, to say the least. I arrived at the Board in 1993 as a member with a forest products background. My first assignment was to chair the Ecosystem Management Committee, which oversees the Board's interests in hardwoods. Consequently, almost from the first day on that job, I realized that the timber perspective on hardwoods was a subset of a much larger, more sweeping set of concerns. In most places in California, the economic worth of hardwoods is related to property values that come from viewsheds, desirable living space, and big, old oak trees in the yard.

I also learned that the Board considered regulation of hardwoods in the mid-1980's because of concerns over loss of deer habitat, negative impacts on water quality, and fear of the environmental effects from a proposed biomass plant in Mendocino County that would have used hardwoods. But the Board rejected actions to bring hardwood harvesting under the Forest Practice Act in favor of a program of research, information, and educational outreach to encourage conservation and wise management of the hardwood resource.

Largely through the efforts of the Board and the University of California, the Integrated Hardwood Range Management Program was formed. And over the next decade some key things happened. More was learned about the status of hardwoods, about regeneration problems, and about interaction with range and other uses. Several research projects were initiated, and some preliminary hardwood guidelines were written. But probably of greatest importance, in the long run, a much wider network of persons concerned about hardwood resources was formed. This was due to the work of University of California (U.C.) Extension, the California Oak Foundation, landowner groups like the California Cattlemen, a host of urban and community forestry groups, and governmental agencies.

Many of you may not appreciate the significance of this achievement. But to me, coming from the outside and late in the process, it seems amazing. My first reaction was surprise because of the wide diversity of interests that bring people's attention to hardwoods—everything from protecting property rights to worry over loss of recreational resources, viewsheds, or wildlife habitat. On further reflection I also thought that this network was a solution, or at least a framework for a solution, to hardwoods issues. People from seemingly very diverse backgrounds could actually agree on things—not always, but often enough to make the effort worthwhile.

About the time I arrived at the Board, in 1993, it was reviewing the status of oaks. Hardwoods were still being lost to firewood removal, especially in some parts of the Sacramento Valley, and to development. The Board, which has been mired in regulatory matters for conifers under the Forest Practice Act, believed that local government was best suited to deal with hardwood issues in their jurisdiction. It gave itself 3 years to see if, by additional focus and encouragement, more local governments would develop strategies that would work locally.

Letters were written to each of the counties with significant hardwood resources, asking them to develop appropriate strategies. A copy of the excellent publication, *A Planner's Guide for Oak Woodlands*, and maps of hardwoods were sent to each county. U.C. Extension, the California Oak Foundation, the California Cattlemen, county planning staffs, and others took the lead in different parts of the state to encourage development of local solutions. The Board followed the progress of the counties and sent another letter in 1994 to those counties from which we had not seen results. With a variety of local input, by 1996 every county with significant oak resources at least had a network of persons interested in hardwoods. Most had developed a formal process to track hardwood resources and discuss issues. These took several forms:

- Some counties have enacted voluntary ordinances, with a local committee to oversee how they are being followed. Tehama County was the first to develop this approach and others have followed. In this county, the cattlemen were very influential, as were environmentalists, agencies, and others. A woodcutter is chairman of the committee.
- Other counties have used their general planning process, with most

focus at the project review level. Examples are Nevada and Tuolumne Counties.

- Still other counties are using an ordinance approach. Examples are Monterey County, with a completed ordinance, and Sonoma County, with one under way.

My assessment of the situation is that much progress has been made but that we are not done. Things are still evolving. Not all efforts are finished and some are taking a long time. I still read about subdivisions being approved that some citizen groups complain remove too many hardwoods. While this reaction of neighbors is usually focused on individual projects or portions of a county, it is a bellwether of the future. Population growth is still tremendous in central Sierra Nevadan and southern California counties. This will continue to put severe pressure on hardwood rangelands and forestlands for living and recreating space.

My sense also is that we will need to rely on the hardwood network to address most of these issues. Threats of state intervention only work to some degree, but often just make local people angry. This is especially true when people are moving to get away from governmental restrictions. What works is when people start to talk and to find some common ground that fits their community; this has been proven again and again. The Sustainable Landscapes project in the central coastal counties and the Tehama Hardwoods Committee are very different but very good examples of this.

The state still will be involved. The Board maintains its basic policy: to conserve and encourage wise management of hardwoods in California. It has put this into a joint policy with the Fish and Game Commission, and we review its implementation at least once a year. And later this year the Board will make another assessment about the success of locally based programs. We still must determine how to judge this, but I am optimistic that we will like what we see.

Both the Commission and the Board will remain very interested in the status of the hardwood resource. The bad news is that budget cuts are lessening the role played by the California Department of Forestry and Fire Protection (CDF) and constraining that played by the California Department of Fish and Game (CDF&G). Neither the CDF nor CDF&G will be able to monitor the status of hardwoods, at least directly. We will be revising the joint policy to reflect this fact. Fortunately, the University of California has reaffirmed its commitment to the Integrated Hardwood Range Management Program, and U.C. Extension will be able to do some work in the monitoring area.

I want to close with a reflection. It seems evident that very little State General Fund money will be available for hardwood programs in the Resources Agency. Perhaps some limited federal funding for urban forestry will be maintained. Some special funds for habitat acquisition will continue from a variety of sources, but they also will be constrained. This further increases the importance of the network solution. It will be vital to find ways locally to deal with conservation and management issues, including the generation of funding for programs or landowner reimbursement.

I hope that the real estate and development communities will become an increasingly important part of the network. Environmental professionals, landscape architects, and developers hold as much or more of the future than the Board does. We have to keep encouraging, facilitating, sharing, and even arguing for conservation and management of hardwoods. In many cases the best advocates for hardwood conservation are the developers and landowners themselves.

I started this talk by describing the perspective of one timber company in particular and the timber industry in general. In the past decade I have seen a significant increase in general understanding of hardwoods as a component of the ecosystems of which they are a part. Whether by conscience, public pressure, or forest practice rules, this understanding is reflected in better hardwood conservation and management. This has been uneven in its evolution, but it is real.

The same is true on hardwood rangelands, but with much greater variety in approach. There is great strength in this diversity and in a framework that encourages people to help find their own answers. Ultimately we all want the quality of life that good stands of hardwoods represent. We could not have gotten very far without our hardwood network. So I want to end by saying "thanks" to all of you. Keep up the good work.

Wake Up, California![1]

Janet S. Cobb[2]

Thank you very much. It has been a very interesting symposium, and I want to thank Norm Pillsbury and Bill Tietje and Jared Verner; the wonderful students who have done such a good job working with John Bryant and Carolyn Shank—all of the people who have put so much energy into bringing us together to share information about our oak ecosystem.

I would also like to thank members of the California Oak Foundation (COF) who have been working hard since 1988 to raise public awareness about the need to protect and preserve California's oak heritage. And I thank the Integrated Hardwood Range Management Program, Rick Standiford, and his able research team; California Department of Fish and Game's Barry Garrison and many of you in this audience such as Professor Tim Plumb, a dedicated professor here at California Polytechnic State University (Cal Poly); the California Board of Forestry, Director Richard Wilson, and so many others who make a difference.

Many people come together to tackle the enormous challenges of conserving the state's hardwoods which are critical to watershed stability and to wildlife habitat viability.

Though we often work separately on our various responsibilities, we have a collective obligation to protect and pass on this vital ecosystem to those who follow us. And it is toward that common goal that we must rededicate ourselves.

When the California Oak Foundation started, there was not much awareness in a public sense about the loss of oaks throughout the state. Many people appreciated oaks from their childhood landscapes, but there was this sense that the trees were connected more with memories than with the future. At the Oak Foundation offices, we often hear stories of tree houses in oaks, of favorite picnic spots, of magical places and special swimming holes surrounded by oaks. Have you noticed that people tend to take many of the most important things for granted?

The rate at which many of those special oak places were disappearing finally hit many of us. "Here today gone tomorrow" summarizes our state's commitment to this important habitat. We are sleepwalking through the dismantlement of our home, and rarely do we wake up long enough to protest.

Our natural environment is threatened, and our built environments do not produce spaces that support community or family. The old and young suffer, not to mention the middle-aged who are often working and commuting along ribbons of asphalt very long distances from affordable housing to their jobs. The daily grind of maintaining their lives prevents them from living fully, from seeing what is going on around them, from speaking up about the tragedies and losses.

A single oak is lost here, a housing development takes out hundreds there, the builders of freeways, golf courses, and vineyards mow the trees down because they have a different goal in mind. And quite frankly, there is little but public opinion to stop them. It is clearly time to rethink our priorities.

This is where public education comes to play. We all believe in the power of learning and communication, but try to make a dent in informing the hurried, the tired, the ignorant, and the greedy. The reality is that we have 33 million diverse people with just as many opinions and wishes from every corner of the

[1]This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif. None of the plenary papers at this symposium was subjected to technical review; they were the views of the presenters, in behalf of the organizations the represented.

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world. We are making up a new way of living together each day, and many important matters are slipping through the cracks. People who are charged with leadership in protecting resources often labor under political and economic pressures that impair their potential effectiveness.

The other day I had yet another wake-up call when Richard Wilson, the very Richard Wilson on this stage with me today, and a person for whom I have great personal regard, stood up here and said: "The Board of Forestry and I are against regulating oaks." Well,... before you lose interest at this early hour, I want to get your attention by saying that I do not care whether we use the "R word" or not, but I want to tell you that I think we have to use all of the tools available to us to meet the considerable challenge of protecting these trees and their related habitat. I think that may include tax and/or other financial incentives for mitigating the loss of oaks, and protecting woodlands, most of which are in private ownership. It almost certainly would have to include incentives for responsible land use, and potentially, we should look hard at increased penalties for land and resource abuses. If the public were awakened enough to hold their public agencies and their elected and appointed officials accountable for responsible resource management, it would make quite a difference statewide.

We lost 95 percent of the wetlands in this state by trusting in the good sense of individuals whose primary motivation was to make a buck. We are now in danger of doing the same thing with oak woodlands. It happens gradually. We are like the frogs in the pot of cool water that is heated ever so slowly. We're cooked before we notice the heat. We watch the trees go down; we monitor their absence; we report their steady decline to committees and boards of directors in high places, never being mindful enough to stay STOP! Never being alert enough to think out of the box and come up with bold policies to win the day.

This Symposium has been layered over with this EMERGENCY called the California Aqueduct Project, which began its march from the Central Valley to Santa Barbara some 3 years ago, I believe. All of a sudden people discovered that oaks were going to be among the missing as the pipeline moved on its long-approved route through the Cal Poly campus.

We had a very interesting time yesterday hiking the pipeline route, and looking at maps with your opening speaker of yesterday, Terry Gorton of the State Resources Department. She seems to be a nice person, and she did bother to come here, and she is coming back today to try to find a solution.However, the fact of the matter is that the budgets in the State Resources Department do not include oak protections, and though they have thousands and thousands of people on staff, Fish and Game has a half of a half-time person and a program unfunded. Barry Garrison is terrific. But if Barry Garrison had a staff of 10 or 15 people, and he actually had a budget, think what he could do. If CDF, with their more than 4,000 people, and millions of dollars in budget actually made oak woodlands a modest priority, or even acknowledged their very existence by assigning more than a part-time person to the subject, think what could take place. Think of it: what if there were items in the budget that acknowledged that oaks are just as important as timber or fire suppression. Isn't it about time that we collectively notice what is happening?

So I am not here to insist on locking in on the word "regulation." But I am here to tell you that we had better be addressing this issue with everything we have available: reasonable zoning and land use laws that make us plan and build better communities; that help us stop ugly, inefficient, resource-gobbling strip malls and leapfrog development to meet the needs of the steady outflows of people fleeing from unlivable cities. When people in large quantities move to the country, the country disappears.

Amy Larson, Executive Director of the Oak Foundation, knows that on any day we almost surely will receive calls from around the State saying "help!" We need to stop such and such development. It is often too late to send the public information because these calls come on the day of the development hearing. How does one console a person who is about to lose something very dear to them? When people wake up to their potential loss, the task for individuals concerned about their quality of life is daunting. They are up against well-financed, slick advertising and highly orchestrated strategies. Have you noticed how many oak trees are in those real estate ads? Have you noticed how many streets and developments are named oak this or that? Oakdale, Oakhurst, Oakmont, it goes on and on. Our descendants are going to wonder why we were so crass as to think that you can replace a tree with a word, and have the neighborhood be the same.

The other very alarming thing when a person is trying to be helpful in these situations is the lack of knowledge that people have of the system which governs them. It is difficult to organize anything if you do not know about the decision-making structure. Our schools have failed to teach the basics of being a responsible citizen in a democracy. When you go back to your communities, please work on simple diagrams that describe the decision points and a brief description of things that make a difference: public testimony at hearings; drawings of how the upcoming decision will make the place look 10 years from now; letters to the editor; meetings with elected officials to brief them in a factual way about a community's concerns. Democracy is time consuming and often messy. It takes rolling up our sleeves and motivating others to do the same if we are going to make a difference.

At COF, we are pretty good at putting together information packets for planning commissions, city councils, and boards of supervisors so that they can hopefully make better, more informed, decisions. It is not easy being an elected or appointed official; it is very important that we help them as much as possible.

We cooperate fully with the press, giving them the very latest information available in a situation so that their readers will know, and hopefully act in their own best interests.Terry Gorton said to me yesterday: "You've amped up this pipeline issue 'till you have all of our attention." Thank you for noticing! We need the attention of the people in the Resources Department in Sacramento. It is where decisions are being made and—just as often—not made on these important natural resource issues.

It is not enough to say we love oaks. We must do better than that.

So, if it takes getting on the front page; if it takes injunctions and stop-work orders to get people's attention, so be it. Doesn't it seem like a waste of energy and an awful lot of drama when good planning and open communication could have produced a better route that would have honored the importance of these trees that have had standing in this community for 300 or 400 years?

There are always going to be temptations to be co-opted in these negotiations. You think, she is a nice woman. She is from the Resources Agency. Let us be reasonable. But, the fact is that this is an untenable situation. While everybody says we need to preserve these resources that are a very important part of our natural inheritance, people are not putting those words into responsible actions.

After a meeting in Sacramento last week where I spoke on the importance of protecting the Central Valley's agricultural land—a 40-million-acre watershed, not to mention a food-producing mecca like no other in the world—Doug Wheeler, Secretary of Resources, and Carol Whiteside, former mayor of Modesto and now with the Office of the Governor, said once again that there is no political will on behalf of the environment. It barely makes a blip in the polls. "It is not on the political agenda," says Carol Whiteside. And I respond to them very directly: "Put it on the agenda." Since you are the politically appointed environmental leaders and you are in these positions of power, then it is your responsibility to make protection of the state's resources rise to the top on the political agenda." Now I realize that I am not being totally fair. They are, after all, nice people with a different perspective. And they are reading different polls because the ones I read say that more than 80 percent of all Americans think of themselves as highly concerned about the environment because people are beginning to connect the dots between a healthy environment and their own health.

Our natural world should not be a partisan issue. Responsible, sustainable use of resources has to be on everyone's agenda: business, labor, childcare specialists, doctors, lawyers, and teachers. Everyone, we must all be conservationists.

Our health is at stake. Our wealth is at stake. Our quality of life is at stake.

Since we are, for all practical purposes, shut out of the political process in Sacramento at this time as far as the environment is concerned, we are looking at trying to build more capacity for good at the grass-roots level. That is what we have been trying to do for some time through the Oak Foundation's outreach programs. We need to enable people out there to stand up for their communities and their children's futures. When COF began, people were coming primarily from a tree-hugger mentality. Everybody wanted to save a single tree. There is still some of that, and the ordinances tend to focus on the large trees, because we have been taught to like big things. We forget about the need for seedlings and saplings in order to have a continuing, healthy forest.

So, we have been working very hard to move people from the single-tree mentality to an oak woodlands awareness. It is really critical for people to understand how it all interconnects. We are talking about an entire ecosystem.

Yesterday, we were up on the hill with the Department of Water Resources representatives; people are focused on saving the oak trees, which is a laudable goal, but there is so much more. With their spreading branches, they make a very nice symbol. However, these generous trees represent more than themselves. I was so proud of Neil Havlik, who is, as of last night, the new president of the California Oak Foundation. He had the audacity to bring into the discussion the importance of the remarkable wildflowers and native grasses on the site.

William Stafford, a poet, said, "Even the ocean believes in the upper end of the river." And he could have gone on: the river believes in the brook, the brook believes in the rivulet, which believes in the rain, and the rain believes in the clouds.

When a bulldozer pushes over a 300-year-old oak, the grass and wildflowers around it do not do well either. The silt fills the creek and kills the fish; the birds, bugs, and other wild things cannot possibly do as well as they did with a standing tree to call home. On and on it goes. We are affected by every action we are taking so we need to be more careful. We need to be more thoughtful. We have good science on why we should conserve our woodlands, but it does not do us any good unless we pay attention to it. It doesn't take us far unless we can educate our elected officials and policy makers to make better decisions. It doesn't end up in better communities unless we change our own behavior and urge others to do the same.

I know that Richard Wilson went out the day before to see the creek and to see how to get across the creek with the minimum impact. He saved his very own home valley from becoming a dam many years ago.

Some of the things we have learned over the last few years is that these resource negotiations are kind of like being right in a fatal car accident. It does not matter how right we are, and we are often right, if we cannot string our arguments and actions together in such a way as to convince others to reevaluate, to pay closer attention to all of the impacts, to think very carefully about their route to so-called progress. No matter how right we are about these trees representing an entire community of plants and animals, at this moment in this state we are losing ground every day.

There are 110 new towns on the books in California: 110! There were 36 major developments about 24 months ago, and we thought that was astounding. Approximately 7 to 10 million people are expected to move into the oak woodlands in the next couple of decades, and they bring with them their recreation vehicles and their chainsaws, their kids and their cats and dogs. Some people say: "Oh, well, there will not be much impact on the ecosystem." Baloney! We humans change what we come in close contact with, and we do it in a major way. We are so self involved that we tend to not take a look at our own impacts. Developers sometimes ask: "Tell us what we can do so that you will not be on our case if we cut down a tree." I say that the most meaningful thing that they could do would be to move their project to Oakland or some other existing city. Take all these existing buildings with existing infrastructure — sewers, sidewalks, transit, and you could turn the place into a livable city. There are so many vacant buildings. Why don't we put apartments on top floors, offices for businesses on the next level, and retail on the street level. If we operated in this fashion, there would still be oak woodlands to visit in the 21st century and beyond.

What we are looking at, with this pipeline situation, is a good example of what is happening across our state. This pipeline has been on the books for years, and I think Terry Gorton said yesterday, there is enough blame and error to go around. University representatives should have been on the case a long time ago. It is one thing for us to roll into town and crank up the heat to get everybody's attention, but it is quite another thing for people to be vigilant about their part of the world. The pipeline should never have been planned for its present route. It is kind of like the deer in the headlight syndrome. You say to Department of Water Resources' representatives as Neil kept saying yesterday, "Why don't you go down the existing road?" And Norm Pillsbury says: "Stay away from these big trees; go around them. And they respond: "But we already have the pipe and the pipe is straight." So I challenge Cal Poly's Engineering Department to come up with a water pipe that is flexible because imagine how many trees and wildflowers and grasses and streams you could save if you could go around things. Our linear brains, inflexible processes, and the rigid resulting products are killing what we hold most dear.

We must change. We must wake up! The pipe does not have to be straight. Pipe can go around things; the pipe could go under things. It's an amazing thing! We ask: "Could the pipe go over?" And they say, "Oh, over. Uh, you know, the pipe is straight, and it has to go…" So I'm telling you we have a communication problem. When you look at maps that do not show the trees, you are not reading a worthy document.

We need a negotiating class at Cal Poly, and we need a negotiating class in every school and community in this state. We need a negotiation class in every single agency because wherever we go, these challenges require new skills. How do you respond when you have a stop-work order and you find that the tractors started along their path—only across the grassland you understand. This is not called negotiating in good faith.

So we have them in a "dead to rights" situation. Then the University's highest representative at the table says "We have decided to go along with the alignment because it will cost extra money to change the alignment." So, he handed it to them. If you are going to negotiate, you do not give the opposition all of the cookies right off the get-go. They are coming back today, and we are starting from a place of unnecessary vulnerability. We have to do better.

These trees; this ecosystem cannot speak for itself. We were in the car with one of the engineers, and the guy said something, and Neil said, “No, no, I’m representing the trees.” And the guy gave him an “Oh my gosh, he’s really weird” look. It is understandable from his perspective of not taking the trees into account. He just needs to get the pipe in the ground and covered and move on to the next stretch of the project. He has a budget and a deadline for completion. Meanwhile, we are thinking, the trees cannot talk or walk and they add a lot of value as they stand; the trees need a little help.

Terry Gorton talked a lot about values in her speech yesterday. As we talked, however, the issue of money kept coming up. This is a $435 million-project, and that is a lot of money. And I do not know how many trees have been mowed down in the pipeline path, but I am sure it is a substantial number. The high cost to the ecosystem is not included in the economic analysis. We have to change our entire way of thinking about these things.

And while we are changing from the outdated Command and Control mode to our present Chaos, which will hopefully lead to a Better Order model, we need to try to listen to each other and agree to struggle with these issues one at a time, all the while attempting to maintain some compassion for one another.

Terry Gorton is not perfect; I, of course, am perfect: two nice ladies. MMMMMmm. Are we going to stay in those roles? It’s very unlikely; highly unlikely. I am perfectly prepared to drop my midwestern Methodist upbringing in this case. I definitely believe in good will and improved communications, but stop and think about it. When are we going to take these losses seriously?

These are small negotiations in the total scheme of what we are losing each day. While we have been diverted into defending a handful of trees, no one at this conference has mentioned what we are really talking about: delivering water to a community that needs it because it has grown beyond its carrying capacity. When this water line is completed, what do you think is going to happen in Santa Barbara? The D word: Development. So the people in these communities need all of our help and support to protect what they hold dear. They need as much technical information as they can get. They need a vision and a plan of how they want their communities to look and feel. How big is big enough? How spread out can a community be before it is not one any more? Wouldn’t it be better to save the ranches and farms and open spaces and build inward? Couldn’t we come up with a way to compensate private landowners who hold about 85 percent of our open lands to keep them that way—on a voluntary buy-in basis of course!

We send local people information every day to try to deal with their city councils and to appeal to their supervisors. When we were going around the state—and I think you know about the seven workshops that we did with the University of California, California Department of Fish and Game, CDF, and others. We were primarily aiming our message at planning departments and decision makers. And what we have found over the past 2 years now that we are through that process is that the planning departments have changed. Many of the people that we educated in that round have moved to different jobs; some who tried to redesign developments with their newfound information are gone, replaced, because the fact of the matter is that land use decisions are politically motivated decisions. A supervisor in El Dorado County has said in public meetings: “You are not going to let facts get in the way of development, are you?” And I say, “Vote Him Out of There.” Ignorance should not be tolerated or celebrated with so much at stake.

Where there is land in California, greed is often lurking. People often assert that local supervisors are bought off on development projects, and there is considerable evidence to substantiate that assertion. City council elections are often funded by developers, who if they do not have smooth sailing at the planning commission level, make all-out stands at the council level. Paid advertising masquerading as folksy newsletters and communities of concern manufactured to counter local opposition.

And so the only thing that stands in the way of really bringing together some kind of comprehensive ecosystem planning and protections for this state's remarkable biodiversity is you-all. You have to be the sparkplugs.

We have to work together better and more effectively to provide these local people with as much information as they need to make persuasive cases for the integrity of their places, of people, and of vital natural systems.

We are starting something new at the California Oak Foundation. We received a grant for a Conservation Circuit Riders program to train non-profit organizations to do more effective media, marketing, and fundraising. We will try to further empower the local people to do their work.

While assisting other non-profit organizations in building capacity to face these issues, we are also attempting to create a Conservation Clearinghouse. All of the technical presentations that have been featured here need to go beyond us to the general public. In my view, we need bulletins, we need press releases, we need to create understandable public information if we are going to save these trees and the ecosystem that they represent.

We need to buddy up with other groups. Some people who like oaks do not like certain groups. They don't like the way people dress; they don't like the color of their hair; they don't like the way they talk. And I say, "Get over it! Just get over it!" There is too much at stake in California to be so provincial; there is too much at stake for all this pettiness. We cannot afford it. There is too much to do.

We have to look at estate tax relief for owners of large pieces of land. I talked to Dick O'Sullivan from the Cattlemen's Association about this yesterday. My oldest son and his family live on a 20,000-acre cattle ranch in Parkfield, and all of my children and grandchildren have a solid connection to the land, for which I'm grateful. Dick and I have many things in common. And still it is going to take work on both of our parts to reach common ground where we can move forward together.

I say: "Dick, we need to tie estate tax relief to conservation easements." He says: "Sure, but what about private property rights." And I say: "Dick, conservationists and cattlemen need to work together in a cooperative fashion." And he says, "Yes, but they can't tell us what to do with our land." Now I know that I need to do better. I say: "My kids are the rodeo champions named Santos. My sons have been known to win the Salinas Rodeo and the Cow Palace, and my daughter has just finished a book on the World Champion Cowboy, Ty Murray." "You're one of the Santos?" he says. It turns out that he went to Davis as a pre-vet student with their father who is a veterinarian. Suddenly I'm not just another Greenie! My family gives me a better place to come from with this man who can play an important role in spreading the word about estate tax relief and other winning strategies for private landowners.

I have worked on efforts which have raised billions of dollars for public land acquisition and parks — Prop 70 and Props 43 and 117, Measure AA and others. I believe that we need parks and public lands in habitat preserves. I salute the Natural Communities Conservation Program efforts that Doug Wheeler, The Endangered Habitat League, The Nature Conservancy, and others are working on. There is a new state park bond in the works as we speak. It may or may not make it to the November ballot, not because there isn't a need, but because of politics. In my view, at this time in this state, the highest priority is to find ways to keep private landowners on their land. We need to use every strategy we can think up because the potential for these privately held lands to turn over in ownership to foreign land speculation companies or developers in the next decade or so is overwhelming. People who own land age just like the rest of us.

Estate taxes, as presently implemented, will force many of these land-holding families to make decisions they do not want to make. Keeping these open and productive lands in the current ownership patterns is much more cost effective than public ownership, given all of the demands for today's dollars.

We need the University of California people and other experts to be funded well in order to have a chance to disseminate research information on more efficient and cost-effective management strategies.

I mean, what I am going to urge Terry Gorton to do after today is to go back to Sacramento and ask, "Where is the oak woodlands budget in CDF?" "Where is it in Fish and Game"? When I mentioned this yesterday, she said, "Oh, I don't get into budgets." Please get into budgets if you want to make a difference to oaks.

If there isn't money for technical assistance and incentives to save oaks; if there isn't money for conservation easements; if there isn't money for producing and disseminating public information to developers, realtors, nursery owners; if agencies don't share their research and other resources and work with the private sector, then we don't really have any chance of saving California's natural oak heritage.

And to the Board of Forestry I say, thank you very much for the Integrated Hardwood Range Management Program and the Communications-Outreach Program to counties. It has moved us along. However, in most cases, the adopted documents count on people's good sense, not on their overriding greed for cents. The language in most counties is weak and not up to the challenges we face. People often try to adapt city tree ordinances for rural areas, which does not work well in most cases. We have to put some meat and potatoes on this thing.We need incentives for landowners to keep ownership in their families or with other like-minded folks, and we need incentives for them to manage these open lands for watershed, wildlife, and scenic values.

We need budgets to be reallocated; we need personnel to be reassigned. We need the experts that we have—the Bill Tietjes, the Norm Pillsburys, the Rick Standifords, the Doug McCrearys—all of these people who know so much—we need them to be training a whole cadre of other oak people until we get critical mass.

Otherwise, this is just an intellectual exercise. These oak trees are very beautiful, and that is what a lot of people say to us when they call for help. They are very concerned about a single branch being removed from something they hold dear. We have to take that concern and care, which comes from a very good place, and we have to translate it into being concerned about 17,000 oaks removed in one development's path; a dam being proposed with 4,000 oaks being flooded. It goes on and on. We think that removing five or six oaks up here on the hill is the end of the world. It is not the end of the world. It is just a piece of the pie, and all of the pieces add up.

It has been a privilege and a pleasure to be President of the California Oak Foundation. I have enjoyed it a great deal. I have learned a lot, and had a wonderful time meeting so many good folks around the state. I couldn't have asked for better people to work with over the years. My thanks to each and every one of you who contribute to this worthwhile effort. I do plan for the time being to keep on working with the Oak Foundation on these challenges, and I would urge you to do the same.

Make no mistake, California's oaks are under siege!

It seems to me that there are times when you have to step out of a more structured situation, give up titles and decorum to make the maximum impact. I believe the time for nice, polite discourse has probably just about run out if we are going to make any substantive difference to the state's oak woodlands. I like the vision of myself as the little old lady who speaks the truth and just gets a lot of pleasure out of kicking _ _ _ , as required. Thank you.

Why the System Does Not Work and How to Fix It[1]

Richard A. Wilson[2]

I would like to begin this morning with the realities of being a California landowner, a resource professional, and appointed Department of Forestry and Fire Protection Director, living in a state with tremendous resource diversity and values; in a state of 31 million residents, the 8th largest economy in the world, and in a state which is predicted to witness unprecedented growth in the next 20 years. Simply stated, change will occur on the California landscape, but is it necessary or prudent that the resources upon which our cherished values and economy have been built be eliminated as we grow? The issues related to conservation of open spaces, agricultural land, and forest management go far beyond the so-called green line between urbanization and our wildlands.

Let's go back in history and quickly review how we have arrived in our present dilemma. How can we save these prized lands?

People came to the United States from England because of property rights. This was the one way they could get freedom. The value of "property" was based on use, and the uses were agriculture, forestry, and mining. As settlement of the eastern seaboard took place, people crowded against each other. The west became the opportunity for cheap land upon which one could build a future producing basic values in agriculture, timber, and mining. Between 1812 and 1848, the Louisiana Purchase was made along with a series of land secessions by the Mexican and British governments leading to a seemingly endless supply of western lands. When times got tough because of the pressures of too many people, the western settler packed up and moved farther west.

As this western migration took place for the use of cheap land, an infrastructure began to be built: railroads, canals, navigational waterways, and better roads and communication. The Civil War brought newer technologies.

The eastern part of the country gained population and with the demographic growth came the change in perceived value of land from its use to its marketability as a commodity. In the early 1900's, we began to see land booms. People ran about excitedly during these times, staking a future in the use of such lands. These values were short lived as communities, and infrastructures quickly focused land values on its marketability as a commodity or investment. From this time forward, people have become more interested in the value of land rather than the use of the land. (Example: Early settlers along railroad right-of-ways soon developed wealth and power, based not upon farming or ranching but value of the land commodity in proximity to the tracks.)

The courts have also become more interested in land valued as commodity rather than use. We see this in large judgments today throughout the country. But the courts still hold that you can use your property as you see fit so long as you do not harm or endanger someone else (possibly your neighbor) by this use. This brings us to the environmental uses of today.

We are in trouble because the so-called solutions do not fix the problem. The political system prefers to stay on the fringes rather than go to the core issues. Before we get to the core issues, we need to examine why agriculture and forestry seem to wind up as the "bad guys." The answer comes easily. They represent the economic interest required to manage and use the land if it is to

[1] This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March, 1996, San Luis Obispo, Calif. None of the plenary papers at this symposium was subjected to technical peer review; they were the views of the presenters, in behalf of the organizations they represented.

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return a profit and/or pay for itself. This does not necessarily meet the agendas of all factions.

Growth management and all its tools—zoning, land acquisition, tax relief, and regulations—have not done the job. We are continuing to lose our best agricultural and timber lands. The system, as it is devised, will not allow a property owner to manage his or her land to optimal sustainable values. This is because a large segment of the time allowed for the property owner to manage his land is being devoted to working with lawyers, consultants, and bankers to hold on to his land.

Beyond the lawyers, consultants, and bankers is local government. Local government is casting its eyes on ways to bring in more revenues for the tax base, looking at sprawl or growth as income-generating opportunities. That drive for more revenue always leads to changing densities from the green space of agriculture, timber, and wooded landscapes to densities that support houses, business, and roads. In other words, the land-use change is from managing a productive sustainable forest to growing houses, and these uses over the long-term have not proven compatible. The usual scenario after the green line on density is broken is that the resource owners fold their tents and either retire or sell out at a higher price or try to relocate —possibly on a poorer site than the one they have lived on—and, in some cases, they leave the country and go offshore (examples: dairy industry, citrus, ranchers, timber industry, etc.).

If the sprawl then becomes a threat to the property rights of agriculture and timber, what can be done? It is difficult for owners of agricultural land and timber/wood resources not to accept zoning changes or higher density ratio on their land, because they mean a higher land value. If the landowner does not accept these zoning/density changes, capital needs for expansion, improvements, inheritance, etc. may be jeopardized because of reduced or limited value added. So the landowner is in a "Catch 22." On the one hand, the landowner wants to stay on the land and take a stewardship posture, and on the other hand, local government (in many cases) will press to increase density to provide local income, thus breaking the green line. To put it more directly, the current view is that houses and roads bring in more revenue to the local government/political body than maintaining productive open space in agriculture and forests. Should this continuous breaking of the green line be allowed, or is there a way to prevent the sprawl and stop the elimination of our agriculture and forests?

Slowly, evidence is being gathered to show that urban sprawl is costing more than it is bringing in. It is an interesting time; we have created a mousetrap through the tax code at all levels to force people from the open space, productive lands into the city and just as soon as they can make enough money, they want to move out of the city and strive to get back into open space and the wilderness landscape. Does this say something about human nature and our society?

The fiscal contributions of growing crops, trees, and animals on landscapes have been demonstrated by studies like the Coastal Community Services (CCS) evaluation performed in 11 southern New England towns. The evidence of such fiscal contributions (land versus forest, farm, and open space) was recently completed by the USDA Forest Service. If it can be fiscally shown that urban sprawl is costing society more dollars than it is generating, means must be found to keep the farmer and the forest owners economically viable for generations today and in the future.

We know the following do not work:

- Government under its current process will not save the property owner.
- The legal system cannot protect property rights.
- More laws and regulations will not do the job.

- There is a two-tiered system in place.

The landowners who have the financial means to play the game to afford the overhead of consultants and lawyers hang on, and those who cannot, move on, probably to the city.

Let's look at some possibilities.

First: We must get out of the "good guy"/"bad guy" relationship. It leads to polarization. Working relationships must be established which serve to unite philosophies to meet common goals rather than create obstacles leading to all-or-nothing viewpoints. A trapped landowner will sell out in the best interest of survival; that is human nature.

Second: Leadership does not want to make decisions to keep agriculture and timber lands whole and productive because this affects people's lives, so it turns to government, and government turns to regulation. On the other hand, burdensome and miscrafted or misunderstood regulation frustrates landowners and the public, therefore setting the trap for sell-out by the landowner.

Third: There must be long-term investment made by unification of agriculture and timber landowners. If given financial relief, the landowner must ensure long-term use versus market value of the land as a commodity.

Fourth: There must be better science, education, and communication to show what agriculture and timber interest bring to the table for the public's well-being. This is not just a matter of food on the table or wood for homes. Our lands are habitat for species, provide us liquid gold (water), conserve our soils, clean our air, and so much more.

Fifth: There must be changes in the federal and state tax codes that protect the property owner. Taxation codes are in immediate need of change if we are to meet the challenges of growth facing California in the next 20 years. This will have to be negotiated. If property owners are willing to zone their land in perpetuity to use rather than value, then the tax code needs to reflect that decision. Such changes would protect the land resources, the landowners' way of life, and the public interest both environmentally and economically.

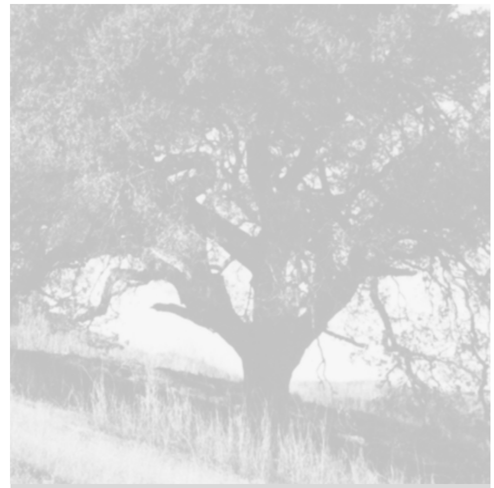
Sixth: Through a clearer mandate for the use of the land, there needs to be some way to establish consensus where, so long as acceptable, Best Management Practices (BMP) are maintained by the landowner. The state's only regulatory function at that time should be to see that there is compliance with established BMP's.

Seventh: Value Added: There must be ways to recognize and reward the property owner for value added in non-commodity areas. Without such rewards for private or industrial landowners, they cannot rise to the bureaucratic and financial burden of maintaining open space in urbanizing California.

Conclusion: Society at large must see the value of maintaining people working in the open-space landscapes, striving to achieve sustainable and productive economies.

We are currently doing it all backwards, and we are suffocating from our confusion. Action is required now if we are to save our most precious resource, our lands, for their intrinsic resource values as well as the economic well-being of our State and nation.

PLENARY PRESENTATIONS



Oak Woodland Management in the Bureau of Land Management[1]

Ed Hastey[2]

The Bureau of Land Management (BLM) in California manages approximately 14.3 million acres of which approximately 970 thousand acres are classified as hardwoods. Of this total, approximately 180 thousand acres of hardwoods are classified as timberland; the remaining 790 thousand acres are hardwoods associated with grazing management.

Of the 19 species of Native California Oaks, 13 are found on BLM-managed lands.

Hardwoods on BLM forest lands are not part of any Allowable Sale Quantity (ASQ) (No harvest of oaks planned). In fact each of our three Sustained Yield Unit Timber Management Environmental Assessments has specific mitigation measures protecting the hardwood resources.

In 1986, BLM reexamined its hardwood management policy at the same time the California Department of Forestry was looking into the cutting of hardwoods in Northern California. A hardwood management policy was adopted for the Redding Resource Area, ensuring retention of the hardwood ecosystem on BLM lands, and was incorporated into the current Resource Management Plan. BLM does not offer for sale live hardwoods except on a case-by-case basis for such actions as road right-of-ways.

BLM in California has actively been pursuing partnerships to ensure sustainable ecosystems in support of the California Biodiversity Council. The Agreement on Biological Diversity began in 1991 and established the framework by which public agencies and locally elected leaders could establish collaborative conservation planning and management programs on a bioregional and local scale.

Key oak woodland areas have been protected and expanded under this process. Some examples are:

North Coast Area - King Range National Conservation Area: 60,000 acres

Key Actions:	Maintenance and restoration of old-growth forest habitat and watershed improvements to improve and protect water quality for salmon and steelhead
Principal Partners:	Mattole River Restoration Council

North Central Valley Area - Cache Creek Management Area: 50,000 acres

Key Actions:	Protection of key wildlife and cultural value along Cache Creek (Tule elk and Bald Eagles). Protection of riparian habitats
Principal Partners:	California Department of Fish and Game, Yolo County Sacramento River Management Area: 13,600 acres
Key Actions:	Protection of 26 miles of Sacramento River frontage Protection of key wildlife and salmon and steelhead habitat
Principal Partners:	California Department of Fish and Game Wildlife Conservation Board

[1]This was an invited, plenary paper for the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif. In the absence of the author, it was presented by Carl D. Rountree, Deputy State Director for the Division of Natural Resources, California State Office of the Bureau of Land Management. None of the plenary papers was subjected to technical peer review.

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	American Land Conservancy Trust for Public Lands
	California State Lands Commission
	California State University—Chico
	Department of Boating and Waterways
	El Paso Natural Gas Company

Central Sierra Area - Inimim Forest - Yuba River Watershed: 1600 acres

Key Actions:	Community-based forest management plan
	Maintenance of old-growth forest for local community economic stability (farmers guild hued beam and furniture operation)
Key Partners:	Yuba Watershed Institute
	Timber Farmers Guild of North America
	Tahoe National Forest

Central Valley Area - Consumes River Preserve: 1600 acres

Key Actions:	Restoration of valley oaks
	Maintenance and restoration of wildlife habitat
Key Partners:	Ducks Unlimited
	The Nature Conservancy
	Wildlife Conservation Board
	California Department of Fish and Game
	Sacramento County Parks and Recreation
	Sacramento County

Central Coast Area - Fort Ord: 15,000 acres

Key Actions:	Habitat maintenance of 45 Special Status botanical species and 7 Listed Endangered Species.
Key Partners:	Department of Defense
	Monterey County Board of Supervisors
	U.S. Fish and Wildlife Service
	Environmental Protection Agency
	California Department of Fish and Game
	State Parks and Recreation
	Local governments

The Role of the California Department of Fish and Game in the Conservation of California's Oak Woodlands[1]

Terry M. Mansfield[2]

As you put the role of the California Department of Fish and Game in hardwood conservation in perspective, it is important to focus on the resource and the Department's interest in oaks. Depending on the source of the estimates, there are somewhere between 7.5 and 11 million acres of hardwood-dominated rangelands in California. From a wildlife perspective, they are very rich in native species, providing important habitats for more than 300 species of amphibians, reptiles, birds, and mammals. Key featured species draw a lot of public attention, including mule deer (*Odocoileus hemionus*), black bear (*Ursus americanus*), western gray squirrel (*Sciurus griseus*), band-tailed pigeon (*Columba fasciata*), and mountain quail (*Oreortyx pictus*). These five species provide recreational hunting and wildlife viewing opportunities on both privately and publicly managed oak woodlands. Furthermore, the myriad nongame species also provide innumerable wildlife-viewing opportunities.

There have been significant losses, fragmentation, and other negative impacts on oak woodland throughout California during the past century. In particular, losses and changes due to residential and commercial development have increased over the past 20 to 30 years. We need to recognize that there have been some changes in the land uses which most affect oak woodlands. We know traditional impacts to oak woodlands in rural areas were fuel wood cutting, removal, and control of oaks for rangeland improvement. However, in recent years and in different areas including southern California, the San Francisco Bay Area, and some of the expanding urban areas, removal of oaks and fragmentation of hardwood-dominated plant communities are due to the demand for human developments on lands in and around urban areas.

So what is the role of the Department in conserving oaks? Generally speaking, under state laws and public policy in California, the Department is the agency primarily responsible for conserving, protecting, and managing wildlife resources. The Department's hardwoods programs are guided by these laws and public policies. We carry out these responsibilities as generally framed by the California Environmental Quality Act and the more recent public policy jointly developed and implemented by the California Board of Forestry (Board) and California Fish and Game Commission.

The Department recognizes that adopting policies and regulations is not the only option to encourage oak woodland conservation. An important component of the Department's program involves developing and implementing guidelines for enhancing both the wildlife species and oak woodland habitats upon which they depend. Participation in the Integrated Hardwood Range Management Program through the University of California and involvement with both the California Department of Forestry and Fire Protection and the Board offer other means to represent wildlife interests.

An important role, of course, is land management, and the Department is also a land manager. The Department administers approximately 200 wildlife areas and ecological reserves involving more than 750,000 acres. These areas support some 55,000 acres of significant oak woodland habitats that we are responsible for managing, protecting, and improving.

[1]This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif. None of the plenary papers at this symposium was subjected to technical peer review; they were the views of the presenters, in behalf of the organizations they represented.

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What does the future hold? There is cause for concern. The well-documented declines and fragmentation in oak woodland habitats, along with the commensurate pressures on oak woodland-dependent species, should be seen as a serious warning. Valley oak woodlands, for example, are suffering from urban and agricultural development pressures. They have suffered extensive losses, and these losses continue at an alarming rate.

In the face of these human pressures and increasing levels of residential and commercial development in oak woodlands near major urban areas, it is time for a reality check. In light of the down-sizing in natural resource agencies at both the state and federal levels, there are fewer people and funds available specifically for hardwood and oak woodland management programs. The reality is that there is going to be less done by government natural resource agencies. The key to addressing that challenge, of course, is what we can and will do together. I think we need to recognize the importance of partnerships. I think we need to recognize the importance of partnerships. In light of the fact that approximately 80 percent of California's hardwood rangelands are on private land, successful programs will involve landowners, local governments, and nongovernmental organizations. We need to use some new techniques, such as interest-based negotiations. By doing so, we can identify the mutual benefits and the mutual desires of landowners, local, state, and federal governments, and other interested parties involved in long-term efforts to protect and manage the state's magnificent oak woodland plant communities and attendant wildlife.

Those are some of the realities that cause me to be cautious. However, there is also reason for cautious optimism. We are seeing a higher level of public recognition of the importance, from a natural resource perspective, of oak woodlands in California. They do support a wide variety of wildlife, and the public expects and demands protection of those values. We are seeing unprecedented levels of cooperation at higher levels between some of the most important government agencies and private partners. Cooperating agencies include the Department, California Department of Forestry and Fire Protection, University of California, California Oak Foundation, California Cattlemen's Association, and conservation groups in general.

The Department is actively involved in a wildlife management area program for private lands, and much of the private land enrolled in this program occurs in oak woodlands. Incentives are offered to the owners of private lands to manage their property so that it benefits wildlife and complements their primary land uses. Under this program, fee hunting and wildlife-associated recreation can be custom fit into a 5-year habitat and land management plan. More than 50 of those areas are licensed by the California Fish and Game Commission. The landowners pay fees to defray the costs of administering the program. We see this program as a win-win outreach situation. About two-thirds of those areas are north of Sacramento, with most interest in the northeastern part of the state.

It is also important to look at the results of current applied management investigations. An example is timber stand manipulation in California black oak (*Quercus kelloggii*) communities involving the Department and the USDA Forest Service on the Tahoe and Eldorado National Forests. Results can provide the standards we need to better guide future management programs. Conferences such as this that encourage the exchange of information and improved awareness are also important. That kind of commitment is what we need and is a reason to be optimistic.

I encourage you to build on this cooperative spirit, expand the partnerships, and encourage the exchange of information in order to reach those mutually beneficial outcomes that we would all like to see for California's oak woodlands.

Management of Oaks Within the Pacific Southwest Region[1]

G. Lynn Sprague[2]

The Pacific Southwest Region of the USDA Forest Service manages 20.3 million acres of National Forests lands, primarily within the State of California, 16.5 million of which, or 81 percent, are forested. The hardwood forest types are limited to 1.4 million acres, or 7 percent of the land base. Although this is only a small portion of the forested land base that we manage, oak management represents a number of complex issues involving the balancing of environmental, cultural, and economic concerns.

The major hardwood forest types found on National Forest lands in California consist of Canyon Live Oak, Black Oak, Blue Oak, Tanoak/Madrone, and Coast Live Oak. Other types also are found but represent small percentages.

Forest type	Acres	Pct of total hardwood acres
Canyon Live Oak	555,000	40
Black Oak	420,000	30
Blue Oak	145,000	10
Tanoak/Madrone	107,000	8
Coast Live Oak	50,000	4
Quaking Aspen	37,000	3
Interior Live Oak	30,000	2
Willow/Alder/Cottonwood	22,000	2
Other Hardwood	6,000	<1
All types	1,372,000	

Oaks are also found as a stand component in many of the conifer forest types as well. Westside Ponderosa Pine, Sierrian Mixed Conifer, Klamath Mixed Conifer, and Douglas-fir forest all contain important hardwood resources and add to the diversity of the National Forests.

In our Region, information on hardwood resources is available from two major sources: the Forest and Resource Database and a new integrated resource vegetation survey. Existing vegetation maps have been completed for all National Forest lands in California. These maps reside as digital information in our Forest and Resource Database and Geographic Information System. The existing vegetation maps describe the distribution and extent of vegetation using the CALVEG classification system, and are easily cross-walked to the Wildlife Habitat Relationship (WHR) classification system. The integrated resource vegetation inventories are part of the national program for forest monitoring and assessment. Permanent plots are being established in all vegetation types using a common 3.4-mile-grid sampling design. This program is approximately 50 percent completed in California on National Forest lands. This grid system can be (and has been) intensified to meet specific information needs of our National Forest. We have recently completed the mapping of all vegetation on the four National Forests in southern California using this inventory method.

[1] This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March, 1996, San Luis Obispo, Calif. None of the plenary papers at this symposium was subjected to technical peer review; they were the views of the presenters, in behalf of the organizations they represented.

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Historical inventory information is also available for the productive timberlands, which sampled California black oak and Tanoak/Madrone types along with the conifer forests on each National Forest. These ground-based sample plots from old and newly established inventories allow assessment of hardwood species, trees per acre, standing wood volume and growth, mortality, general forest health, fuel loading, and wildlife habitat elements.

Our forest pest management specialists also monitor the health of our oak resource and report the results of various surveys in conditions reports published in cooperation with California Forest Pest Control. These reports show that black oaks in the Northern California coast range and along many drainages of the Klamath Mountains were defoliated by Septoria leaf blight. The defoliation was quite evident, but damage to the trees was minimal. This indicates that the drought did not affect the oaks as it has the fir and pine in California. However, although occurrence of this type of defoliation may not significantly affect forest health, it can influence public perceptions because of its visibility.

Although oaks and other hardwoods represent a relatively small portion of the forest lands we manage, our goal is to manage this resource for a range of social, environmental, cultural, and economic benefits. All of our forest plans contain standards and guides that dictate the management of the hardwood species. In most cases our hardwood woodlands are maintained to maximize watershed protection benefits. However, there is also an underlying goal of retaining larger oaks for mast production to meet wildlife and cultural resource needs.

Through our relationship with tribal governments, we have reinforced our knowledge that oaks are a vital part of California's cultural landscape, particularly for Native Californians. Acorns are undeniably the most important and most "characteristic" California Indian basic food. While other tribes may have relied more on various cultivated grains, California tribes managed the California oak that provided their daily bread. Acorns were processed into meal, combined into a mush, or baked into a bread.

We are working with tribal communities to help our line officers understand that one of the strongest traditions shared by members of a cultural group is the food they eat. The preparation and sharing of traditional food is an important way for a culture to literally and figuratively sustain itself. Today, acorns may still be processed in a blender as well as a stone mortar, but either way they are an important food tradition. The gathering, drying, shelling, grinding, cooking, and enjoyment of acorn bread or mush is an important part of California Indians' ceremonies and festivals. Many tribes celebrate the fall acorn festival which marks the harvest.

The perpetuation of California's oaks is a great concern for many tribes. Tribal governments, communities, and native plant nurseries are attempting to ensure that this cultural staple is maintained. The Forest Service is working with tribal communities to identify and protect key oak stands and other important plant resources that are so basic to their traditional lifestyles.

Population growth in the urban/wildland interface is an issue being addressed at this symposium. We are also concerned with this population growth, especially when it occurs adjacent to National Forest lands. This issue encompasses differing social, economic, scenic, and recreational values as well as presenting fire suppression agencies with the complex challenge of providing cost-effective fire protection. We share their concern about the direct loss of oak woodlands caused by this development, but we are also concerned about the increased threat of fire in this urban/wildland interface. Fire suppression agencies continue to expend firefighting resources to protect life and property at the expense of letting fires burn larger areas of wildland vegetation. We are also concerned about the increased risk to the safety of our firefighters who must fight those structural fires.

Our support for sound ecological management of oaks extends beyond the National Forest boundaries through the many programs administered by our State and Private Forestry program in partnership with California Department of Forestry and Fire Protection and a number of forestry-dependent communities. The Forest Stewardship Program can provide a non-industrial private forest landowner with financial assistance to improve oak woodlands or to regenerate stands to meet wildlife habitat or other ecological objectives. These objectives must be described in a forest stewardship plan that is approved by the State Forester. The Urban and Community Forestry Program also provides technical and financial assistance to our urban communities to support oak woodland restoration.

The Rural Community Assistance Program has supported a number of studies and examinations of the feasibility of developing small businesses based on the management and utilization of hardwoods, including oaks, in California. One such study has recently been completed for the Hoopa Tribal Council. It reviewed their hardwood inventory, growth, and yield potential, and examined market opportunities and the economics of workforce development as well as cultural issues associated with acorn production and other uses of the resource. The study found that it was feasible to establish a hardwood industry, but the tribal leaders are now struggling with the issues of balancing the cultural and economic interests of their tribal members.

The Rural Community Assistance Program is currently supporting a review of the hardwood industry in California. This assessment will provide us with recommendations on the focusing of financial and technical assistance and whether it is needed to facilitate the development of an ecologically sound hardwood industry for California. This review found that, on the basis of the latest (1988) Forest Inventory and Assessment data, harvest of hardwoods is a small fraction of the net annual growth. This indicates that surplus hardwood inventory exists to support hardwood industries in California, but whether it is economically available or convertible to wood products still must be determined.

In summary, although most oak woodlands are found on private lands, our involvement with the management of oaks is directed at providing a broad range of social, environmental, cultural, and economic resources and benefits. This management often requires the balancing of complex and sometimes competitive issues. We have new, integrated resource vegetation inventories, and when these inventories are completed, we will assess whether our oak resource is at its desired sustained condition. If it is not, we will take advantage of opportunities to move in that direction.

Ecosystem-Based Planning on a Watershed Approach[1]

Charles W. Bell[2]

The United States Department of Agriculture has in recent years adopted a somewhat modified approach to natural resources management. The approach is fairly consistent within the agencies of the Department and stresses the importance of understanding the interrelationships between natural resources and natural resources management.

The Natural Resources Conservation Service (NRCS), previously known as the Soil Conservation Service (SCS), is primarily responsible for direct application of natural resource management-related conservation practices on private agricultural lands. The agency's role differs significantly from that of resource management agencies responsible for management of public lands in that the agency does not control the decision-making process relating to lands where it provides assistance.

Oak woodland management fits nicely into the two-phased ecosystem-based assistance approach currently adopted by the NRCS. The first phase or concept recognizes interrelationships between natural resources and natural resource management activities.

Historically, NRCS (or SCS) worked with private land managers to help install conservation practices that were often single-purpose in function. We were eager to provide the specific assistance desired by our clientele even though the effects of some of the activities on other resources might not have been fully considered. Today, we cross-check our resource management recommendations beyond the individual, specific resource concerns, such as soil erosion, to ensure that the recommended remedial actions do not aggravate the condition of other resources, such as water quantity and water quality or animal habitat within the same planning environment or sphere.

The second phase of the agency's approach recognizes the necessity to consider large-scale impacts of resource management. For purposes of illustration, we might refer to the hypothetical, large-scale area such as a watershed. From this perspective, we recognize the importance of cumulative impacts of resource management activities, not only on the local, site-specific environment or microsystem, but also at the broader scale. This approach is somewhat divergent from the historic agency approach of dealing solely with individual landowner's conservation treatment units, which might be a farm or a field. Although this phase still recognizes the importance of the one-on-one approach, the large-scale perspective ensures that cumulative impacts of best management practices or conservation practices do not in fact result in degradation of the resource base at other scales.

For example, we might assume that the primary purpose of a type conversion from grass to oak is to increase small grain production. Type conversion of plant communities can be advantageous and disadvantageous depending on the scale and the resource management objective from which the activity is viewed. When we view type conversion from the perspective of the land manager, we might find that production of small grains dominates the decision-making process. Some advantages might be increased soil moisture available for small grain production throughout the season, and we may then make available more

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consistent management strategies across a continuous landscape as opposed to a grass-oak mix.

When we view this same objective from the perspective of interrelationships of resources and impacts beyond the site, several other considerations become evident. And some of these might be considered advantageous and some disadvantageous. Some examples of the latter might be reduced habitat diversity; accelerated soil movement and associated erosion due to excessive soil moisture in the upper soil profile; reduced shade and riparian areas and, hence, increased surface water temperatures at the site and watershed levels. Surface and subsurface water may move downslope more rapidly because of reduced interception and evapo-transpiration. From the standpoint of plants, reduced micro-environment and diversity decreased complexity in the ecosystem.

From this discussion, it should be fairly evident that meeting the landowner's objective of increased small grain production without considering the impacts on other natural resources could result in an entirely different suite of land management activities. Beyond the site, it is quite possible that the cumulative impacts of our best conservation strategies might in fact degrade critical resources which we are trying to improve. For example, we might agree that the tolerable soil loss for a soil map unit might be 5 tons per acre per year at the site level. That amount of soil loss, when accumulated throughout the watershed, might in fact be degrading a critical surface water body.

It is not enough to make decisions based upon the condition or trend of natural resources at the site level alone. Multiple land-use strategies must also be recognized at the larger scale. For example, it is not logical to work to improve nutrient management strategies in one sector or land use within a watershed without considering the contributions of other sectors, for example, urban areas. We need to identify the sources, convince all land-use sectors within the watershed that they have a stake and a hand in natural resource conditions in the watershed, and help them to develop remedial measures.

The critical success requirement for this modified, multi-resource and multi-scale approach to resource management is intensified cooperative working relationships with other agencies, institutions, and organizations. Collectively, we can bring to the table areas of expertise, technical and financial assistance, and natural resource management perspectives that ultimately benefit all natural resources in California.

CCA History and Policy for Hardwood Range Management[1]

Kenneth J. Zimmerman[2]

Today I will discuss the history and policy of the California Cattlemen's Association (CCA) regarding hardwoods on California rangelands. There are 58 counties in California, and all but three have hardwood tree species that are predominantly oaks. Since the European settlement of California, the hardwood rangelands have been primarily managed for livestock production. Livestock production continues to be the dominant hardwood rangeland use, on 67 percent of the estimated 7.4 million acres of hardwood rangelands. Since 1985, the percentage of large-parcel owners who rely on ranching as their major source of income has declined from 70 percent to near 50 percent in 1992. For the most part, the decline has been due to the need to find alternate sources of income to supplement the ranch income. The increased costs of doing business, especially in California, and an unstable cattle market have added pressure to the large-tract landowners to seek out other sources of income, some of which are firewood sales, recreational hunting, and public participation in rangeland activities, such as gathering and moving our cattle from our ranges.

Our livestock operators have been the best caretakers of our land and renewable resources because they need to sustain the resources for future use or go out of business. This means not having the state's rich ranching heritage to pass down to future generations. Since 1986, CCA has recognized the need for an integrated hardwoods range management plan and, through our Range Improvement Committee, has coordinated and communicated with the University of California and the Board of Forestry to help develop a set of basic guidelines. At CCA we support strong private property rights protection and endorse the concepts of landowners having a maximum right of self-determination. Eighty percent of the oak resources are privately owned, and the landowners provide the best source of stewardship. I would like to remind you that Webster's definition of stewardship is "the individual's responsibility to manage his life and property with proper regard for the rights of others."

CCA has consistently encouraged landowners to participate in education, land use management plans, and self-monitoring of their hardwood resources. The Land Use Committee in CCA has a resolution on the books which supports efforts designed to maintain the physical and economical capabilities of agricultural land for the production of food and fiber and allow local governments to determine and implement specific land-use plans for their area. The Range Improvement committee of which I am co-chair has a hardwood policy which encourages landowners who harvest oaks to develop their own management plans and to contact private and public sources for expert assistance when developing their plan. Part of their plan should include a review process to evaluate and substantiate the effectiveness of the program. CCA has been active in review of the draft Integrated Hardwood Range Management Plan guidelines and has participated in the monitoring programs which were used in compiling of data to write these guidelines. In my travels through the state, I have noticed that the large tracts being developed are primarily old rangelands. There is a need to maintain these large tracts because the clearing of these lands removes the residual dry matter, canopy cover, and

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also any potential regeneration of hardwood ranges. It seems ironic that the same people who scrutinize and criticize our management practices on the hardwood ranges are the same people who buy homes on what was once hardwood habitat. CCA supports the counties' development of policies to address issues such as urban sprawl and its impact on oak hardwood ranges, harvesting of oak hardwoods for firewood, habitat enhancement for wildlife, and regeneration and restoration of oak hardwood ranges.

The county policies are referred to as Oak Hardwood Conservation policies and fall into three categories: formal voluntary county guidelines, county ordinances, and county land use planning. It is the policy of the California Cattlemen's Association to encourage local county Cattlemen's Associations to get actively involved within their respective counties in the development of formal voluntary guidelines regarding conservation of oak hardwoods. Management decisions by the landowners and managers are important because 80 percent of California hardwood ranges are privately owned. Hardwood ranges are a rich source of ecological value because of the past and present stewardship by the owners and managers of these lands. We must look at the ever-changing climate of human needs, environmental policies, population growth, and market changes; set broad-base guidelines for the management of our hardwood ranges; and still maintain our options for the future.

Hardwood Protection Needs to Come from Leadership, Not Regulation[1]

Richard A. Wilson[2]

What is the Department of Forestry and Fire Protection's position on hardwoods? We do not want to regulate hardwoods. We have been working and regulating coniferous timberlands for 23 years, and we would like to find a better way, because regulation upon regulation upon regulation brings a lot of unhappiness and unequitable situations to both the public sector and the private landowner. What I hope will happen, and certainly what the Department wants to support, is that the leadership for the areas in California will become organized, as you are around here, with a focal point at California Polytechnic State University at San Luis Obispo. Certainly, areas and regions in this state are very diverse. If you look at a bio-diversity map that states the bioregions, you will see that the Central Coast is different from those upper California areas. You have the University of California Cooperative Extension and you have Chico State University of northern California. With the help of the landowners and leadership through science and research these state university systems can bring, along with government in departments like Forestry and Fire Protection, Fish and Game, and the other cooperating agencies, collectively we can put together a program that is acceptable to landowners, as well as the public, and keep this whole landscape in place and intact and productive. So, from the Department's point of view, from Chairman Kersteins' point of view at the Board of Forestry, regulation is not the answer. Leadership is the answer. This symposium is a source of the leadership needed to accomplish these goals.

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Oak Research Needs[1]

Enoch F. Bell[2]

If you have ever read stories to your children, you have probably read about the little train that "could," but perhaps you have not heard about the oak tree that "wood knot," slight pun intended. It would not regenerate when it was supposed to. Or it would regenerate thousands of seedlings, but not one of them would survive. It would not always respond to thinning. It would not consistently provide mast for cattle and deer. It would not survive fire, but was fire dependent. It would not always sprout after death of the bole, and it would not always interact conistently with the rest of its ecosystem. However, it would frustrate scientists trying to study it and develop management guides for it. Because I come from a research institution, I am well aware of this frustration and, today, propose to talk about what we do not know about oaks and oak woodlands. I will divide my brief remarks into biological and social aspects.

Biological Aspects

One thing we have learned about oak woodlands is they often do not respond the way we think they should. I am reminded of studies on blue oaks in northern California that demonstrated that removing oak trees increases forage production. When this was tried in the San Joaquin Valley, just the opposite seemed to happen—forage production was reduced. On another front, the number of hybrids among the oaks is such that arguments ensue over what species we are actually dealing with—another confounding factor in trying to predict response. Thus, an oak woodland study from a specific area needs testing elsewhere, before its results can be considered as universal truth.

As I look at what research has been accomplished over the past few decades, I am encouraged by our progress, but I still feel we have a ways to go.

- Resource inventories of oak woodlands are a fairly recent phenomenon; thus, changes in resources are not well recognized. You will hear some assessment of changes in oak woodlands here at this conference, but we need more detail. What is actually happening on the urban fringe where change seems to be occurring so rapidly? Are woodland resources declining rapidly, and if so, how fast?
- Much has been done over the past decade on blue oak regeneration. But, what about the other oaks, especially valley and Engelmann, and what about factors that affect survival once the oaks regenerate? Surely more research is needed, before we can assure oak regeneration and survival in the woodlands.
- Oak woodlands do not always respond to management the way scientists expect. Of particular concern to me are the responses to urban development and prescribed fire. In both situations, it is not just the management impacts on oaks that are of concern, but also their effects on the entire ecosystem including related plants, insects, mammals, etc. I am particularly interested in what "ecologically sensitive development" looks like. Can we have both development and a healthy woodland ecosystem?

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Social Aspects

Too often scientists study ecosystems without including the people who inhabit them. Yet, people often have tremendous effects on ecosystems. We need to understand what makes people tick and why they want to tick in the oak woodlands.

- Though there have been some studies of landowners, communities, and the public in general as they relate to the oak woodlands, much more research is needed before we will completely understand how people interact with this ecosystem.
- We need to know the needs, expectations, and motivations of people before we can start solving some of the problems they create. How do their feelings vary by ethnicity or other social groupings? Why do they do the things they do?
- On the economic side, how do we provide incentives or easements for desirable ecosystem management on private lands? How do we fund these programs: with tax dollars, rebates, public taking?
- What are the best organizational structures for ecosystem management in our oak woodlands? Do we use national, state, or local laws with police enforcement; landowner cooperatives; religious teachings; or our economic markets?

Certainly there are lots of unanswered questions. And after looking at all we do not know, I can only conclude that more research is needed in oak woodlands, both on the biological and particularly on the social sides. Without this research the problems addressed in this conference will remain. Would you expect a scientist to say anything else?

ECOLOGY AND REGENERATION

I

Progress on the Ecology and Silviculture of California Oaks During the Past 17 Years[1]

Timothy R. Plumb[2]

Basic knowledge about the ecological processes and silvicultural requirements of California oaks is essential for their effective management and perpetuation. Interest in ecology and all other aspects of oaks has grown dramatically since the 1979 Oak Symposium (Plumb 1980). But, why has it been so difficult to determine the array of critical factors that control oak population dynamics, establishment, survival, and development into healthy, mature trees? What insight do the papers in this Symposium present? Probably one of the most extensive efforts to date to document ecological variables affecting oak recruitment was presented on blue oak saplings. Although a number of environmental factors that affect blue oak (*Quercus douglasii* Hook. & Arn.) were identified, the bottom line is that sapling recruitment is a long time process affected by a number of interacting variables. Current blue oak basal area and relative tree crown size were reported to be significantly linked to stand dynamics.

To complicate matters even more, we must realize that we are dealing with a diverse group of species; at least nine oak species normally grow to tree size, each with its own set of ecological requirements. Further complicating oak ecology is the propensity for subgenera hybridization. One Symposium paper deals with hybridization among coast live oak (*Q. agrifolia* Née), interior live oak (*Q. wislizenii* A. DC.), and *Q. parvula.* Two other papers deal with interspecific variation, indicating local adaptation between and within local blue oak populations, but there is not yet enough evidence to demonstrate a geographic pattern in either latitude or altitude.

An extremely important feature of oaks trees is their canopies; these have a major impact on the local environment. They affect nutrient cycling, seedling establishment and survival, understory species, forage production and growth, organic matter (on and in the soil), and possibly soil texture. Reports of preliminary work indicate that soil texture under a mixed stand of blue and coast live oaks was coarser and higher in organic matter under coast live oak. Other work reported confirms past evidence that nutrient level under blue oak is several times greater than that of adjacent grassland. Part of the higher nutrient concentration is undoubtedly due to litter and possibly leaching of nutrients from the canopy. But, where lichens are present, new evidence shows that they enhance nutrient cycling fluxes and do not hinder tree growth.

Canopy density likewise affects understory species composition, productivity, and nutrient status. The last two factors are enhanced over grasslands when canopies are open and annual rainfall is less than 50 cm. To the contrary, production under dense canopies is reduced where rainfall is greater than 50 cm. Based on tree mortality and sapling recruitment, blue oak density and canopy cover is decreasing at most of the sites studied. However, in a mixed oak-pine area of the Sierra Nevada foothills, recent longer-than-natural fire-free intervals have resulted in increased oak density.

For oaks to capitalize on the under-canopy nutrients, they should have appropriate root size and distribution. Blue oak root mass was correlated with

[1]Presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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tree age, diameter at breast height (dbh), and bole weight. Only 8 percent of the roots were less than 5-10 mm in size, and they were found to be somewhat deeper than grass roots. Oak roots are sensitive to low soil oxygen concentration which is reduced by soil compaction and especially high water content.

In regard to recruitment, canopy shade is more important for coast live oak than for blue oak. Compared to coast live oak, fewer blue oaks were found to emerge, but a much higher percentage of them survive beyond 3 years. In fact, in the southern Sierra Nevada foothills, 10 percent of the blue oak "seedlings" at one site were more than 23 years old. However, the sapling-sized oaks in this area are few in number. On the average, only 15.3 percent of the plots throughout the range of blue oak had saplings present.

Before there can be seedlings or saplings, two basic requirements must be met. One, there must be an adequate seed source, enough to overwhelm herbivory; and two, there must be sustained suitable climatic conditions to promote germination and good root development. Acorn production this year, 1996, was extremely low throughout the state for the 1-year acorn species. Acorn crops of 2-year acorn species were large this year; it will be interesting to see how large their crop will be next year. Work reported at the Symposium indicates that acorn crops are synchronous over 500- to 1,000-km distances. As just noted, the state-wide low acorn crop for 1995–96 bears this out. The assumption is that large-scale weather patterns moderate tree growth and acorn production.

In contrast to the large proportion of oak research in the 1950's and 1960's that was involved in the control of hardwoods, most work since 1970 has been oriented toward promotion of oak recruitment in one way or another. However, total oak management requires the ability to selectively perpetuate or control oaks and other hardwoods. In regard to control, stump treatment of tan oak with undiluted amine of tryclopyr was reported to be very effective. But, promoting oak recruitment and sustainability is still the major oak challenge today.

Reference

Plumb, Timothy R., technical coordinator. 1980. **Proceedings of the symposium on the ecology, management, and utilization of California oaks;** June 26-28, 1979; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 368 p.

Challenges of Inventorying and Monitoring Oak Woodlands[1]

Charles L. Bolsinger[2]

California's oak woodlands are inventoried periodically by the USDA Forest Service as part of the nationwide Forest Inventory and Analysis (FIA) effort. Forest inventories were originally authorized by the McSweeney-McNary Forest Research Act of 1928. Fifty years later Congress reaffirmed the need for forest inventories in the Forest and Rangeland Renewable Resources Research Act of 1978. FIA inventories in California are conducted by the Pacific Northwest Research Station (PNW) in Portland, Oregon. PNW collects data on lands outside National Forest, and the Pacific Southwest Region of the Forest Service collects data on National Forest lands. About 84 percent of the oak woodland in California is outside National Forests, including about 69 percent in private ownership, and 15 percent in State and National Parks, military reservations, Bureau of Land Management holdings, and miscellaneous public tracts. PNW has the responsibility for compiling, analyzing, and reporting the data for all ownerships.

The inventory cycle is about 10 years, subject to variations related to budget and other factors. Data currently being compiled from a mid-1990's inventory will update a mid-1980's inventory (Bolsinger 1988). The rest of this paper deals with PNW's inventory of privately owned oak woodlands in California, an area of about 5 million acres.

The inventory design is Cochran's (1977) double sampling for stratification. The primary sample consists of several thousand aerial photo plots which are classified by land use and broad vegetation and density classes. A secondary sample of several hundred of the photo plots visited on the ground provides a check of the aerial photo classification and details on tree and stand characteristics. Ground plots consist of three to five subplots distributed over a 2-ha area. More than a million data items were recorded on these plots in the latest inventory, including tree measurements, ground cover, and physiographic factors. About half of the plots have been visited twice and provide detailed information on change in land use and vegetative cover, and tree growth, mortality, and removal.

Most of the technical problems of inventorying California's oak woodlands have been worked out and used successfully for at least 15 years (Bolsinger 1988, Pillsbury and Brockhaus 1981, Pillsbury and Kirkley 1984). As forest inventories go, the oak woodlands would seem to present few problems. As one forester commented while driving through the oak-dotted grasslands, "A piece of cake." Challenges there are, however, and in two areas not covered in my curriculum when I was an undergraduate in forestry school: people skills and sleuthing ability.

People, specifically the owners of the hardwood range, presented the biggest single challenge in the oak woodland inventory. Getting permission to go onto the landwas first and foremost. Landowners were contacted by letter, and sometimes later by phone, to ask for their cooperation. Most landowners—96 percent—were cooperative, but the process was anything but straightforward.

[1]Presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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The owners of many properties had changed since the county courthouse records had been posted. Several owners had died. In a few cases, crews found that there were errors in the ownership records, and the real land owner had no clue we were coming until we showed up. Among the problems were lands registered under one name and occupied or managed by someone else, or listed as a bank, or title or trust corporation, or in receivership or other in-between status. Absentee owners were common, with the addresses ranging from Kings City to Kuwait. Some owners who gave us permission, in writing, changed their minds by the time crews arrived. In a couple of cases, an owner gave crews permission, and then another family member decided against it. In one case crews were asked to leave when they were half finished measuring an inventory plot.

Though we were denied access to only 4 percent of the plots (in a previous inventory we were denied access to 2 percent), statewide, the plots that we were not allowed to visit tend to be clustered in certain geographic areas, and do not represent average conditions. Denied access has probably introduced some bias into the inventory. Why do land owners deny access to inventory crews?

Reasons given include:

Fear of regulation. Several landowners in Tulare and Kern Counties were afraid crews would find *Pseudobahia tulare*, a listed endangered plant, on their lands. Some landowners were concerned that other plants on their land might later be listed, or that other conditions as noted on inventory records would somehow be used to prove that their management practices were violating some regulation or law. Some owners were concerned that the inventory crews might classify their land as "critical wildlife habitat," resulting in restrictions on land use activities. It did not matter that we were not evaluating management practices or classifying critical habitat. What mattered was what landowners thought.

Fear of liability for injuries received by inventory crews. At least one owner denied access after refusing to accept the release statement provided by the Forest Service.

Fear that inventory crews would damage property or leave gates open.

Unstated or unspecified fears, which are known or thought to include the following reasons: presence of drug-producing plants (marijuana or opium poppies); anti-government sentiment and a chance to say "no" to Feds; the notion that allowing access may result in higher property taxes, or conversely that denying access may lower Federal taxes; that allowing one crew on the land will set some kind of precedent and many other crews will follow. One landowner expressed concern that the inventory crew's vehicle would leave ruts that could become gullies, a reasonable concern by a good land steward. The crew offered to walk to the plot from a gravelled road, but was still denied access to the land.

Next to dealing with landowners, a major challenge is finding plots that were established at an earlier date. Forest Service plots in the oak woodland were established in the 1980's and relocated and measured in the 1990's. During the 10-year period a lot happened out in the hardwood rangelands: many plots were affected by tree cutting, road-building, residential and commercial development, livestock grazing, insects, disease, fires, floods, windstorms, and landslides. Natural vegetation succession was also a factor, and, in a few areas, the growth of stump sprouts had transformed open "savannas" into oak jungles.

Inventory crews rose to the challenge and "sleuthed out" more than 98 percent of the plots. Relocating plots, including matching up trees tallied in previous projects, is time-consuming and costly. It is considered essential, though, for quantifying change in the hardwood range, including trends in land use by cause, changes in stand characteristics (type, size, density, understory, health), tree growth, mortality, and tree cutting.

Plots are marked on aerial photographs and "monumented" on the ground with distance and azimuth to "witness trees" and other features. If any one of the three to five subplots is found, the others can be located by measuring off distances at the appropriate azimuths. Each tally tree is marked with a numbered tag near the ground and a nail at breast height. Azimuth and distance from plot center are recorded for each tree.

Heavily disturbed plots presented the biggest challenge. The best technique for finding these plots is whatever works. Among them: Landowners were often helpful in telling crews where they had cut trees that had tags on them, or where the plot was located in reference to new developments. One crew found tree tags still attached to logs in a stack by a road 100 m from the plot and followed skid roads to the plot area. Some trees on a "conversation-piece" plot on an unstable slope slid out of the plot, and some slid in between inventories. A more common situation was to find a plot or a portion of a plot altered by heavy machinery—trees and brush pushed into piles, vegetation scraped off, all evidence of the plot destroyed. Such plots were usually relocated by measuring from nearby locations that had not been heavily disturbed, or if the entire area had been altered, by triangulating and measuring in from areas outside of the disturbed area. Where the plot was entirely wiped out, a new plot was located in the area and new data collected, unless, of course, the plot area was converted to a housing tract, highway, or other non-wildland development.

Take-home lesson: Every aspect of the resources on the hardwood rangelands is changing, and perhaps none at a faster rate than the people who have the most influence on the future of the hardwood rangelands—the landowners. It is something to keep in mind by anyone planning an inventory and monitoring project or, for that matter, developing programs to manage or protect these lands.

References

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas.** Resource Bulletin PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Cochran, W.G. 1963. **Sampling techniques.** 2d ed. New York: John Wiley & Sons; 413 p.

Pillsbury, Norman H.; Brockhaus, John A. 1981. **Hardwood biomass maps for California's central coast.** San Luis Obispo, CA: California Polytechnic State University; 12 p.

Pillsbury, Norman H.; Kirkley, Michael L. 1984. **Equations for total, wood, and sawlog volume for thirteen California hardwoods.** Res. Note PNW-414. Portland, OR: PacificNorthwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 52 p.

Soil Characteristics of Blue Oak and Coast Live Oak Ecosystems[1]

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Abstract: *In northern San Luis Obispo County, California, soils associated with blue oaks (*Quercus douglasii*) are slightly more acidic, have finer textures, stronger argillic horizons, and sometimes higher gravimetric water content at -1,500 kPa than soils associated with coast live oaks (*Quercus agrifolia*). Soils associated with coast live oaks generally are richer in organic matter than those associated with blue oaks. Blue oaks seem to grow more frequently on erosional surfaces and in soils that sometimes have a paralithic contact at about 1 m depth, whereas coast live oaks may be found more frequently on depositional surfaces. Although the two species sometimes occupy seemingly comparable sites, results point to significant microsite differences between them. Full, conclusive characterizations useful in managing and enhancing oak woodlands will require study of many more sites.*

The distribution and productivity of California's 3 million hectares of oak woodlands are controlled in part by the soils of these ecosystems; moreover, proficient management of oak woodlands requires ample knowledge of one of the most important, but least understood, habitat components—the soil. Blue oak (*Quercus douglasii* Hook. & Arn.) and coast live oak (*Quercus agrifolia* Née) are two important species in the central coast region that commonly grow in proximity, including in mixed stands. Nonetheless, the two species may have different site preferences, suggesting that different approaches to stand evaluation and management may be appropriate. An important step in determining site preferences is to adequately characterize the soils of these ecosystems.

Given the paucity of published information regarding specific soil–plant relations in California oak woodlands, this project was undertaken as a pilot work to identify potential correlations between the occurrence of the two species and soil morphological properties. Sites supporting mature blue oak and coast live oak in northern San Luis Obispo County were chosen for this study.

To improve readability of this paper, soils associated with blue oaks or with coast live oaks may be referred to simply as "blue oak soils" or "coast live oak soils." These designations are not taxonomic names, and they do not imply any distinctive morphological or chemical properties of the soils.

Literature Review

Blue oaks often occur in mosaics of grassland, savannah, and chaparral that may reflect differences in slope, aspect, soil depth, and fire frequency (Barbour 1987). Throughout their range, blue oaks commonly occur on rolling hills of 10 to 30 percent slope (Barbour 1987, Rossi 1980). In southern San Luis Obispo County and northern Santa Barbara County, valley grasslands support scattered, nearly pure stands and individuals of blue oak, whereas upper, higher-elevation slopes are dominated by mosaics of blue oak woodland and chaparral (Borchert and others 1993). In some areas of central California, blue oaks favor southerly-facing slopes (Griffin 1973); in other areas they favor northerly-facing slopes, but they also can be found on easterly, westerly, and southerly-facing aspects (Borchert and others 1993).

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif. The paper is adapted from the first author's master's thesis (Downie 1996)

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While blue oaks may grow on a wide range of slope positions and aspects, coast live oaks along the central coast seem to be confined more often to drainages and northerly-facing aspects. In the San Luis Obispo area, coast live oaks have been reported on soils derived from diverse parent materials and having a variety of textures, including sand, loamy sand, sandy loam, loam, clay loam, and clay (Wells 1962). Although soil and site characteristics of these stands may be diverse, evidence suggests that in the Chimney Rock Ranch area coast live oaks are found on sandier soils than are neighboring blue oaks (Plumb and Hannah 1991). Soils supporting blue oaks often are characterized by a claypan or an argillic horizon (i.e., clay-rich subsoil layer) (Borchert and others 1993, Hunter 1993, Lytle and Finch 1987).

Blue oaks may occupy droughtier sites and survive severe drought conditions better than coast live oaks (Griffin 1971, Rossi 1980). This hypothesis is supported by the drought-deciduous nature of blue oaks, as well as by studies of plant water relations, root morphology, and root distribution patterns (Callaway 1990, Griffin 1973, Matsuda and McBride 1986, McCreary 1990). Blue oaks have shown higher xylem sap tensions than have coast live oaks under a variety of site conditions, suggesting that of the two species, blue oak may lose more water to transpiration under conditions of mild to moderate stress (Griffin 1973). Under these conditions, sclerophyllous evergreens, such as coast live oak, can more efficiently reduce transpiration rates through stomatal closure than can deciduous species such as blue oak (Chabot and Hicks 1982, Poole and Miller 1975). These transpiration differences have been inferred in comparisons of matched pairs of blue oak and coast live oak (Griffin 1973). Nevertheless, under conditions of severe stress, blue oaks may be better adapted because of their ability to drop their leaves, thus eliminating transpiration losses.

The dominant source of water for the two tree species, whether from vadose soil moisture (i.e., soil water in the unsaturated zone above the water table) or deeper ground water, is unknown, especially for different conditions. In the Sierra Nevada foothills, blue oak and interior live oak (*Q. wislizenii*) can extend their roots more than 20 m deep, allowing them to extract water from below the water table (Lewis and Burgy 1964). Phenotypic similarities between interior live oak and coast live oak suggest the possibility of coast live oak attaining similar rooting depths. Water table penetration may allow some coast live oaks in Monterey County to maintain low xylem sap tensions during severe drought (Griffin 1973).

Root production in blue oaks can exceed that in coast live oaks during the first growing season, because of blue oak's earlier germination and faster root growth (Matsuda and McBride 1986). In response to water stress in the field and greenhouse, blue oaks were observed to significantly increase lateral root growth while coast live oaks did not. In contrast, under conditions of adequate moisture, blue oaks produced few new lateral roots, while coast live oaks produced a moderate amount of new lateral roots. Both species may be able to alter their root systems in response to changing moisture availability. The type and extent of change may be influenced by the presence or absence of mycorrhizae (Callaway 1990). Mycorrhizae increase soil moisture uptake and may enable some plants to obtain water held at otherwise unavailable tensions (Bethlenfalvay and others 1986).

Soils beneath oak canopies have higher organic carbon contents and greater fertility than do adjacent soils (Dahlgren and Singer 1991, Holland 1973, Parker and Muller 1982). Moreover, soil organic matter under evergreen oaks may differ from that under deciduous oaks because of differences in leaf production and retention. In California, the evergreen coast live oak produces about twice as much litter biomass as the deciduous valley oak (Hollinger 1984). In addition, evergreen leaves often have slower rates of decay and mineralization than do deciduous leaves. Contrastingly, in northern temperate forests, evergreen and deciduous species produce similar amounts of litter (Chabot and Hicks 1982).

Site Description

Five sites were selected in northern San Luis Obispo County, California: four at Chimney Rock Ranch, approximately 13 km northwest of Paso Robles, and one at Camp Roberts, about 10 km north of Chimney Rock Ranch. All sites currently are grazed by cattle, with grazing intensity and congregating preferences of the animals varying from site to site. Sites were selected for accessibility and presence of blue oak and/or coast live oak.

The Chimney Rock Ranch sites are blue oak and coast live oak woodlands, in either separate or mixed stands, with understories of herbaceous annuals. The soils, which are dominantly Ultic Haploxeralfs and Ultic Argixerolls, are underlain by calcareous and noncalcareous sandstone and conglomerate, and diatomaceous shale. Aspects vary considerably for both oak species. Slopes range from 5 percent to 40 percent, and elevations are between 335 m and 450 m. Annual rainfall is about 600 mm. At Paso Robles, average air temperatures are as follows: winter average overall is 9 °C, winter average minimum is 1 °C; summer average overall is 21 °C, and summer average maximum is 33 °C (Lindsey 1983). Water well log data at one of the sites indicate that the water table was at 20 m on October 3, 1991.

The Camp Roberts site is open woodland with an annual herbaceous understory. Soils are underlain by soft, calcareous sandstone. The site is limited to blue oaks that grow on north-facing slopes and in drainages. Slopes range from 5 to 30 percent, and elevation is about 275 m. Mean annual maximum air temperature is 24 °C; mean annual minimum temperature is 6 °C, and mean annual rainfall is approximately 180 mm in the Camp Roberts area (Nakata and Associates 1987).

Methods

Soil pedons (i.e., small, three-dimensional soil bodies) were described according to *Soil Survey Manual* guidelines (Soil Survey Division Staff 1993). At Chimney Rock Ranch, 17 pedons (eight blue oak and nine coast live oak) were described in backhoe-dug pits, and at Camp Roberts, three blue oak pedons were described in road cuts and hand-dug pits. The choice of soil pedon locations was limited by safety considerations in backhoe operation. Pedons were chosen to be under the tree canopy or close to it, without regard for aspect or topographic position. The mean distance of soil pits from the nearest tree was similar for each species, but any possible relationship between this distance and soil properties was not evaluated.

Approximately 1 liter of soil was collected from each horizon of each pedon (92 samples total) for laboratory testing. Particle size analyses followed the ASTM (American Society for Testing and Materials) hydrometer method (Gee and Bauder 1986). Gravimetric water contents at -1,500 kPa water potential were determined in a pressure membrane apparatus (Klute 1986). (Although this water potential value is commonly taken as the permanent wilting point, it is an inapplicable designation when applied to most plants other than agricultural row crops. Nonetheless, it is a helpful and commonly used reference point.) Soil reaction (i.e., pH) was measured in a 2:1 0.01M $CaCl_2$ (calcium chloride) solution using a Corning model 420 pH meter. Carbonate content was determined by the acid neutralization method (Allison and Moodie 1965), and organic carbon content was determined by acid dichromate digestion (Allison 1965).

Additional soil chemical analyses were conducted to test the potential for correlating soil taxonomic classifications published in soil surveys with the distribution and possible site preferences of the two oak species. For the taxonomic purpose of distinguishing Mollisols (which must have base saturation of 50 percent or greater) from Alfisols, base saturation percentages were determined for A horizons in the 14 of 20 pedons that met all other criteria for Mollic epipedon (i.e., the upper layer of soil used for taxonomic classification), and that had pH values between 5.0 and 7.0. Base saturation was calculated as the proportion of the sum of Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+} (analyzed by atomic absorption or atomic emission spectrophotometry) removed from the cation exchange complex, the capacity of which was measured by NH_4OAc (ammonium acetate) saturation (Chapman 1965, Doll and Lucas 1973). Soils having pH greater than 7.0 were assumed to have base saturations greater than 50 percent. Base saturations were not measured in soils that did not meet other Mollisol criteria (i.e., depth, color, structure, or organic carbon content).

Data were analyzed for statistical significance of differences between blue oak and coast live oak sites using the Student's t-test, run on Minitab, version 7.2.

Results and Discussion

Land surfaces were characterized as being dominantly erosional or depositional, depending on whether they tended to lose or accumulate soil. The total sample was composed of 45 percent erosional surfaces and 55 percent depositional surfaces. In the study area, blue oaks more frequently grow on erosional surfaces, and coast live oaks occur more frequently on depositional surfaces. Seven of the 11 (64 percent) blue oak surfaces were erosional, whereas 7 of the 9 (78 percent) coast live oak surfaces were depositional.

Although soil depths could not be measured conclusively, even in backhoe-dug exposures, some observations suggest that on these sites blue oaks may grow in shallower soils than do coast live oaks. At two of the three sites that support both tree species, the proportion of blue oaks is greatest in shallower soils near rock outcrops, and least in deeper soils away from the outcrops. Conversely, coast live oaks increase with increasing distance from outcrops to become pure stands in the deepest soils. In one case, soil depth increases from 90 cm near a rock outcrop to more than 300 cm less than 50 m distant. Both species grow in the shallower soil, but only coast live oak grows in the deeper soil. Moreover, three of the five blue oak pedons at this site have paralithic contacts (i.e., weathered bedrock surfaces) at depths ranging from 90 to 110 cm, while none of the coast live oak pedons have either a paralithic or lithic (i.e., hard rock) contact within 150 cm of the surface. At another site, bedrock appeared to be at about 160 cm under blue oak, but was deeper than 300 cm under coast live oak. Additional observations at this site suggest that the two oak species are growing on different soils, with the blue oaks occupying finer textured, rockier soils than the coast live oaks.

The coast live oak soils generally were richer in organic matter than were blue oak soils, although considerable overlap of properties was noted. Overall, the coast live oak soils exhibited significantly greater frequency of occurrence and thickness ($P = 0.097$) of O horizons (i.e., litter layers), more organic carbon in A horizons ($P = 0.008$), and darker color ($P = 0.047$) as reflected by Munsell values (*table 1*). All organic layers consisted primarily of oak leaf litter, with no significant contribution from grasses and forbs in the understory. In addition, although Munsell color values varied, hues were 10YR (yellow-red) for all A horizons studied.

Somewhat in contrast to the organic matter and color value data, mean thickness of A horizons was not significantly different; nonetheless, the mean thickness of coast live oak A horizons was 6 cm greater than those in blue oak soils. This point suggests that A horizon thickness may depend on the nature of the organic matter and its rate of decomposition, as well as on the organic carbon content. Evergreen leaves tend to be tougher and richer in lignins and other resistant components than are deciduous leaves (Chabot and Hicks 1982). Also, the difference in organic carbon contents found in this study may not be significant when the entire process of A horizon pedogenesis, including nutrient cycling, humus cycling, and bioturbation, is considered.

The mean and range of soil pH values suggested stronger acidity, by about one-half pH unit, in coast live oak soils than in blue oak soils (*table 2*). Differences were not statistically significant between A horizons ($P = 0.13$), but they were significant between subsoils ($P = 0.038$) and between pedons taken as a whole ($P = 0.026$). Subsoils and whole pedons showed similar pH values. Although statistically significant, differences in mean pH values between soils of the two species may be of no importance to reproduction and growth of the trees, because both species clearly thrive within a similar range of pH values.

No consistent patterns of pH change with soil depth emerged under either species, although pH consistently decreased with increasing depth under oaks in an earlier central coast study (Borchert and others 1993). The lack of consistent decrease in pH with increasing soil depth probably is due to the calcareous parent materials in several pedons. In addition, no correlation between pH and organic carbon content was found in the A horizons.

Soils ranged from weakly developed Entisols to well-developed Alfisols for each species, a range similar to that noted in an earlier study of blue oaks in southern San Luis Obispo and northern Santa Barbara Counties (Borchert and others 1993). Ten of the 14 sites that were analyzed for taxonomic purposes had base saturations between 45 percent and 55 percent. The base saturations were only weakly correlated with pH, with the correlation being slightly stronger under coast live oaks than under blue oaks. The average base saturation of A horizons was significantly ($P = 0.051$) less, and the range of values was wider in coast live oak soils than in blue oak soils (*table 2*). Nonetheless, tree species distribution is unrelated to the base saturation distinction between Mollisols and Alfisols.

Blue oak soils tended to be more finely textured than coast live oak soils (*table 3*), with blue oak soils having more silt near the surface, and more clay and

Table 1—Organic matter-related characteristics of soils associated with blue oak and coast live oak

			A Horizons						
	O Horizons		Thickness		Organic carbon concentration		Munsell color value[1]		
Species	No./No. of pedons	Mean thickness	Mean	Range	Mean	Range	2 (darker)	3	4 (lighter)
		cm	*cm*	*cm*	*pct*	*pct*			
Blue oak	4/11 (36 *pct*)	2.00	36	20-75	2.35	1.09-3.56	0	8 (40 *pct*)	3 (15 *pct*)
Coast live oak	8/9 (89 *pct*)	3.63	42	10-99	3.55	2.20-4.67	1 (5 *pct*)	8 (40 *pct*)	0

[1]Data beneath Munsell color values are numbers of pedons in which that color was observed.

Table 2—pH and base saturation values for soils associated with blue oak and coast live oak

Species and associated soil	pH		Base saturation percentage	
	Mean	Range	Mean	Range
Blue oak				
A horizons	6.0	5.1–7.5	49.7	44.9-53.6
Subsoils	5.8	3.9–7.9	NA	NA
Coast live oak				
A horizons	5.5	4.3–6.4	38.5	14.1-53.8
Subsoils	5.2	3.7–7.8	NA	NA

Table 3—Soil particle size percentages and levels of statistically significant differences for blue oak soils and coast live oak soils

Species	Sand		Silt		Clay		
	Mean	Range	Mean	Range	Mean	Range	Increase with depth
Blue oak	53.9	8–88	24.9	6–52	21.4	6–64	19.3
Coast live oak	64.2	20–87	18.9	3–48	16.8	5–35	6.89
	$P = 0.030$		$P = 0.030$		$P = 0.089$		$P = 0.047$

less sand at depth. Although argillic horizons, which were identified by the presence of clay films as well as by clay increase with depth, were present in 16 of the 20 (80 percent) pedons described, they were slightly more common and more strongly developed under blue oaks than under coast live oaks, suggesting somewhat stronger leaching of clay in the blue oak soils. These differences led to soil taxonomic distinctions at the family level, but not at the higher (i.e., broader) levels in the taxonomy. While all coast live oak pedons were classified in the coarse-loamy particle size class, only about half of the blue oak pedons fell into this class. The remaining blue oak pedons (5 of 11) fell into the fine-loamy, fine, or very fine classes.

Overall, blue oak soils and coast live oak soils showed no significant differences in water content at –1,500 kPa among the five sites; nonetheless, values were significantly higher in blue oak soils than in coast live oak soils on two of the three sites that supported both species (*table 4*). The differences at these two sites are attributed to higher clay content in the blue oak soils than in the coast live oak soils. Soils on one of these sites exhibited –1,500 kPa water content that was approximately three times greater than that of other sites (*table 4*). This difference appears to be a function of soil parent material, which is derived from diatomaceous shale on the site that retains more water, and from sandstone and conglomerate on the two sites that retain less water.

Table 4—Gravimetric water content (pct) at -1,500 kPa in blue oak and coast live oak soils

	All sites		Site 1*		Site 2*		Site 4*	
Species	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Blue oak	12.8	4.5-39.3	10.8	4.5-23.0	7.6	4.5-16.1	36.6	32.4-39.3
Coast live oak	12.3	2.0-34.5	6.1	2.0-15.4	8.0	5.7-9.6	31.6	29.3-34.5
	$P = 0.83$		$P = 0.001$		$P = 0.72$		$P = 0.04$	

*Soils of sites 1 and 2 are derived from sandstone and conglomerate; soil of site 4 is derived from diatomaceous shale. Site numbers correspond to those presented in Downie (1996).

Field moisture contents for three soils (two blue oak and one coast live oak) sampled in mid-September 1992 were close to the –1,500 kPa values obtained in the laboratory, indicating that at that time soils were at or near the so-called permanent wilting point. No rain had fallen since the previous spring, and rainfall that year was close to average. In contrast, soil water potentials at the Sierra Foothill Range Field Station in Yuba County, California, ranged from –3,600 kPa at the soil surface to –1,800 kPa at 40 cm depth in August 1986 (Gordon and others 1991). Removal of the litter layer may partially account for the low potentials in the Yuba County study. In our study, the presence of depositional surfaces (including a flood plain), which are likely to accumulate litter as well as soil, and the presence of diatomaceous parent materials at some sites may have helped maintain higher moisture concentrations in the fall.

Macropores and casts attributed to earthworms often were noted in pedon descriptions, but their significance was not assessed. Future studies of oak woodland soils should consider the role of earthworms, which often are abundant in California oak soils and can significantly affect soil physical and chemical properties (Graham and others 1995, Wood and James 1993).

Conclusions and Recommendations

Even though considerable overlap of site and soil characteristics was found, this study reveals significant microsite differences between blue oak and coast live oak. These differences further suggest that the two species have different site adaptations or preferences, each of which should be more fully investigated, with larger data sets, on a scale that covers the full geographic range of each species.

Virtually none of the differences noted are revealed by soil taxonomic classifications, except for taxonomic criteria related to soil texture and depth. Although using soil taxonomy to differentiate site preferences at this time would be dubious, additional work with large data sets might reveal soil taxonomic differences between soils associated with the two species.

Given the differences in litter layers, organic carbon contents, and pH between soils of the two species, additional differences in soil cation exchange capacity and fertility are possible. The effects of these on seed germination and seedling growth deserve attention.

Soils from the two sites having widest textural differences also exhibited significant differences in –1,500 kPa water content. Likewise, soils having no significant differences in texture showed no significant differences in –1,500 kPa water content. Overall, the relationships noted among soil texture, water potential, water content, and oak species distribution are inconclusive. Nonetheless, given that weak relationships were noted, and that blue oaks tended to favor finer soils than did coast live oaks, soil water potential through the year may be an important site discriminator on a broader scale than was covered in this study. This possibility merits further investigation.

The final point is clear: the soil component in oak ecosystems must be much more intensively and extensively investigated if these systems are to be understood, enhanced, and managed efficiently and effectively.

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References

Allison, L.E. 1965. **Organic carbon.** In: Black, C.A., editor-in-chief. Methods of soil analysis, Part 2, chemical and microbiological properties. Madison, WI: American Society of Agronomy, Inc.; 1367-1378.

Allison, L.E.; Moodie, C.D. 1965. **Carbonate.** In: Black, C.A., editor-in-chief. Methods of soil analysis, Part 2, chemical and microbiological properties. Madison, WI: American Society of Agronomy, Inc.; 1379-1396.

Barbour, Michael G. 1987. **Community ecology and distribution of California hardwood forests and woodlands.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 18-25.

Bethlenfalvay, Gabor J.; Thomas, R.S.; Dakessian, S.; Brown, M.S.; Ames, R.N. 1986. **Mycorrhizae in stressed environments: effects on plant growth, endophyte development, soil stability, and soil water.** In: Whitehead, Emily E.; Hutchinson, Charles F.; Timmerman, Barbara N.; Varady, Robert G., editors. Arid lands today and tomorrow, proceedings of an international research and development conference; 1985 October 20-25; Tucson, AZ. Boulder, CO: Westview Press; 1015-1025.

Borchert, Mark I.; Cunha, Nancy D.; Krosse, Patricia C.; Lawrence, Marcee L. 1993. **Blue oak plant communities of southern San Luis Obispo and northern Santa Barbara Counties, California.** Gen. Tech. Rep. PSW-GTR-139. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 49 p.

Callaway, R.M. 1990. **Effects of soil water distribution on the lateral root development of three species of California oaks.** American Journal of Botany 77(11): 1469-1475.

Chabot, B.F.; Hicks, D.J. 1982. **The ecology of leaf life spans.** Annual Review of Ecological Systems 13: 299-359.

Chapman, H.D. 1965. **Cation-exchange capacity.** In: Black, C.A., editor-in-chief. Methods of soil analysis, Part 2, chemical and microbiological properties. Madison, WI: American Society of Agronomy, Inc.; 891–901.

Dahlgren, Randy; Singer, Michael J. 1991. **Nutrient cycling in managed and unmanaged oak woodland-grass ecosystems.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 337-341.

Doll, E.C.; Lucas, R.E. 1973. **Testing soils for potassium, calcium, and magnesium.** In: Walsh, L.M.; Beaton J.D., eds. Soil testing and plant analysis. Revised edition. Madison, WI: Soil Science Society of America; 133-152.

Downie, Denise. 1996. **Soil characteristics of blue oak and coast live oak ecosystems.** San Luis Obispo, CA: California Polytechnic State University; 111 p. M.S. thesis.

Gee, G.W.; Bauder, J.W. 1986. **Particle-size analysis.** In: Klute, Arnold, ed. Methods of soil analysis, part 1, physical and mineralogical methods. Madison, WI: Soil Science Society of America; 383-411.

Gordon, Doria R.; Rice, Kevin J.; Welker, Jeffrey M. 1991. **Soil water effects on blue oak seedling establishment.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 54-58.

Graham, R.C.; Ervin, J.O.; Wood, H.B. 1995. **Aggregate stability under oak and pine after four decades of soil development.** Soil Science Society of America Journal 59: 1740-1744.

Griffin, J.R. 1971. **Oak regeneration in the upper Carmel Valley, California.** Ecology 52: 862-868.

Griffin, J.R. 1973. **Xylem sap tension in three California oaks.** Ecology 54: 152-159.

Holland, V.L. 1973. **A study of vegetation and soils under *Quercus douglasii* H & A compared to adjacent open grassland.** Berkeley: University of California; 369 p. Ph.D. dissertation.

Hollinger, D.Y. 1984. **Photosynthesis, water relations, and herbivory in co-occurring deciduous and evergreen California oaks.** Stanford, CA: Stanford University; 173 p. Ph.D. dissertation.

Hunter, J.C. 1993. ***Q. douglasii* (Fagaceae) in California's Central Valley.** Madroño 40(1): 62.

Klute, A. 1986. **Water potential: laboratory methods.** In: Klute, Arnold, ed. Methods of soil analysis, part 1, physical and mineralogical methods. Madison, WI: Soil Science Society of America; 635-662.

Lewis, D.C.; Burgy, R.H. 1964. **The relationship between oak tree roots and ground water in fractured rock as determined by tritium tracing.** Journal of Geophysical Research 69: 2579-2588.

Lindsey, Wesley C. 1983. **Soil survey of San Luis Obispo County, California, Paso Robles area.** Soil Conservation Service, U.S. Department of Agriculture; 236 p.

Lytle, Dennis J.; Finch, Sherman J. 1987. **Relating cordwood production to soil series.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 260-267.

Matsuda, K.; McBride, J.R. 1986. **Difference in seedling growth morphology as a factor in the distribution of three oaks in central California.** Madroño 33(3): 207-216.

McCreary, D.D. 1990. **Blue oaks withstand drought.** California Agriculture 44(2): 15-17.

Nakata, C.S. and Associates. 1987. **Camp Roberts master plan report.** Sacramento, CA: Sacramento District Corps of Engineers, Department of the Army, U.S. Department of Defense.

Parker, V.T.; Muller, C.H. 1982. **Vegetation and environmental changes beneath isolated live oak trees (*Quercus agrifolia*) in a California annual grassland.** American Midland Naturalist 107(1): 69-81.

Plumb, Tim R.; Hannah, Bennie. 1991. **Artificial regeneration of blue and coast live oaks in the central coast.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 74-80.

Poole, D.K.; Miller, P.C. 1975. **Water relations of selected species of chaparral and coastal sage communities.** Ecology 56: 1118-1128.

Rossi, Randall S. 1980. **History of cultural influences on the distribution and reproduction of oaks in California.** In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on the ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 7-18.

Soil Survey Division Staff. 1993. **Soil survey manual.** Agric. Handb. 18. Washington, DC: U.S. Department of Agriculture; 437 p.

Wells, P.V. 1962. **Vegetation in relation to geologic substratum and fire in the San Luis Obispo Quadrangle, California.** Ecological Monographs 32(1): 79-103.

Wood, Hulton B.; James, Samuel W. 1993. **Native and introduced earthworms from selected chaparral, woodland, and riparian zones in southern California.** Gen. Tech. Rep. PSW-GTR-142. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 20 p.

The Influence of Epiphytic Lichens on the Nutrient Cycling of a Blue Oak Woodland[1]

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Abstract: *We evaluated the importance of epiphytic lichens in the nutrient cycling of a blue oak (*Quercus douglasii*) woodland in California. Each oak tree contained an average of 3.8 kg lichen biomass, totaling 590 kg per ha. For comparison, oak leaf biomass was 958 kg per ha. We compared tree growth, volume and composition of throughfall (rainfall falling though the tree canopy), litterfall, and soil nutrients under 20 trees from which we removed the lichens to 20 control trees. The removal of lichens had no effect on the growth of the oak trees, but it did influence nutrient cycling fluxes significantly. We calculated an enhanced atmospheric deposition for nitrogen of 2.85 kg/ha/yr and for phosphorus of 0.15 kg/ha/yr. This is caused by the presence of epiphytic lichens in the canopy where they act as an intercepting surface, enhancing dry deposition into the tree canopy. Thus, epiphytes can significantly influence nutrient fluxes in blue oak woodlands. This also supports the hypothesis that the tree canopy influences atmospheric deposition and that this, in turn, contributes to the observed "canopy effect" on the understory productivity in oak savannas.*

A large part of the California landscape is made up of oak woodlands, and in the past 20 years considerable research has focused on understanding the functioning of these ecosystems. Most of these studies have focused on the dominant growth forms in these ecosystems, and consequently, there is abundant evidence that oak trees and the annual grass understory both influence energy, water, and nutrient balances (Callaway and others 1991, Gordon and Rice 1992, Holland 1973, Huenneke and Mooney 1989, Jackson and others 1990, McNaughton 1968, Mooney and others 1986). However, one understudied group is the epiphytic community, which can make up a substantial part of the aboveground biomass in oak woodlands (Boucher and Nash 1990, Callaway and Nadkarni 1991). Epiphytes are known to affect ecosystem processes in various forest ecosystems (Knops and others 1996, Lang and others 1980, Nadkarni 1986, Pike 1978). In this study, we examine whether epiphytes are a significant part of California oak woodlands.

Lichens are the dominant taxonomic group of epiphytes present in Californian oak woodlands, and *Ramalina menziesii* (lace lichen) is the most conspicuous lichen in the coastal foothill oak woodlands (Larson and others 1985, Rundel 1974) and is considered the unofficial State lichen of California (Hale and Cole 1988). *Ramalina menziesii* occurs along the coast from Baja California to southern Alaska. It is very sensitive to air pollution (Boonpragob and Nash 1991, Sigal and Nash 1983) and is especially abundant in areas with frequent fog (Larson and others 1985). This is partly because lichens do not tap into the vascular system of their host trees, but they depend entirely on rainfall, dew, fog, and atmospheric water vapor (Matthes-Sears and Nash 1986).

Study Area and Methods

This research was conducted at the Hastings Natural History Reservation, which is a field station of the University of California at Berkeley. Hastings is located in the Santa Lucia Mountains in the central coast of California (Carmel Valley, Monterey County) approximately 20 km east of the Pacific Ocean and 42 km

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southeast of Carmel. Hastings has a typical Mediterranean climate with winter rains and summer droughts. Annual rainfall averaged 524 mm over the past 55 years, with a mean monthly minimum temperature ranging from 1.4 °C in January to 9.7 °C in August and the mean maximum ranging from 15.6 °C in January to 30.4 °C in July. Coastal fog occasionally reaches the study site in the spring and early summer; however, the effect of the fog on the vegetation and specifically on the epiphytic lichens is minimal (Matthes-Sears and others 1986).

Our study site was a south-facing blue oak (*Quercus douglasii)* woodland (elevation 550 m), with a tree density of 157 trees per ha and a canopy cover of 58 percent. A 0.65-ha area was fenced with a deer-proof fence in December 1989. A factorial experiment was established with combinations of two factors: canopy with and without lichens, and soil with and without lichens as a component of the litterfall. This experimental design allowed us to examine independently the effect of epiphytic lichens in the canopy and the effects of lichen decomposition on the ground. We selected 40 trees within our study site and randomly divided them into four groups of 10 trees, with individual trees as the basic sampling units. The lichen removal trees were stripped of canopy and branch lichens in December 1989. The soil treatments were established by either removing or not removing the lichen litterfall on a monthly basis, the lichen litter from the treatment with canopy lichens (but no lichen litter) was moved to the treatment of no-canopy lichens but with lichen litter starting in February 1990.

Throughout 3 years we measured the effect of the treatments on litterfall, throughfall (rainfall falling through a tree canopy), soil nitrogen and phosphorus, and tree growth. In addition, atmospheric deposition was measured outside the canopy, and we measured oak leaf and lichen litter decomposition in a separate experiment. A complete description of all experimental methods is given by Knops (1994). In short, litterfall was measured, in 200 black plastic plant pots (top diameter 50 cm and 40 cm high) on a monthly basis in five collectors under each tree, beginning March 20, 1990. Throughfall was collected in a bottle with a funnel on the top, starting February 20, 1990. Soil nutrients were measured both as total nitrogen and phosphorus and available nitrogen and phosphorus. The latter were measured by using ion exchange resin bags, buried in the field from October 1992 through April 1993. Tree growth was measured by comparing the annual amount of leaffall and acorn litterfall under each tree and by measuring the tree ring width. Tree ring width was measured on two 5-cm-long cores taken on opposite sides of the tree, using an increment borer, processed and measured following standard dendroecological methods (Phipps 1985). Atmospheric deposition was measured in two Aerochem Metrics automated wetfall/dryfall collectors and in 10 throughfall collectors placed outside the canopy. Litter decomposition was measured in litterbags, for a 4-year period, starting in January 1990. We constructed 160 litterbags containing either oak leaves, or a mixture of equal amounts of oak leaves and lichen litter. Twenty litterbags of each type were collected each year. Chemical analyses of rainfall, throughfall, litter, and soil samples were performed with standard autoanalyzer techniques following a persulfate digestion for measurements of total nitrogen and phosphorus in liquid samples. Throughfall and rainfall were also analyzed for chloride, sulfate, nitrate, ammonium, calcium, magnesium, sodium, and potassium (cations on an atomic absorption spectrometer and anions on an ion chromatograph).

Results and Discussion

We removed all epiphytic lichens from 21 blue oak trees and these trees contained on average 3,794 ± 658 g dry lichen biomass per tree (average ± 1 S.E.). One tree was a hybrid (between *Quercus douglasii* and *Quercus lobata*) and was used only to calculate the lichen biomass. There were 101 trees in our 0.65-ha experimental area, so the standing crop of epiphytic lichens was 590 kg per ha. *Ramalina menziesii* was the dominant lichen species, contributing 78 percent of the biomass, followed by *Usnea* spp. (20 percent). All other lichen species contributed less than 2 percent.

Rainfall was 463 mm from July 1, 1990 through June 30, 1991, and 545 mm in the following year, giving an average of 504 mm (*table 1*). The average throughfall amount was 428 mm under the trees with epiphytic lichens and 469 mm under the trees from which we removed the epiphytic lichens. Thus, a tree canopy without lichens intercepts 7 percent of the rainfall; a tree canopy with lichens, 15 percent; and the lichens in the tree, 8 percent. Our canopy cover was 58 percent, which implies that the presence of epiphytic lichens lowers the total rainfall reaching the soil by 5 percent. We should keep in mind here that most of the rainfall occurs in the winter months and that this reduction in rainfall is not likely to influence the growth of the trees or the grass, because the oak trees are leafless and inactive and the grass productivity during the winter months is limited by the low temperatures. We found no differences in xylem water potential of the trees in the different treatments in late summer, the time when blue oak trees have the highest water stress (Griffin 1973, Knops 1994, Knops and Koenig 1994). However, the total runoff and groundwater recharge is likely to be lowered, resulting in a lowered water yield, but also lower rates of soil erosion.

Table 1—Total annual deposition of the throughfall, nitrogen (N) and phosphorus (P) [1]

Element	Year	Treatments			*F*-values	
		Bulk deposition	Canopy without lichens	Canopy with lichens	Canopy versus bulk deposition	Canopy with versus Canopy without lichens
		mm				
Throughfall	90-91	463 ± 3	422 ± 8	387 ± 10	17.59 ***	7.09 *
Throughfall	91-92	545 ± 4	515 ± 11	468 ± 14	7.76 **	6.89 *
		g/m²				
Total N	90-91	95 ± 12	261 ± 14	299 ± 18	47.67 ***	2.66
Total N	91-92	141 ± 7	283 ± 16	329 ± 17	44.40 ***	3.88
		g/m²				
Total P	90-91	13 ± 4	166 ± 13	145 ± 14	55.55 ***	1.28
Total P	91-92	43 ± 8	218 ± 17	195 ± 17	43.84 ***	0.86

[1]The means ± 1 S.E. are given for the canopy without lichens (n=20), canopy with lichens (n=20), and the bulk deposition (90–91 n = 16, 91–92 n = 10). Data were collected monthly and tabulated by year from May 16, 1990 through May 16, 1991, and from May 16, 1991 through July 16, 1992. The two canopy treatments and the canopy-versus-bulk deposition were compared with an ANOVA, and the F-values associated with the treatments are given (*P<0.05; **P<0.01; ***P<0.001). The two canopy treatments were combined to compare canopy versus open deposition (resulting in a sample size of 40 for the canopy).

Because blue oak woodlands frequently occur on low-fertility soils and understory productivity is often limited by nitrogen and / or phosphorus (Menke 1989), we focused most of the research on these two elements.

In the short term, phosphorus cycling is controlled by biological processes, and the phosphorus availability is primarily dependent on the rates of litter decomposition and mineralization of soil organic matter (Cross and Schlesinger 1995). Globally, the largest pool of phosphorus is in rocks and ocean sediments, and the long-term main source of phosphorus for terrestrial plants is rock weathering (Schlesinger 1991). We did not study rock weathering, because it is not likely that epiphytes have any measurable effect on this.

Global nitrogen pools are strongly dominated by the atmosphere, because air contains 78 percent nitrogen (N_2). However, this form of nitrogen is inert and not available for plants. Transformations from atmospheric N_2 to plant-available nitrogen are through biological fixation by micro-organisms (Schlesinger 1991), but these rates are generally low in California oak woodlands (Ellis and others 1983). Consequently, intrasystem recycling is the dominant source of plant-available nitrogen (Woodmansee and Duncan 1980). However, nitrogen is much more mobile than phosphorus, and ecosystems in general are much less closed, so that inputs and outputs of nitrogen compounds are important on time scales of decades in natural ecosystems. Atmospheric deposition is the main input pathway of nitrogen into ecosystems, and air pollution episodes show that we can influence the productivity of an ecosystem with the amount of nitrogen in atmospheric deposition (Vitousek 1994).

Atmospheric deposition (bulk deposition) of nitrogen was 1.18 kg/ha/yr and that of phosphorus was 0.28 kg/ha/yr (*table 1*). These values, especially for nitrogen, are very low, and there is no indication of air pollution at this site. The throughfall amounts of both nitrogen and phosphorus are much higher because a substantial amount of both elements can be leached from the oak leaves. In addition, there is also an accumulation of dry deposition (dust) into the tree canopy, which can be washed off by rainfall. Dry deposition is difficult to quantify because it is indistinguishable from the leached nitrogen and phosphorus, but dry deposition is potentially important as a nutrient input (Johnson and Lindberg 1991). Dry deposition rates are strongly influenced by the intercepting surface. Although we cannot determine the exact dry deposition of both elements in our study, we can get an indication of its importance by subtracting the amount of throughfall in a tree canopy without lichens from the amount of throughfall in a tree canopy with lichens. Because lichens have no vascular connection to the soil, the depletion or enrichment of nutrient elements in throughfall must be caused by dry deposition onto the lichen thallus surface. We calculated this for nitrogen and phosphorus and found that the throughfall was enriched by 42 mg $N/m^2/yr$ (i.e. 299+329-261-283) and depleted by 22 mg $P/m^2/yr$ (i.e. 145+195-166-218) (*table 1*).

Lichens also take up nutrients for their growth and incorporate these into their thallus. If we assume that the canopy lichen biomass is in a steady state (i.e., their loss of biomass in the litterfall is balanced by their growth), we can use the amount of lichen litterfall as an index of their growth. The lichen litterfall contained 445 mg $N/m^2/yr$ (i.e. (0.39+0.52)/2) and 48 mg $P/m^2/yr$ (i.e. (0.045+0.051)/*2)* (*table 2*). If these amounts are added to the throughfall amount, this suggests that 497 mg $N/m^2/yr$ and 26 mg $P/m^2/yr$ are deposited by dry deposition into the tree canopy as a result of the presence of epiphytic lichens as an intercepting surface in the canopy. For our study site, which has a tree cover of 58 percent, this is equivalent to 2.85 kg nitrogen (N) and 0.15 kg of phosphorus (P) per hectare per year. Thus, epiphytic lichens substantially enhance atmospheric deposition of nitrogen into these ecosystems. We do not know how much additional dry deposition occurred on oak leaves and branches; however, this would likely add substantially to these dry deposition estimates. If the deposition on leaves is proportional to their surface area and we assume that their surface area per amount of mass is half that of the lichens, then atmospheric deposition of nitrogen is approximately 5 kg/ha/yr. This is substantially higher than our bulk deposition estimates and implies that atmospheric deposition is an important component of the available nitrogen in this ecosystem; by comparison, we estimate the nitrogen mineralization in the soil at approximately 50 kg/ha/yr (Knops 1994).

Despite the large quantity of lichen biomass present, we found no major effects of our experimental removal of lichens on the growth of oak trees. Trees in the different treatments produced the same amount of leaves and/or acorns *(table 2)* and tree ring growth did not differ between the treatments *(table 3)*. There are several likely explanations for the lack of a significant effect of our experimental treatments on tree growth and nutrient dynamics. First, plants occupying infertile environments are often not very responsive to nutrient additions (Chapin and others 1986, Koide and others 1988). Second, it is possible that a different factor, such as water availability, limited tree growth. Water correlates strongly with the annual ring width increment in *Quercus douglasii* at Hastings (Knops and Koenig, unpublished data[5]) and throughout its range (Kertis and others 1993). Third, the intrasystem nutrient pools are large, compared to the change in nutrient fluxes induced by our experiment, so the enhanced deposition might be too small to be detected in soil fluxes and pools in 3 years. Surface soils under *Quercus douglasii* at Hastings average 6.7 mg N/g soil and 0.3 mg P/g soil (*table 4*, Knops 1994), with a bulk density of 1.0 g/cm^3 (Callaway and others 1991). For the upper 30 cm, this translates to 2,100 g/m^2 of nitrogen and 90 g/m^2 of phosphorus. We found an enhanced atmospheric deposition because of the epiphytic lichens of 497 mg N/m^2/yr and 26 mg P/m^2/yr. Thus, annual enhancement of either nutrient is minor compared to the total soil nutrient pools and the annual mineralization in these pools, which is approximately 1-3 percent annually (Jackson and others 1988, Knops 1994). The past contribution of lichens to the soil pool of nitrogen, a development process likely occurring over centuries, is unknown, and its estimate is beyond the scope of our data.

Table 2—Total annual litterfall biomass [1]

	Category	Treatments				*F*-values		
		Canopy without lichens, litter without lichens	Canopy without lichens, litter with lichens	Canopy with lichens, litter without	Canopy with lichens, litter	Canopy	Litter	Canopy by litter
		g/m^2						
Biomass	Total biomass	246 ± 20	302 ± 17	377 ± 36	377 ± 35	13.27**	0.95	1.00
	Oak leaves	139 ± 13	175 ± 9	179 ± 14	168 ± 13	1.71	1.06	3.51
	Acorns	18 ± 7	18 ± 5	22 ± 4	20 ± 4	0.23	0.01	0.07
	Miscellaneous	79 ± 8	96 ± 9	143 ± 24	138 ± 24	8.76**	0.11	0.37
	Lichens	9 ± 1	11 ± 1	33 ± 5	50 ± 12	23.96***	2.31	1.26
		g/m^2						
Nitrogen	Total biomass	2.05 ± 0.17	2.51 ± 0.16	3.01 ± 0.25	2.96 ± 0.21	12.64**	1.11	1.60
	Oak leaves	0.97 ± 0.08	1.22 ± 0.07	1.21 ± 0.10	1.18 ± 0.10	1.30	1.57	2.56
	Acorns	0.12 ± 0.04	0.13 ± 0.04	0.16 ± 0.03	0.14 ± 0.03	0.41	0.00	0.22
	Miscellaneous	0.84 ± 0.08	1.01 ± 0.09	1.25 ± 0.14	1.13 ± 0.09	6.37*	0.05	1.93
	Lichens	0.11 ± 0.02	0.14 ± 0.02	0.39 ± 0.06	0.52 ± 0.10	30.74***	1.68	0.59
		g/m^2						
Phosphorus	Total biomass	0.462 ± 0.040	0.583 ± 0.039	0.633 ± 0.049	0.594 ± 0.048	4.23*	0.85	3.26
	Oak leaves	0.326 ± 0.034	0.414 ± 0.026	0.427 ± 0.033	0.403 ± 0.035	1.98	0.97	3.03
	Acorns	0.015 ± 0.006	0.018 ± 0.005	0.020 ± 0.004	0.019 ± 0.004	0.50	0.02	0.15
	Miscellaneous	0.108 ± 0.010	0.134 ± 0.016	0.140 ± 0.013	0.121 ± 0.011	0.53	0.08	3.16
	Lichens	0.013 ± 0.002	0.017 ± 0.002	0.045 ± 0.007	0.051 ± 0.010	28.28***	0.63	0.01

[1] All data are 3-year means ± 1 s.e., n = 10 trees in all cases. F values are from a two-way ANOVA with 36, 1, 1, 1 degrees of freedom (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

[5]Unpublished data on file at the Hastings Natural History Reservation, 38601 E. Carmel Valley Road, Carmel Valley, CA 93924

Table 3—Annual relative tree ring width [1]

Year	Treatments				*F*-values		
	Canopy without lichens, litter without lichens	Canopy without lichens, litter with lichens	Canopy with lichens, litter without lichens	Canopy with lichens, litter with lichens	Canopy	Litter	Canopy by litter
	N						
	10	9	7	8			
1990	0.71 ± 0.04	0.71 ± 0.04	0.89 ± 0.16	0.63 ± 0.10	0.33	2.17	2.14
1991	1.49 ± 0.18	1.41 ± 0.12	1.34 ± 0.08	1.23 ± 0.14	1.28	0.44	0.01
1992	1.48 ± 0.20	1.39 ± 0.10	1.27 ± 0.07	1.40 ± 0.27	0.29	0.01	0.33
1993	1.91 ± 0.14	1.95 ± 0.21	1.73 ± 0.19	1.97 ± 0.31	0.14	0.41	0.21
Total	5.59 ± 0.48	5.47 ± 0.37	5.24 ± 0.31	5.23 ± 0.74	0.33	0.02	0.01

[1] All data are expressed as annual growth divided by the average growth from 1984 through 1989 and are means ± 1 s.e. *F*-values are from a two-way ANOVA with 30, 1, 1, 1 degrees of freedom (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

Table 4—Soil total nitrogen (N) and phosphorus (P) and absorption of ions on ion exchange resin bags [1]

Soil Element	Treatments				*F*-values		
	Canopy without lichens, litter without lichens	Canopy without lichens, litter with lichens	Canopy with lichens, litter without lichens	Canopy with lichens, litter with lichens	Canopy	Litter	Canopy by litter
	mg/g dry soil						
Total N	1039 ± 73	1292 ± 68	1185 ± 48	1120 ± 34	0.05	2.64	7.59**
Total P	462 ± 29	473 ± 54	414 ± 22	437 ± 34	1.29	0.21	0.02
----- Resin --	*mg/L* effluent						
Ammonium	4.23 ± 0.43	3.58 ± 0.40	4.20 ± 0.58	3.74 ± 0.31	0.02	1.55	0.05
Nitrate	18.5 ± 3.0	21.6 ± 7.0	19.7 ± 3.7	22.6 ± 4.8	0.05	0.39	0.00
Nitrogen	22.7 ± 3.4	25.2 ± 7.3	23.9 ± 4.2	26.4 ± 5.1	0.05	0.23	0.00
Phosphate	44.0 ± 3.8	35.1 ± 3.9	46.2 ± 4.5	37.8 ± 2.9	0.43	5.14 *	0.00

[1]All data are means ± 1 s.e., n=10 in all cases. Samples were collected on April 17, 1992. *F*-values are from a two-way ANOVA with 36, 1, 1, 1 degrees of freedom (* $P < 0.05$, ** $P < 0.01$, *** $P < 0.001$).

Summary and Conclusions

Nutrient availability is higher under the blue oak canopy relative to the surrounding grasslands and it increases understory productivity and species composition (Callaway and others 1991, Frost and McDougald 1989, Holland 1980, McClaran and Bartolome 1989). This canopy effect has also been observed under different oak species in California (Parker and Muller 1982) and in other savannas throughout the world (Belsky 1992, 1994 ; Belsky and others 1989; Kellman 1979; Ko and Reich 1993; Vetaas 1992). The higher local fertility under oaks has been attributed to the presence of a reservoir of organic matter under the tree canopy resulting in higher rates of mineralization and consequently higher availability of nutrients (Jackson and others 1990). However, this does not explain the long-term origin of this organic matter and, thus, the ultimate cause of this canopy effect. The accumulation of the organic matter can be caused by at least three processes. First, trees are thought to concentrate nutrients by taking up from deeper soil layers or intercanopy areas, thereby inducing greater spatial heterogeneity by influencing nutrient cycling within the ecosystem (Vetaas 1992). Second, large herbivores, like cattle and deer, often aggregate for extended periods under tree canopies, concentrating their dung under the canopy area. Third, the canopy may enhance atmospheric deposition (Kellman 1979, Kellman and Carty 1986) and thereby produce a spatial heterogeneity of nutrient input. Our study provides further evidence that tree canopies enhance atmospheric deposition and that epiphytes can influence these nutrient fluxes.

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References

Belsky, A. Joy 1992. **Effects of trees on nutritional quality of understory gramineous forage in tropical savannas**. Tropical Grasslands 26: 12-20.

Belsky, A. Joy 1994. **Influences of trees on savanna productivity: tests of shade, nutrients, and tree-grass competition**. Ecology 75: 922-932.

Belsky, A.J.; Amundson, R.G.; Duxbury, J.M.; Riha, S.J.; Ali, A.R.; Mwonga, S.M. 1989. **The effects of trees on their physical, chemical, and biological environments in a semi-arid savanna in Kenya**. Journal of Applied Ecology 26: 1005-1024.

Boonpragob, Kansi; Nash, Thomas H., III. 1991. **Physiological responses of the lichen *Ramalina menziesii* Tayl. to the Los Angeles urban environment**. Environmental and Experimental Botany 31: 229-238.

Boucher, V.L.; Nash, T.H., III. 1990. **The role of the fructicose lichen *Ramalina menziesii* in the annual turnover of biomass and macronutrients in a blue oak woodland**. Botanical Gazette 151: 114-118.

Callaway, Ragan M.; Nadkarni, Nalini M. 1991. **Seasonal patterns of nutrient deposition in a *Quercus douglasii* woodland in central California**. Plant and Soil 137: 209-222.

Callaway, Ragan M.; Nadkarni, Nalini M.; Mahall, Bruce E. 1991. **Facilitation and interfering of *Quercus douglasii* on understory productivity in central California**. Ecology 72: 1484-1499.

Chapin, F. Stuart, III; Vitousek, Peter M.; Van Cleve, Keith. 1986. **The nature of nutrient limitation in plant communities**. American Naturalist 127: 48-58.

Cross, Anne Fernald; Schlesinger, William H. 1995. **A literature review and evaluation of the Hedley fractionation: applications to the biogeochemical cycle of soil phosphorus in natural ecosystems**. Geoderma 64: 197-214.

Ellis, Barbara A.; Verfaillie, Joseph R.; Kummerow, Jochen. 1983. **Nutrient gain from wet and dry atmospheric deposition and rainfall acidity in southern Californian chaparral**. Oecologia 60: 118-121.

Frost, William E.; McDougald, Neil K. 1989. **Tree canopy effects on herbaceous production of annual rangeland during drought**. Journal of Range Management 42: 281-283.

Gordon, D.R.; Rice, K.J. 1992. **Partitioning of space and water between two California annual grassland species**. American Journal of Botany 79: 967-976.

Griffin, James R. 1973. **Xylem sap tension in three woodland oaks in Central California**. Ecology 54: 152-159.

Hale, Mason E, Jr.; Cole, Mariette. 1988. **Lichens of California**. Berkeley: University of California Press; 254 p.

Holland, V.L. 1973. **A study of vegetation and soils under blue oak compared to adjacent open grassland**. Berkeley: University of California. Ph.D. dissertation; 369 p.

Holland, V.L. 1980. **Effect of blue oak on rangeland forage production in Central California**. In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on ecology, management and utilization of Californian oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 314-318.

Huenneke L.F.; Mooney, H.A. 1989. **Grassland structure and function: California annual grasslands**. Dordrecht: Kluwer Academic Press; 220 p.

Jackson, L.E.; Strauss, R.B.; Firestone, M.K.; Bartolome, J. 1988. **Plant and soil nitrogen dynamics in Californian annual grassland**. Plant and Soil 110: 9-17.

Jackson, L.E.; Strauss, R.B.; Firestone, M.K.; Bartolome, J. 1990. **Influence of tree canopies on grassland productivity and nitrogen dynamics in deciduous oak savanna**. Agriculture, Ecosystems and Environment 32: 89-105.

Johnson, D.W.; Lindberg, S.E. 1991. **Atmospheric deposition and nutrient cycling in forest ecosystems**. New York: Springer Verlag; 707 p.

Kellman, Martin. 1979. **Soil enrichment by neotropical savanna trees**. Journal of Ecology 67: 565-577.

Kellman, M.; Carty, A. 1986. **Magnitude of nutrient influxes from atmospheric sources to a central American *Pinus caribaea* woodland**. Journal of Applied Ecology 23: 211-226.

Kertis, Jane A.; Gross, Rob; Peterson, David L.; Arbaugh, Michael J.; Standiford, Richard B.; McCreary, Douglas D. 1993. **Growth trends of blue oak (*Quercus douglasii*) in California**. Canadian Journal of Forest Research 23: 1720-1724.

Knops, Johannes M.H. 1994. **The influence of epiphytic lichens on the nutrient cycling of an oak woodland**. Tempe: Arizona State University; 146 p. Ph.D. dissertation.

Knops, Johannes M.H.; Koenig, Walter D. 1994. **Water use strategies of five sympatric *Quercus* species in central coastal California**. Madroño 41: 290-301.

Knops, Johannes M.H.; Nash, Thomas H., III; Schlesinger, William H. 1996. **The influence of epiphytic lichens on the nutrient cycling of an oak woodland**. Ecological Monographs 66: 159-180.

Ko, Leonora J.; Reich, Peter B. 1993. **Oak tree effects on soil and herbaceous vegetation in savannas and pastures in Wisconsin**. American Midland Naturalist 130: 31-42.

Koide, R.T.; Huenneke, L.F.; Hamburg, S.P.; Mooney, H.A. 1988. **Effects of applications of fungicide, phosphorus and nitrogen on the structure and productivity of an annual serpentine plant community**. Functional Ecology 2: 335-344.

Lang, Gerald E.; Reiners, William A.; Pike, Lawrence H. 1980. **Structure and biomass dynamics of epiphytic lichen communities of balsam fir forests in New Hampshire**. Ecology 61: 541-550.

Larson, D.W.; Matthes-Sears, U.; Nash, T.H., III. 1985. **The ecology of *Ramalina menziesii*. I. Geographical variation in form**. Canadian Journal of Botany 63: 2062-2068.

Matthes-Sears, U.; Nash, T.H., III. 1986. **The ecology of *Ramalina menziesii*. V. Estimation of gross carbon gain and thallus hydration source from diurnal measurements and climatic data**. Canadian Journal of Botany 64: 1698-1702.

Matthes-Sears, U.; Nash, T.H., III; Larson, D.W. 1986. **The ecology of *Ramalina menziesii*. III. *In situ* diurnal field measurements at two sites on a coast-inland gradient**. Canadian Journal of Botany 64: 988-996.

McClaran, Michael P.; Bartolome, James W. 1989. **Effect of *Quercus douglasii* (Fagaceae) on herbaceous understory along a rainfall gradient**. Madroño 36: 141-153.

McNaughton, S.J. 1968. **Structure and function in California annual grassland**. Ecology 49: 962-972.

Menke, J.W. 1989. **Management controls on productivity**. In: Huenneke, L.F.; Mooney, H., eds. **Grassland structure and function**. Dordrecht: Kluwer Academic Publishers; 173- 200.

Mooney, H.A.; Hobbs, R.J.; Gorham, J.; Williams, K. 1986. **Biomass accumulation and resource utilization in co-occurring grassland annuals**. Oecologia 70: 555-558.

Nadkarni, Nalini M. 1986. **The nutritional effects of epiphytes on host trees with special reference to alteration of precipitation chemistry**. Selbyana 9: 44-51.

Parker, V.T.; Muller, C.H. 1982. **Vegetational and environmental changes beneath isolated live oak trees (*Quercus agrifolia*) in a California annual grassland**. American Midland Naturalist 107: 69-81.

Phipps, Richard L. 1985. **Collecting, preparing, crossdating, and measuring tree increment cores.** Reston, VA: U.S. Geological Survey, Water-Resources Investigations Report 85-4148.

Pike, Lawrence H. 1978. **The importance of epiphytic lichens in mineral cycling**. Bryologist 81: 247-257.

Rundel, Philip W. 1974. **Water relations and morphological variation in *Ramalina menziesii***. Bryologist 77: 23-32.

Schlesinger, William H. 1991. **Biogeochemistry. An analysis of global change**. San Diego: Academic Press; 443 p.

Sigal, Lorene L.; Nash, Thomas H., III. 1983. **Lichen communities on conifers in southern California mountains: an ecological survey relative to oxidant air pollution**. Ecology 64: 1343-1354.

Vetaas, Ole R. 1992. **Micro-site effects of trees and shrubs in dry savannas**. Journal of Vegetation Science 3: 337-344.

Vitousek, Peter M. 1994. **Beyond global warming: ecology and global change**. Ecology 75: 1861-1876.

Woodmansee, R.G.; Duncan, D.A. 1980. **Nitrogen and phosphorus dynamics and budgets in annual grasslands**. Ecology 61: 893-904.

Woody Root Biomass of 40- to 90-Year-Old Blue Oaks (*Quercus douglasii*) in Western Sierra Nevada Foothills[1]

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Abstract: *This research examined biomass of blue oak (*Quercus douglasii *Hook. and Arn.) roots at the University of California Sierra Foothill Field and Range Research and Extension Center. Six blue oak root systems were excavated by trenching around the tree and removing the "root ball" with a backhoe. Before tree removal, soil from two 1-m*^{3} *trenches was sieved and roots were collected to estimate root biomass outside the root ball. Root ball mass ranged from 7 to 184 kg, and estimated total root biomass ranged from 12 to 193 kg. Root ball mass correlated with age, diameter at breast height, and bole mass. However, because of the small sample size, these relationships cannot yet be used for predicting belowground biomass.*

Although little information regarding coarse root biomass of tree species exists, these large structural roots have great value and importance for ecosystem processes. Coarse roots (generally, all roots >2 mm) not only offer physical support for the tree, but also influence the distribution of fine (<2 mm) roots, the roots responsible for water and nutrient uptake. Coarse roots also serve as a carbon and nutrient sink, and as such they represent an important component of biogeochemical studies of forest and woodland ecosystems (Nadelhoffer and Raich 1992, Vogt and others 1986).

Historically, most coarse root studies focused on morphology (Henderson and others 1983, Lyford 1980, Stout 1956) or biomass, in relation to stand productivity (Baskerville 1965, Santantonio and others 1977, Westman and Rogers 1977). Morphological studies require careful dissection to expose root systems and often include detailed mapping procedures. Biomass studies, on the other hand, have generally been less precise, and methods included hydraulic excavation (White and others 1971), excavation with large machinery (Honer 1971, Johnstone 1971, Westman and Rogers 1977), and measurement of naturally uprooted trees (Santantonio and others 1977). In some instances, annual coarse root production has been measured as well as total biomass (Deans 1981, Kira and Ogawa 1968). A typical goal of biomass studies has been to obtain allometric relationships between root mass and more easily measured parameters, such as diameter at breast height (DBH) and tree height. With these relationships, the amount of biomass allocated belowground can be determined for an entire stand.

For this study, six blue oak (*Quercus douglasii* H. and A.) trees were excavated in the Sierra Nevada foothills, northeast of Sacramento. Goals of the study included determining biomass distribution radially and with depth, as well as determining allometric relationships that would facilitate whole-stand belowground biomass estimation. This paper reports on allometric relationships between root mass and aboveground parameters (diameter, height, bole mass); biomass distribution data will be reported elsewhere.

Methods

In spring 1995, six blue oaks were sampled from three different areas of the University of California Sierra Foothill Field and Range Research and Extension

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996; San Luis Obispo, Calif.

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Center (northeast of Sacramento and near Browns Valley, California). This station has a mean annual precipitation of 73 cm and mean annual temperature of 15 °C. Soils are classified as fine, mixed, thermic Typic Haploxeralfs and are derived from basic metavolcanic rock (Dahlgren and Singer 1991). Vegetation is oak woodland with annual grasses. Dominant trees include blue oak and foothill pine (*Pinus sabiniana*). Shrub species include poison oak (*Toxicodendron diversiloba*) and manzanita (*Arctostaphylos manzanita*). *Bromus* spp., *Avena fatua*, *Elymus glaucus*, and *Hordeum* spp. are common grasses at the site.

Trees were selected on the basis of backhoe accessibility and absence of neighboring trees within 5 m. In addition, trees of various sizes were selected in order to obtain regression equations relating tree size (diameter, height, bole mass) to root mass. Aboveground measurements included DBH, basal diameter (at ground level), height, and bole (aboveground portion of tree) mass. Ages were determined using cross sections from the base of the bole.

Two 1-m^3 trenches were excavated for each tree to estimate the biomass of roots not recovered during the root ball excavation. Trenches were located 1.5 m from the tree and were approximately 2 m long, 0.5 m wide, and 1 m deep (*fig. 1*).

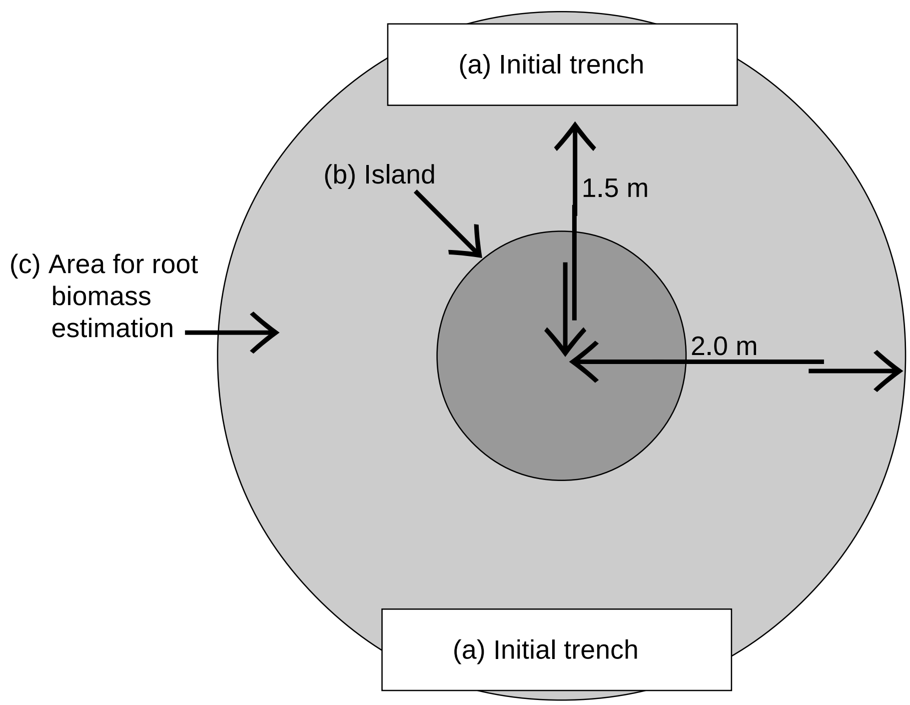

Figure 1—Schematic diagram of (a) trenches used for total root biomass estimation, (b) "island" of soil and roots remaining after connecting and widening trenches, and (c) 2-m-radius circle within which root biomass was estimated.

Soil from these trenches was sieved through a 5-cm (2-inch) mesh, and roots were collected. Roots were hand washed and weighed. Subsamples were oven dried at 60 °C for 5 days, and dry weight was determined. Root biomass per unit volume in trenches was used to estimate root biomass contained in the area between the root ball and a circle with 2-m radius (*fig. 1*).

After the trench excavations, "root balls" (root crowns and the lateral roots attached to them) were removed with a backhoe. The two trenches described above were connected to create a trench encircling the tree. This 1-m-deep trench was then widened inward (i.e., toward the tree), leaving an "island" of soil approximately 1.5 m in diameter. Soil around the root ball was loosened by inserting the backhoe at the base of the "island" and lifting up on it. The root ball was then removed by attaching a chain to the stump and pulling the stump and root ball out of the soil with the backhoe. These roots were washed with a fire hose, and oven dry weight was determined on subsamples.

Results

Aboveground parameters, root ball mass, and total root biomass estimates are shown in *table 1*. Tree age ranged from 40 to 90 years. Basal diameter ranged from about 12 cm for the youngest tree to almost 40 cm for the oldest trees. Tree height and bole mass generally increased with increasing basal diameter. However, the relationship between age and basal diameter was less strong.

Table 1—Size, age, and biomass data for six excavated blue oak (**Q. douglasii*****) trees***

Tree no.	Diameter at breast height	Basal diameter	Height	Age	Bole mass	Root ball mass[1]	Total root biomass[2]
	cm	*cm*	*m*	*yr*	*kg*	*kg*	*kg*
1	7.6	11.9	4.0	42	30.6	11.5	16
2	8.1	13.0	4.0	48	28.5	7.5	12
3	10.7	—	17.2	40	49.8	17.2	23
4	13.7	19.1	5.0	42	95.3	10.3	15
5	29.0	39.6	—	72	651.9	125.2	131
6	33.3	39.1	9.8	90	709.4	184.4	193

[1]Root ball mass refers to dry mass of crown and lateral roots removed by the backhoe.

[2]Total root mass includes root ball dry mass and an estimate of remaining roots, determined from 1-m^3 trenches.

To determine allometric relations, the logarithm of total root mass was regressed against the logarithms of the following aboveground parameters: DBH, basal diameter, bole mass, and height (*table 2*). Logarithmic transformations were used because variance in root biomass tends to increase as independent variables increase (Santantonio and others 1977). Multiple regression with DBH and height as independent variables yielded the following equation:

$$\log y = -0.810 - 1.26 \log x_1 + 5.00 \log x_2 \qquad (R^2 = 0.96)$$

where y is root mass, x_1 is DBH, and x_2 is height.

Table 2—Allometric equations derived from six excavated blue oak (**Q. douglasii*****) trees***[1, 2]

Equation no.	x	b (y intercept)	m (slope)	R^2
1	DBH	–0.559	1.81	89.4
2	BD	–1.34	2.19	90.0
3	Stem	–0.079	0.79	90.8
4	Height	–0.749	3.01	93.9
5	$(DBH)^2$*Height	–0.584	0.689	87.3

[1]Equations 1–5 follow the model y = mx + b, where y is the logarithm of root biomass (kg) and x is the logarithm of the tree parameter listed.

[2]Abbreviations are as follows: DBH, diameter at breast height (cm); BD, basal diameter (cm); Bole, aboveground mass (kg); Height, tree height (m).

As *figure 2* indicates, the relationship between aboveground parameters and root mass may not be as strong as R^2 values suggest. When the two largest trees are not included in regressions of root mass against DBH, height, and stem mass, R^2 values are less than 0.01. For the smaller trees, stem mass correlated less to root mass than did DBH or height.

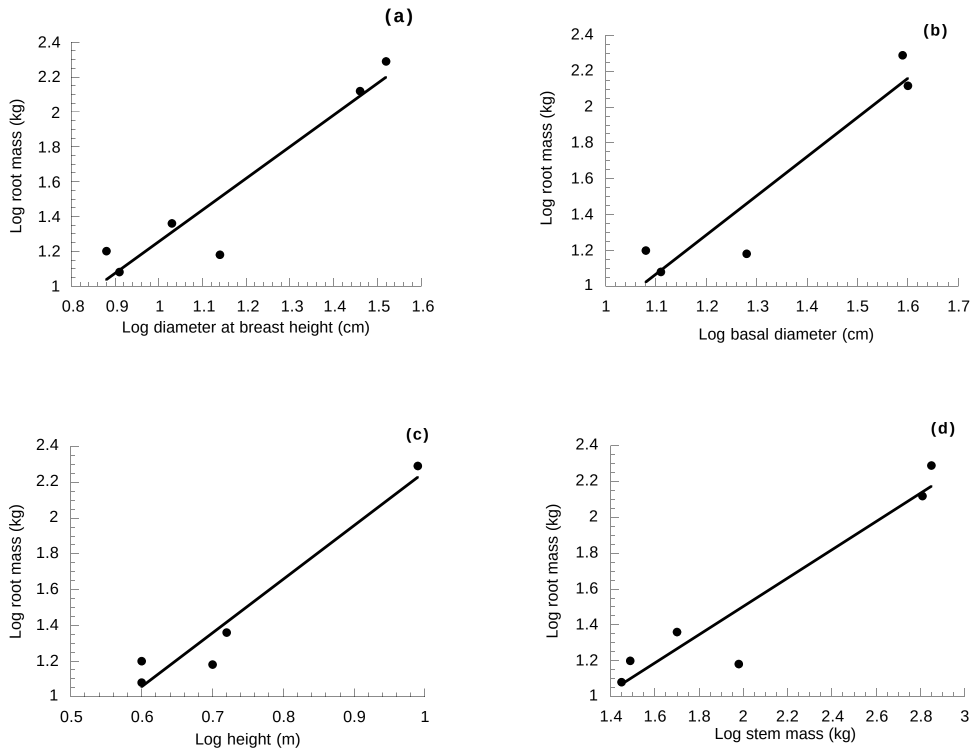

Figure 2—Relationship between the logarithm of root biomass (kg per tree) and the logarithm of the following aboveground dimensions: (a) diameter at breast height in cm, (b) basal diameter in cm, (c) tree height in cm, and (d) aboveground (stem) biomass, in kg per tree.

Discussion

Santantonio and others (1977) extensively reviewed information available on total root biomass and demonstrated a linear relationship between log DBH and log root biomass using 19 different tree species (both hardwood and softwood). Despite the small sample sizes often involved in root system studies, the allometric relationships between aboveground parameters, such as DBH, height, or bole mass, and root biomass seem fairly consistent. However, allometric relationships for individual stands must be determined to estimate carbon or nutrient flow for those stands or watersheds.

Allometric equations from this study and studies of other species are compared in *table 3*. Because excavation methods differ and some sample sizes are small, valid statistical comparisons between these regression equations cannot be made. However, some general observations can be made. The regression equations for *Q. ilex*, an oak species found in montane forests of Spain, are similar to those for *Q. douglasii*. Both species grow in a Mediterranean climate, where summer drought would make extensive root systems advantageous. *Eucalyptus signata* also grows in a seasonally dry climate, and its regression of root mass against DBH is very similar to that of *Q. douglasii*. The regression equation for *Q. robur,* excavated from a Swedish woodland, differs slightly from that of *Q. douglasii*. However, the equation for *Q. robur* is more similar to that of *Q. douglasii* than that of *Pinus contorta*.

*Table 3—Allometric equations for blue oak (***Q. douglasii***) and 5 other tree species reported in the literature*[1]

Species	b (y intercept)	m (slope)	R^2	*n* (no. of samples)	Reference
	(a) Regressed against log DBH (cm)				
Quercus douglasii (California)	-0.559	1.81	89.4	6	this study
Quercus ilex (Spain)	-1.047	2.191	73	32	Canadell & Roda (1991)
Eucalyptus signata (Australia)	-0.599 [2]	1.903	71.5	11	Westman & Rogers (1977)
Fagus grandifolia (NewHampshire)	-1.400	2.316	0.98	14	Westman and others (1974)
Mixed conifer (Oregon)	-2.407 [1]	2.461	89.8	40	Honer (1971)
	(b) Regressed against log Stem Mass (kg)				
Quercus douglasii (California)	-0.079	0.790	90.8	6	this study
Quercus ilex (Spain)	-0.212	0.894	83	11	Canadell & Roda (1991)
	(c) Regressed against log DBH^2*H (cm^2m)				
Quercus douglasii (California)	-0.584	0.689	87.3	6	this study
Quercus robur (Sweden)	0.1145	0.4619	—	3	Andersson (1970)
Pinus contorta (Canada)	-1.702 [1]	0.806	90.0	221	Johnstone (1971)

[1]The model is log y = b + m log x , where y is total root biomass and x is (a) diameter at breast height (DBH), (b) aboveground biomass (bole mass), and (c) $(DBH)^2$ times height (H).

[2]Original value was obtained using different units. The value shown is the intercept obtained when DBH is in cm, mass is in kg, and height is in m.

The method used to determine total root biomass in this study probably underestimated root biomass. Trenches for estimating root biomass not included in the root ball were located 1.5 to 2.0 m from the tree (*fig. 1*). These trenches were used to estimate biomass between the root ball and a circle 2.0 m in diameter. This method could underestimate biomass in two ways. First, root biomass may be greater at 1 m from the bole, for example, than at 1.5 m from the bole. Second, roots appeared to extend farther than 2 m from the bole. Estimated amounts of root biomass outside the root ball were small compared to root ball mass. Thus, for purposes of stand-level estimation of belowground biomass, these estimations are probably adequate.

Allometric equations like those presented here can be used for estimating belowground biomass at a stand level. Root biomass can be determined from height and diameter, which can be measured nondestructively on a large number of trees. Stem mass regressions are generally less practical. However, if biomass of trees were determined following a harvest, the stem mass regressions could be used for determining belowground biomass. Although our equations had high r^2 values and were similar to others reported in literature, more trees should be excavated before applying the equations. Trees with DBH between 14 and 29 cm and greater than 34 cm should be included to make the regression more accurate and useful for large-scale estimations.

The nature of blue oak development and reproduction must also be considered before applying these allometric equations. Blue oaks can resprout if the aboveground portion is damaged (by fire, for example). Resprouted trees may have a large root system despite their small size. The trees used in this study did not appear to have developed from sprouts. Consequently, the equations reported may not be useful for a stand where many trees have resprouted. Also, these trees were single-stemmed and open-grown. Following disturbance or when grown at higher densities, blue oak root systems may develop differently from those that we measured.

Summary

This study provides valuable data on coarse woody root biomass. Numerous regression equations were tested for their ability to predict coarse root biomass from aboveground tree measurements. Multiple regression with height and DBH as independent variables resulted in the highest correlation coefficients. These two variables can be measured relatively easily, so the regression equation could be very useful for predicting coarse root biomass on a larger scale. However, before the equations reported here can be used with confidence, more trees (especially with DBH between 14 and 29 cm) should be analyzed.

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References

Andersson, Folke. 1970. **Ecological studies in a Scanian woodland and meadow area, southern Sweden: II. Plant biomass, primary production and turnover of organic matter**. Botaniska Notiser 123: 8-51.

Baskerville, G.L. 1965. **Estimation of dry weight of tree components and total standing crop in conifer stands**. Ecology 46(6): 867-869.

Canadell, Josep; Roda, Ferran. 1991. **Root biomass of *Quercus ilex* in a montane Mediterranean forest**. Canadian Journal of Forest Research 21: 1771-1778.

Dahlgren, Randy; Singer, Michael J. 1991. **Nutrient cycling in managed and unmanaged oak woodland-grass ecosystems**. In: Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 337-341.

Deans, J.D. 1981. **Dynamics of coarse root production in a young plantation of *Picea sitchensis***. Forestry 54: 139-155.

Henderson, R.; Ford, E.D.; Renshaw, E.; Deans, J.D. 1983. **Morphology of the structural root system on Sitka spruce 1. Analysis and quantitative description**. Forestry 56(2): 121-135.

Honer, T.G. 1971. **Weight relationships in open- and forest-grown balsam fir trees**. In: Young, Harold E., ed. Forest biomass studies. Orono, ME: University of Maine; 65-77.

Johnstone, W.D. 1971. **Total standing crop and tree component distributions in three stands of 100-year-old lodgepole pine**. In: Young, Harold E., ed. Forest biomass studies. Orono, ME: University of Maine; 81-89.

Kira, T.; Ogawa, H. 1968. **Indirect estimation of root biomass increment in trees.** In: Methods of productivity studies in root systems and rhizosphere organisms. U.S.S.R. Academy of Sciences. Leningrad: Publishing House NAUKA; 96-101.

Lyford, Walter H. 1980. **Development of the root system of northern red oak (*Quercus rubra* L.).** Harvard Forest Paper 21. Petersham, MA: Harvard University, Harvard Forest; 31 p.

Nadelhoffer, K.J.; Raich, J.W. 1992. **Fine root production estimates and belowground carbon allocation in forest ecosystems**. Ecology 73(4): 1139-1147.

Santantonio, D.; Hermann, R.K.; Overton, W.S. 1977. **Root biomass studies in forest ecosystems**. Pedobiologia 17(1): 1-31.

Stout, Benjamin B. 1956. **Studies of the root systems of deciduous trees**. Black Rock Forest Bulletin 15. Cornwall-on-the-Hudson, NY: Harvard Black Rock Forest; 45 p.

Vogt, K.A.; Grier, C.C.; Vogt, D.J. 1986. **Production, turnover, and nutrient dynamics of above- and belowground detritus of world forests**. Advances in Ecological Research 15: 303-377.

Westman, W.E.; Rogers, R.W. 1977. **Biomass and structure of a subtropical Eucalypt forest, North Stradbroke Island**. Australian Journal of Botany 25: 171-191.

White, Edwin H.; Pritchett, William L.; Robertson, William K. 1971. **Slash pine root biomass and nutrient concentrations**. In: Young, Harold E., ed. Forest biomass studies. Orono, ME: University of Maine; 165-176.

Whittaker, R.H.; Bormann, F.H.; Likens, G.E.; Siccama, T.G. 1974. **The Hubbard Brook Ecosystem Study: forest biomass and production**. Ecological Monographs 44: 233-252

Rooting Responses of Three Oak Species to Low Oxygen Stress[1]

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***Abstract**: Rooting characteristics were compared in blue (*Q. douglasii*), valley (*Q. lobata*), and cork oak (*Q. suber*) seedlings under hypoxic (low oxygen) conditions. A 50 percent reduction in root growth occurred in all species at an oxygen level of 4 percent, or an oxygen diffusion rate of 0.3 µg $cm^{-2}min^{-1}$. Blue oak formed few lateral roots regardless of oxygen level, but valley and cork oak root production decreased under hypoxic conditions. Four percent soil oxygen might be viewed as a minimum requirement for sustaining root growth of oaks in the field, and differences in root branching morphology may be correlated with tolerance of root hypoxia.*

Blue oak (*Quercus douglasii* Hook. and Arn.), valley oak (*Q. lobata* Née), and cork oak (*Q. suber* L.) vary in tolerance to flooding, with blue oak considered the least tolerant and valley oak the most tolerant (Harris and others 1980, Whitlow and Harris 1979). Cork oak is considered moderately tolerant to flooding in its native, Mediterranean habitat (Cooke and others 1961). Blue and valley oaks are indigenous to California and are deciduous species in the subgenus *Leucobalanus* ("white oaks"). Blue oak occurs at elevations between 300 and 1,250 m, primarily on xeric slopes of the Sierra Nevada-Cascade foothills and coastal mountain ranges. Valley oak occurs at elevations between sea level and 1,200 m and is especially prevalent in deep, alluvial soils (Griffin and Critchfield 1976, Miller and Lamb 1985). Cork oak is an evergreen species in the subgenus *Erythrobalanus* ("black oaks"). It grows on coastal hills and mountains in the Mediterranean region, akin to the distribution of California live oak (*Q. agrifolia* Née) in California. It is also found in interior regions of Spain and Portugal at elevations from 500 to 1,300 m (Velaz de Medrano and Ugarté 1922). Cork oak was introduced into California in the mid-1800's for cork production and ornamental purposes (Metcalf 1947), and the species has become a common landscape tree there.

Oaks are exposed increasingly to soil compaction, back-filling, turf irrigation, and other stresses associated with urban development in California. These practices can reduce soil aeration and oxygen diffusion to roots (MacDonald 1993). Low soil oxygen, or hypoxia, inhibits root growth and diminishes tree vigor (Kozlowski 1985). Moreover, hypoxia stress may predispose a plant to disease and insect pests, particularly root rots (Heritage and Duniway 1985, Miller and Burke 1977). Phytophthora root rot of cork oak and coast live oak occurs in mature trees grown under conditions of low soil aeration (Mircetich and others 1977). Jacobs and others (these proceedings) showed that oxygen levels below 3-4 percent, or an oxygen diffusion rate (ODR) of 0.3 µg $cm^{-2}min^{-1}$, significantly increased the incidence of *Phytophthora cinnamomi* root disease in cork oak seedlings. Costello and others (1991) and MacDonald (1993) note that even lower oxygen diffusion rates occur in irrigated turf sites associated with declining coast live and cork oaks.

The objective of this study was to compare root growth and morphology of blue, valley, and cork oak seedlings subjected to different oxygen concentrations. The information gained might offer insight regarding the variation observed in flooding tolerance among the species and aid in managing oaks in urban landscapes.

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Materials and Methods

Acorns were collected from several trees of each species during October and November of 1987 through 1990. Acorns were soaked overnight in water, air-dried, and stored in plastic bags in lots of 50, at 4-6 °C. Seeds were removed from cold storage as needed and germinated in vermiculite-filled flats in a greenhouse at 20-25 °C.

Mini-rhizotrons were made from 24- by 32- by 2-cm plastic crisper lids with a removable plexiglass plate clamped to one side (*fig. 1*). Holes were drilled in the

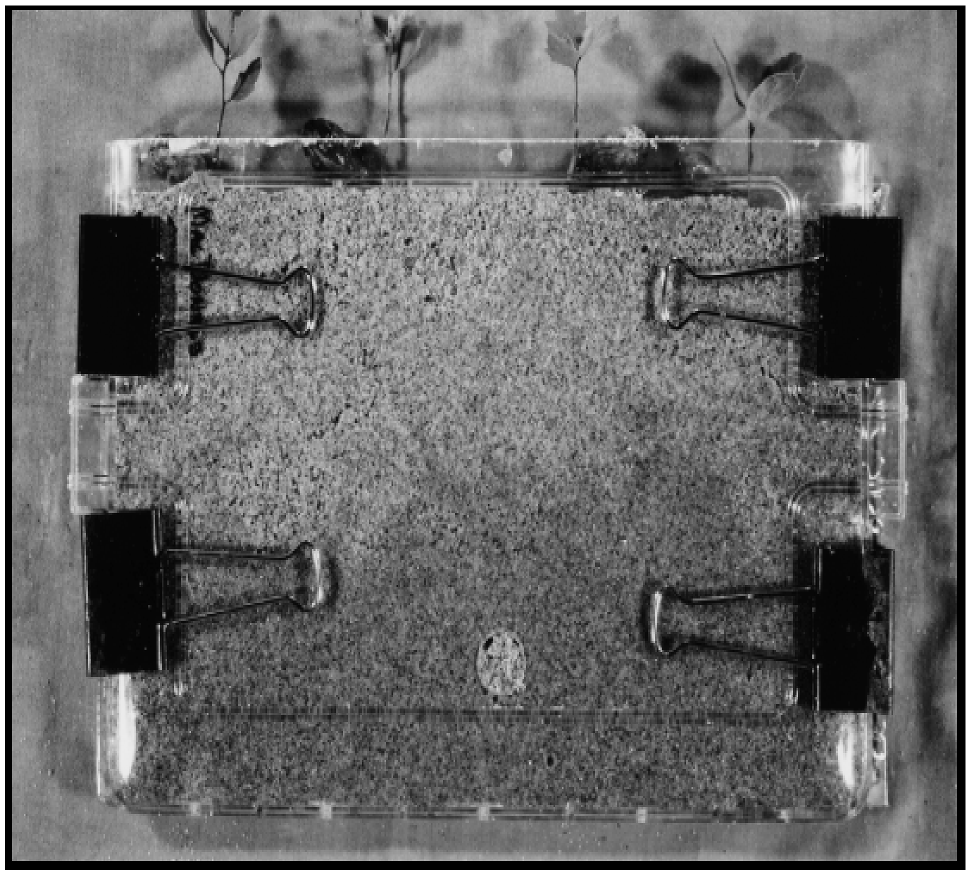

Figure 1—Mini-rhizotron showing polarographic oxygen sensor port in base (arrow). Roots are facing away from camera.

bottom of the lids for drainage, and at the base of the mini-rhizotrons for measuring oxygen (described below). A graded, coarse-textured sand (#0/30) (RMC Lonestar, Pleasanton, Calif.) was selected as the soil medium in order to encourage rapid drainage and oxygen diffusion and have similar moisture conditions in each mini-rhizotron. The water- holding capacity of the sand was determined by constructing a moisture release curve, and, the sand was autoclaved for 1 hour and thoroughly wetted with distilled water before use.

Five to seven germinated acorns were transferred to each mini-rhizotron when radicles were approximately 5 cm long (e.g., 2-6 weeks old). The shoots had typically emerged but were still in the cotyledonary stage of growth, although this varied somewhat with species. Seedlings were placed on the open surface of the sand-filled mini-rhizotron, and the plastic plate was carefully clamped over the exposed roots, leaving the shoots exposed. Mini-rhizotrons were placed in a 25 °C growth chamber with a 12-hour daylength for one week before treatment and were kept at a 45° angle to encourage root growth along the plastic plate. The mini-rhizotrons were watered daily. On the day the oxygen treatments were imposed, root growth that occurred along the removable plastic plate was traced onto an acetate sheet. Mini-rhizotrons were drained to container capacity (comparable to field capacity) and placed at a 45° angle into airtight treatment chambers kept in a 25 °C controlled environment room. The incubation period lasted for 5 days.

Varying mixtures of nitrogen and compressed air were used to generate oxygen concentrations between 0 and 21 percent, and gas mixtures entered the chambers at a flow rate of 16 l/hr. One-milliliter gas samples were collected from three points in the apparatus to monitor oxygen levels (*fig. 2*), and samples were

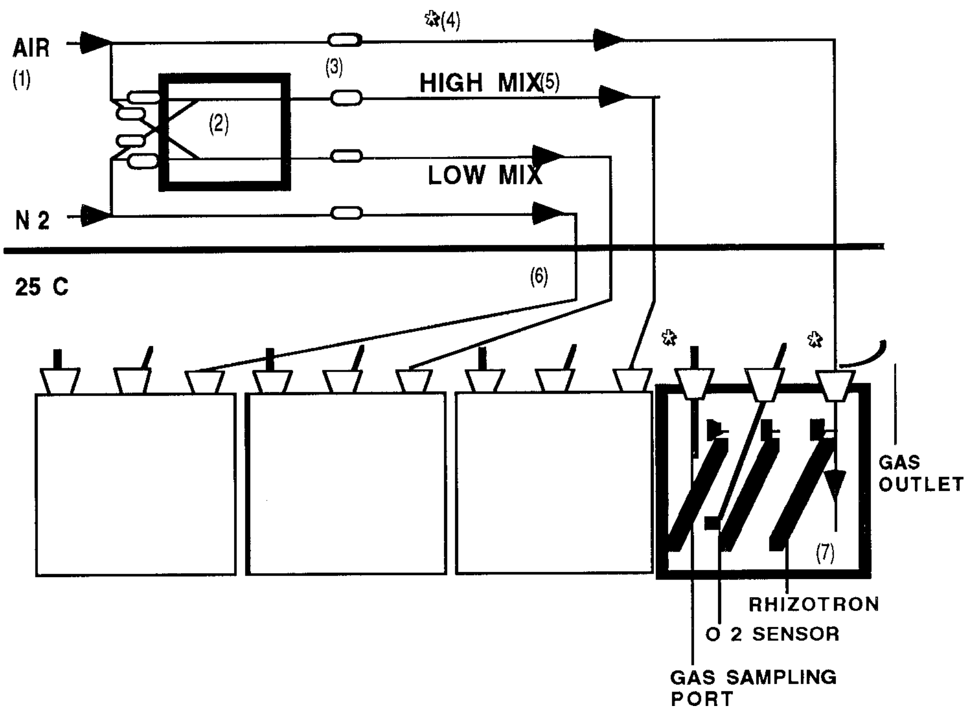

Figure 2—Experimental apparatus used to impose oxygen treatments. (1) Gas inlet lines supplying compressed air and pure (99.99 pct) nitrogen. (2) Gas mixing board. (3) Capillary tubes used to regulate flow rate of gases. (4) Stars indicate points where gas samples were taken to monitor oxygen levels. (5) Up to four oxygen treatments were run simultaneously: a high oxygen mix, low oxygen mix, 0 percent oxygen (= nitrogen), and 21 percent oxygen (= control). (6) Each gas line led to an airtight incubation chamber inside a controlled environment room. (7) Side view of three mini-rhizotrons placed at a 45° angle in a treatment chamber. A polarographic oxygen (O_2) sensor was attached to one mini-rhizotron in each treatment chamber. Seedlings were incubated for 5 days.

measured electrochemically using an oxygen analyzer (Saltveit and Strike 1989). Polarographic oxygen sensors (Jensen Instruments, Tacoma, Wash.) were used to monitor oxygen concentrations inside one mini-rhizotron in each treatment chamber. The sensors were inserted into holes drilled into the base of the mini-rhizotrons. Oxygen diffusion rate (ODR) (see Birkle and others 1964) was monitored inside the mini-rhizotrons for the 21 percent, 3-4 percent, and ≤1 percent oxygen treatments using platinum microelectrodes (Jensen Instruments, Tacoma, Wash.). We did not monitor ODR in later trials because oxygen concentration correlated directly with ODR measurements, and, in our system, the polarographic sensors varied less and were easier to use than the microelectrodes.

Three to four treatment chambers were run simultaneously, and a minimum of 15 seedlings of each species were treated for each oxygen level. More treatments were included at low, rather than high, oxygen concentrations because root growth was found to be unaffected until oxygen levels fell below 6 percent.

At the end of 5 days, mini-rhizotrons were removed from the treatment chambers, and root growth was evaluated. Root growth was measured on a per-seedling basis as the ratio of root length that occurred during incubation to total root length. The ratio was used to help account for initial variation in root length between seedlings. New root growth was traced over the pre-incubation tracings, and initial and total root lengths were input into a computer using a digitizing tablet (model MM1202, Summagraphics Corp., Fairfield, Conn.) and MacMeasure software (Research Services, National Instituite of Mental Health, Bethesda, Md).

Root tracings were also used to measure daily taproot growth for 10 seedlings with aerated shoots per species in a 25 °C growth chamber with 12-hour daylength. Measurements were made until taproots reached the base of the mini-rhizotrons (approximately 1 week).

The number of lateral roots that formed along a single taproot during the incubation period was determined for six seedlings per species at each of five oxygen levels: 0-2, 2-5, 5-7, 7-10, and 21 percent. Only seedlings that developed single taproots were measured, and we grouped similar oxygen concentrations together in order to have sufficient seedling numbers for the analysis.

The experiment was set up as a split-plot design with oxygen concentration as the main-plot, replicated over time, and species as the sub-plot. Differences in root length were compared utilizing regression analysis and curve fitting. To compare lateral branching, the oxygen treatment was considered a fixed effect, and the analysis of variance procedure with Tukey-Kramer and Duncan's means separation tests were used (SAS Institute 1991).

Results

Apparatus

The moisture release curve indicated that the soil medium was very well drained with a moisture content ranging from 17 percent at the top of the mini-rhizotron (25 mbar tension) to 23 percent at the bottom of the mini-rhizotron (0 mbar tension). It was important to have the same soil moisture content in all mini-rhizotrons because of the potential impact of moisture on root branching, and oxygen diffusion, discussed later.

Polarographic oxygen sensors indicated that the oxygen concentration inside mini-rhizotrons equilibrated with the surrounding atmosphere within 5 hours. The relationship between oxygen concentration, measured by the sensors, and oxygen diffusion rate, measured with platinum microelectrodes, was determined for three treatment levels:

Oxygen concentration (pct)	*Oxygen diffusion rate* ($\mu g\ cm^{-2} min^{-1}$)
21	0.7-0.8
3-4	0.3
≤1	0.1

Growth Response with Aerated Shoots

The average taproot extension rate under atmospheric conditions did not differ significantly ($P = 0.05$) between species:

Species	*Root growth (mm/day)*
Blue oak	17
Valley oak	14
Cork oak	13

The number of first order lateral roots that formed along the apical 15 cm of tap root differed significantly ($P = 0.05$) between species:

Species	*Lateral roots* cm^{-1} *taproot*
Blue oak	0.16
Valley oak	0.91
Cork oak	0.63

Growth Response to Reduced Oxygen

Root growth began decreasing at oxygen levels below 6 percent in blue, cork, and valley oak seedlings, and the response was explained best by a saturation growth curve (*fig. 3*). Valley oak root growth decreased more gradually than cork and blue oak roots as oxygen levels fell, and this is reflected in a higher coefficient of correlation (R^2 = 0.87) for the valley oak curve fit. Cork oak root growth dropped off precipitously at about 4 percent oxygen, and considerable variation in growth rate occurred in both cork and blue oak at the lower oxygen levels.

The oxygen concentration that brought about half-maximum root growth, i.e., a 50 percent reduction in the root growth that occurred at 21 percent oxygen, was approximately 4 percent for all species (*fig. 3*).

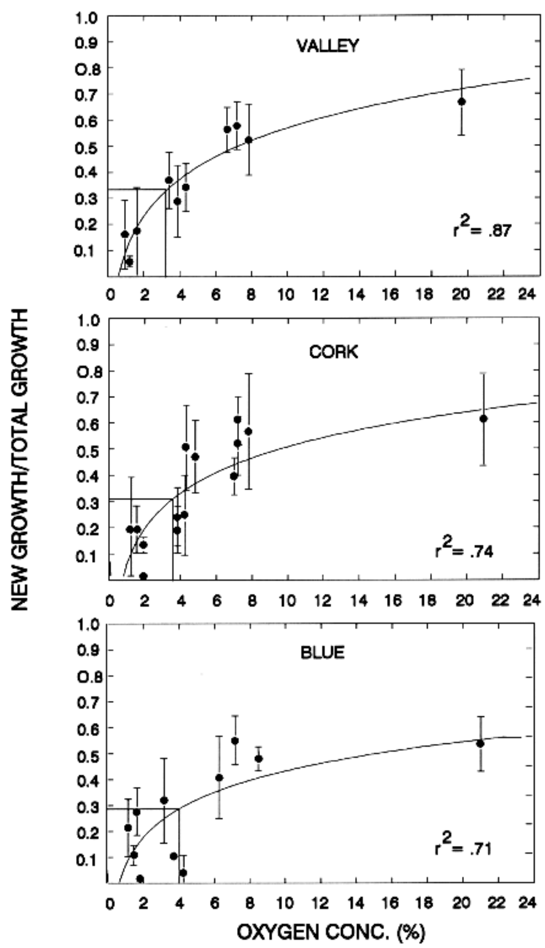

Figure 3—Root growth of valley, cork, and blue oak (new growth/total growth) affected by oxygen concentrations ranging from 0 to 21 percent. Correlation coefficients indicate the closeness of fit of the data to a saturation curve. Each point represents an average of at least 15 seedlings. Half-maximum root growth from that occurring at 21 percent oxygen is indicated by a line drawn from curve to x and y axes.

The number of lateral roots produced on a single tap root decreased significantly (P = 0.05) in cork and valley oak as oxygen concentrations fell (*fig. 4*). In contrast, the number of lateral roots produced by blue oak seedlings did not vary with oxygen concentration and was always less than cork and valley oak.

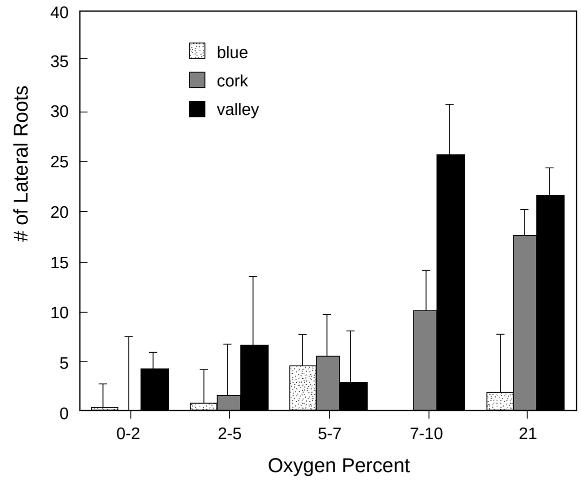

Figure 4—Total number of lateral roots produced along the apical 15 cm of tap root at different oxygen concentrations. A total of 30 seedlings per species were evaluated (6 seedlings/oxygen level/species), and only seedlings producing a single tap root were measured.

Discussion

Root growth of blue, valley, and cork oak seedlings responded similarly to decreasing oxygen in that a 50 percent reduction in growth occurred at 4 percent oxygen. We are not aware of other studies that identify an oxygen concentration corresponding to half-maximum root growth; however, root growth is generally thought to decrease by one third at approximately 6 percent oxygen (Greenwood 1968) and sometimes ceases at or below 5 percent oxygen (Stolzy 1974). Extrapolation from the root growth curves in our study (*fig. 3*) indicates that a 30 percent reduction in oak root growth did occur around 6 percent oxygen, but this varied somewhat among species. Four percent oxygen, and the corresponding ODR of 0.3 $\mu g\ cm^{-2} min^{-1}$, was a definitive "threshold" below which root growth of the three species was significantly inhibited.

The oxygen concentration of wet, clayey soils has been measured at 2 percent (Letey and Stolzy 1967), and compacted soils underlying turf may have ODR values as low as 0.2 $\mu g\ cm^{-2} min^{-1}$ (Costello and others 1991, MacDonald 1993). Our results suggest that oak root growth would be severely restricted under these conditions. Therefore it may be useful to monitor soil aeration in problematic sites (e.g., urban and developed landscapes, over-grazed lands) and if the oxygen concentration is below 4 percent, or the ODR is below 0.3 $\mu g\ cm^{-2} min^{-1}$, improvements to soil drainage and porosity could be attempted.

Oxygen diffusion rate was directly related to soil oxygen concentration in our study because we used a coarse, well-drained sand that was uniformly porous. However, in many urban and field situations the soil is wet and compacted, and consequently, oxygen diffusion to the roots may be impeded. The result is that bulk soil oxygen concentration will probably not reflect accurately the oxygen available for root uptake, as would oxygen diffusion rate (MacDonald 1993). This is because in wet soils, oxygen diffusion is as little as 1/10,000 of that which occurs in dry soils (Letey and Stolzy 1967), and the so-called "water jacket" effect necessitates that oxygen concentrations be higher than that needed for root growth and respiration (Armstrong and Gaynard 1976, Crawford 1982, Letey and Stolzy 1967). Similarly, in compacted soils underlying turf the lack of pore space can diminish ODR despite there being a high bulk oxygen concentration (MacDonald 1993). A potential drawback to ODR is that in dry soils the lack of a continuous water film disrupts electrical conductivity between the electrodes, and erroneous and variable measurement of ODR may result (Birkle and others 1964, Jacobs unpublished[7]). Therefore, ODR should be used to monitor soil aeration in wet and compacted soils, and the measurement of oxygen concentration with polarographic sensors should be reserved for dry, porous soils.

Interspecific differences were found in rooting morphology that might influence tolerance to hypoxia (and flooding) in blue, valley, and cork oak. Despite similar taproot growth rates at atmospheric oxygen concentrations, valley oak formed the most lateral roots, and blue oak formed the least. Our findings agree with reported accounts of root branching in blue and valley oak (Matsuda and McBride 1986). There is little information on the rooting morphology of cork oak, but the root system of coast live oak, a similar xerophytic, evergreen oak, is highly-branched and shallow (Cooper 1926).

In blue oak, the tendency to form a root system with few laterals might confer a degree of sensitivity to hypoxia because of the minimal root surface area available for oxygen uptake. The flooding sensitivity of some tree species, including *Eucalyptus* spp. and *Picea* spp., has been related to a sparsely branched root system (Coutts and Phillipson 1979, Kozlowski 1985). The converse would be true of valley oak, and to a lesser extent cork oak, because of their greater tendency to form lateral roots. A highly-branched root system is associated with plants adapted to flooded conditions (see Whitlow and Harris 1979) and is thought to be an adaptation of valley oak to wet soils and riparian habitats in California (Wolfe 1969).

Although valley oak is considered the most flood tolerant of the species studied, there is evidence suggesting that it is not tolerant of root hypoxia. Cooper (1926) describes mature valley oaks as having a dual root system with both deep tap and primary roots, and shallow, highly-branched lateral roots. He notes that the species is rarely found in nature in topographical positions where soil aeration is limiting. Callaway (1990) found that lateral rooting in blue and valley oak seedlings was highly dependent on soil moisture, and that blue oak adapted to changing moisture conditions better than valley oak. Because of the plasticity of its root system, blue oak might tolerate flooding and hypoxia better than valley oak.

Several of the plant responses believed to confer tolerance to flooding and hypoxia, including lateral and adventitious root proliferation, aerenchyma, and hypertrophied lenticel formation, depend upon ethylene translocation from anoxic roots to aerial shoots (Bradford and Yang 1981, Kawase 1981). These processes were inhibited in the low-oxygen treatments in our study because shoots were enclosed. However, in related experiments, blue, valley, and cork oak seedlings had their root systems flooded continuously for 5 days and all formed hypertrophied lenticels and aerenchyma (Jacobs 1991). The magnitude of the responses were similar among species, suggesting that all three have a similar capacity to respond to flooding as long as shoots remain aerated. Comparing seedling root systems in soils that are hypoxic, but not flooded, e.g. compacted sites, would help to assess the impact of aerated shoots on hypoxia tolerance, and better define how root morphology in blue, valley, and cork oak relates to hypoxia tolerance.

[7]Unpublished data on file at The Morton Arboretum, Route 53, Lisle, IL 60532.

Acknowledgments

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References

Armstrong, W.; Gaynard, T.J. 1976. **The critical oxygen pressures for respiration in intact plants**. Physiological Plantarum 37: 200-206.

Birkle, D.E.; Letey, J.; Stolzy, L.H.; Szusckiewicz, T.E. 1964. **Measurement of oxygen diffusion rates with the platinum microelectrode. II. Factors influencing the measurement**. Hilgardia 35: 555-566.

Bradford, K.J.; Yang, S.F. 1981. **Physiological responses of plants to waterlogging**. HortScience 16: 25-29.

Callaway, R.M. 1990. **Effects of soil water distribution on the lateral root development of three species of California oaks.** American Journal of Botany 77: 1469-1475.

Cooke, G.B.; Rollins, R.C.; Taylor, G. 1961. **Cork and the cork tree**. In: Rollins, R.C.; Taylor, G., eds. International series of monographs on pure and applied biology: botany. New York: Pergamon; 121 p.

Cooper, W.S. 1926. **Vegetational development upon alluvial fans in the vicinity of Palo Alto, California**. Ecology 7: 1-30.

Costello, L.R.; MacDonald, J.D.; Jacobs, K.A. 1991. **Soil aeration and tree health: correlating soil oxygen measurements with the decline of established oaks**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium in oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 295-299.

Coutts, M.P.; Phillipson, J.J. 1979. **The tolerance of tree roots to water-logging: II. Adaptation of Sitka spruce and lodgepole pine to waterlogged soil**. New Phytologist 80: 63-69.

Crawford, R.M.M. 1982. **Physiological responses to flooding**. In: Lange, O.L.; Nobel, P.S.; Osmond, C.B.; Ziegler, H., eds. Encyclopedia of plant physiology. Volume 12B. Physiological plant ecology II: Water relations and carbon assimilation. Berlin: Springer Verlag; 453-477.

Greenwood, D.J. 1968. **Root growth and oxygen distribution in soil**. Transactions of the 9th International Congress of Soil Scientists 1: 823-832.

Griffin, J.R.; Critchfield, W.B. 1976. **The distribution of forest trees in California**. Res. Paper RP-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 118 p.

Harris, R.W.; Leiser, A.T.; Fissell, R.E. 1980. **Tolerance of oaks to flooding**. In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on ecology, management, and utilization of California oaks; June 26-28, 1979; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 238-241.

Heritage, A.D.; Duniway, J.M. 1985. **Influence of depleted oxygen supply on Phytophthora root rot of safflower in nutrient solution**. In: Parker, C.A.; Rovira, A.D.; Moore, K.J.; Wong, P.T.W., eds. Ecology and management of soilborne plant pathogens. St. Paul, MN: American Phytopathological Society; 199-202.

Jacobs, K.A. 1991. **Oak root pathology: effects of oxygen stress on root growth and infection by *Phytophthora cinnamomi* and identification of *Armillaria* spp. in California**. Davis: University of California; 90 p. Ph.D. dissertation.

Jacobs, K.A.; MacDonald, J.D.; Berry, A.M.; Costello, L.R. 1996. **The effect of low oxygen stress on *Phytophthora cinnamomi* infection and disease of cork oak roots.** [These proceedings].

Kawase, M. 1981. **Anatomical and morphological adaptations of plants to waterlogging**. HortScience 16: 30-34.

Kozlowski, T.T. 1985. **Soil aeration, flooding, and tree growth**. Journal of Arboriculture 11: 85-96.

Letey, J.; Stolzy, L.H. 1967. **Limiting distances between root and gas phase for adequate oxygen supply**. Soil Science 103: 404-409.

MacDonald, J.D. 1993. **Soil aeration around declining oaks**. Journal of Arboriculture 19(4): 209-219.

Matsuda, K.; McBride, J.R. 1986. **Difference in seedling growth morphology as a factor in the distribution of three oaks in central California**. Madroño 33: 207-216.

Metcalf, W. 1947. **The cork oak tree in California**. Economic Botany 1: 26-46.

Miller, D.E.; Burke, D.W. 1977. **Effect of temporary excessive wetting on soil aeration and Fusarium root rot of beans**. Plant Disease Reporter 61: 175-179.

Miller, H.; Lamb, S. 1985. **Oaks of North America**. Happy Camp, CA: Naturegraph Publishers, Inc.

Mircetich, S.M.; Campbell, J.N.; Matheron, M.E. 1977. **Phytophthora trunk canker of coast live oak and cork oak trees in California**. Plant Disease Reporter 61: 66-70.

Saltveit, M.E.; Strike, T. 1989. **A rapid method for accurately measuring oxygen concentrations in milliliter gas samples**. HortScience 24: 145-147.

SAS Institute. 1991. **SAS basics**. Cary, NC: SAS Institute, Inc.

Stolzy, L.H. 1974. **Soil atmosphere**. In: Carson, E.W., ed. Proceedings of the institute on the plant root and its environment; 1971; Virginia Polytechnic Institute. Charlottesville, VA: University Press of Virginia; 335-361.

Velaz de Medrano, L.; Ugarte, J. 1922. **El alcornoque y el corcho-cultivo, aprovechamiento e industrias derivadas**. Biblioteca Agraicola Espanola. Ser. 8. Selvicultura e ingenieraia forestal. Madrid: Calpe; 236 p.

Whitlow, Thomas H.; Harris, Richard W. 1979. **Flood tolerance in plants: a state-of-the-art review**. Technical Report E79-2. Vicksburg, MS: Waterways Experiment Station, U.S. Army Corps of Engineers.

Wolfe, J.A. 1969. **Neogene floristic and vegetational history of the Pacific Northwest**. Madroño 20(3): 1-83.

Patterns of Geographic Synchrony in Growth and Reproduction of Oaks within California and Beyond[1]

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Abstract: *We measured patterns of spatial synchrony in growth and reproduction by oaks using direct acorn surveys, published data on acorn production, and tree-ring chronologies. The two data sets involving acorn production both indicate that acorn crops are detectably synchronous over areas of at least 500 to 1,000 km not only within individual species but among species that require the same number of years to mature acorns. Although no tree-ring data are available for California oaks, growth patterns among oaks elsewhere are statistically correlated between sites up to 2,500 km apart. These results indicate that both tree growth and acorn production patterns covary over large geographic scales and support the hypothesis that large-scale weather patterns play an important role in determining these life-history parameters of California oaks. They also have important implications for the population biology of wildlife that live in California's oak woodlands.*

Oaks are a dominant hardwood genus in a variety of temperate and semi-tropical regions throughout the world. Here in California, considerable work has been devoted to understanding the environmental factors influencing growth and reproduction by individuals and within local populations. However, virtually nothing is known concerning the factors influencing these life-history parameters on larger geographic scales. For example, our long-term work on acorn production at Hastings Reservation in central coastal California has revealed that a significant amount of variation in annual acorn crop size of blue oaks (*Quercus douglasii*) is correlated with weather conditions during the spring flowering period, with large crops associated with warm, dry springs and small crops associated with cold, wet springs (Koenig and others 1996). Although such results may eventually allow us to predict acorn crop size in particular localities based on local conditions, they do little to address the question of how synchronous acorn crops of valley or blue oaks are on larger geographic scales. This paper addresses this issue by asking the question: How synchronous is acorn production and other life-history parameters of oaks throughout California and beyond?

Study Area and Methods

We used three sets of data to address the degree of spatial autocorrelation in growth and reproduction of oaks. These are detailed below.

Patterns of Acorn Production within California

Data on acorn production by California oaks is currently being obtained by annual surveys of populations in 14 localities throughout California *(fig. 1; table 1)*. Surveys at Hastings Reservation of *Quercus lobata*, *Q. douglasii, Q. agrifolia, Q. kelloggii*, and *Q. chrysolepis* were initiated in 1980 (Koenig and others 1994b). Surveys at two other central coastal sites of *Q. lobata, Q. douglasii*, and *Q. agrifolia* were begun in 1989. All other sites include 1 to 3 of the above species (plus one site for *Q. engelmannii*) and were set up in 1994. Thus, results presented here are preliminary.

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Figure 1—Sites used for the statewide acorn survey. Sites are numbered and listed in table 1.

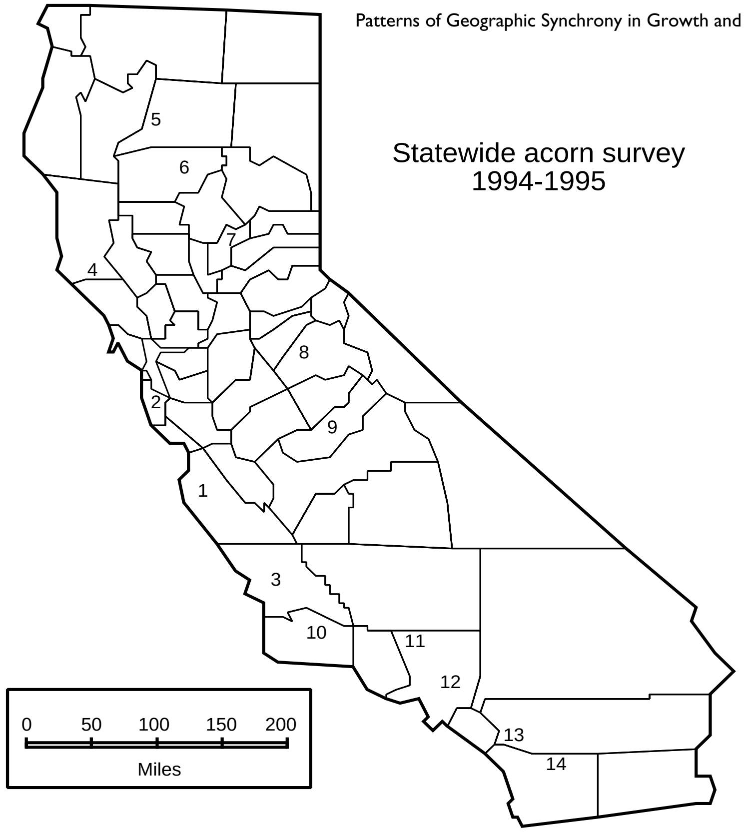

Table 1—Sites and species of **Quercus** *surveyed during the 1994-1995 statewide acorn survey*[1]

Site	l	d	e	a	k	c
1. Hastings Reservation (Monterey Co.)	X	X		X	X	X
2. Jasper Ridge (San Mateo Co.)	X	X		X		
3. Pozo (San Luis Obispo Co.)	X	X		X		
4. Hopland Field Station (Mendocino Co.)		X			X	X
5. Tower House (Shasta Co.)	X				X	X
6. Dye Creek (Tehama Co.)	X	X				
7. Sierra Foothills Station (Yuba Co.)		X				
8. Yosemite Valley (Mariposa Co.)					X	X
9. San Joaquin Exp. Range (Madera Co.)		X				
10. Sedgwick Ranch (Santa Barbara Co.)	X	X		X		
11. Liebre Mtn. (Los Angeles Co.)		X			X	
12. Switzer's Camp (Los Angeles Co.)				X		X
13. Santa Rosa Plateau (Riverside Co.)			X	X		
14. Mt. Palomar (San Diego Co.)					X	X

[1] l = *Q. lobata*, d = *Q. douglasii*, e = *Q. engelmanii* , a = *Q. agrifolia*, k = *Q. kelloggii*, and c = *Q. chrysolepis*.

Sampling is done in September at the height of the acorn crop and includes at least 20 individuals of each species at each site. To reduce among-individual variation, the same individuals are surveyed each year (Koenig and others 1994a).

Relative abundance of acorns on each tree was assessed using a modification of the visual survey method proposed by Graves (1980) and detailed by Koenig and others (1994a). In brief, each of two observers scanned different areas of the tree canopy and counted as many acorns as possible in 15 seconds. These counts were summed to yield "acorns per 30 seconds," referred to as N30. N30 values were log-transformed (*ln*[N30+1]) and then averaged to yield a mean estimate of the acorn crop for each species. At least in California, this method is not only efficient but also yields data that are superior in quality to those obtained by alternative methods, including seed traps (Koenig and others 1994a). Samples of 20 to 25 individual trees per site are sufficient to yield good estimates of annual acorn production, especially if the same individuals are counted each year and sampling continues for at least 7 years (Koenig and others 1994a).

Among-years synchrony of the three central coastal California sites for which we have 7 years of data was tested with a Kendall coefficient of concordance test (Siegel 1956). With only 2 years of data for the remaining sites, we are currently able to see only whether acorn crops tended to be uniformly larger or smaller across sites from 1994 to 1995.

Large-Scale Geographic Patterns of Acorn Production

The data we are accumulating on acorn production within California are a first step toward answering the question: What is the pattern of synchrony in acorn production on a global scale? To answer this, we searched the literature for studies conducted anywhere in the world that provided multiple years of data on acorn production. Ninety-seven data sets from 33 separate studies were found yielding a total of 849 years of acorn production data between the years 1934 and 1993. Studies were divided according to whether the species of oak being examined required 1 (n = 47) or 12 (n = 49) years to mature acorns. The majority (n = 86, or 89 percent) of the studies were from the United States, but others were located for England, Sweden, Finland, and Japan.

For each study, we standardized the data in the following manner. If the data presented were categorical, we ranked the categories in order of increasing crop size, giving the highest category a "10," the lowest category a "0," and making the difference between all intermediate categories equal. Thus, if only three categories were used (i.e., good, fair, and poor), years when the crop was rated as "good" were given a 10; those in which the crop was "poor" were given a 0; and those in which it was rated as "fair" were given a 5. Categories were divided more finely, but still equally, if more than three categories were used.

If values presented were interval or ratio-level data, such as actual counts or number of acorns falling in traps, then values were log-transformed and standardized such that the best year received a 10, the worst year received a 0, and intermediate years received values between 0 and 10.

These data were analyzed as follows: Pearson correlation coefficients (r) were calculated for all pairwise combinations of sites for which data from at least 4 years were in common. For example, if data set A presented data between 1980 and 1989 while data set B went from 1984 to 1992, the correlation between the acorn production values of the two data sets for the 6 years 1984 through 1989 was calculated along with the distance between the two sites.

Correlation coefficients were divided into seven categories depending on whether the distance between the sites being compared was <10 km, 10-99 km, 100-499 km, 500-999 km, 1,000-2,499 km, 2,500-4,999 km, or ≥5,000 km. Within each category, we tested whether r values were significantly greater than 0 by performing trials in which sets of correlation coefficients were chosen at random from the entire pool such that individual sites were used only once. For example, if the correlation between sites A and B was chosen, all other pairwise combinations involving either site A or site B (i.e., not only the correlation between A and B but also that between sites A and C, A and D, B and C, etc.) were eliminated from the pool. This procedure was continued until no sites remained. Once a complete set of correlations was chosen, we calculated the mean r value and counted the number of positive and negative correlation coefficients present in the set.

A total of 100 trials was performed for each distance category. Means (± SD) were calculated from the set of mean r values generated by the randomization trials. Statistical significance of individual analyses was based on the number of trials for which positive *r* values outnumbered negative *r* values. Analyses for which at least 95 (or 99) trials resulted in more positive than negative *r* values were considered significantly ($P < 0.05$) or highly significantly ($P < 0.01$) synchronous.

This procedure reduces pseudoreplication and provides a statistical test that measures whether among-years acorn production at sites a given distance apart tends to be synchronous, defined as having mean *r* values greater than zero. However, this definition of synchrony is much less strict than usually envisioned, because sites may be statistically synchronous according to the test even though mean *r* values are small.

Geographic Patterns of Tree Growth

The third data set we used was a series of tree-ring chronologies from the International Tree-Ring Data Bank, obtained through the internet from the National Geophysical Data Center. More than 1,200 tree-ring chronologies from throughout the world are in this data bank, of which 174 are for oaks. Most of these (103, or 59 percent) are North American, but unfortunately none is from California. Virtually all the data sets are on species that require 1 year to mature acorns; the few requiring more than 1 year were excluded from the analysis. A total of 44,338 years' worth of data were represented by these chronologies. All California data were from conifers, including various species of *Pinus, Abies, Pseudotsuga,* and *Juniperus*. Data from 66 sites summed to 50,867 years.

Raw data from each site had been standardized by the compilers by fitting a curve to each series of ring widths and then calculating the residuals, thereby allowing samples to be compared that had large differences in absolute growth rates or that varied systematically in growth rate during their life spans. Values used were the residuals from this procedure. Chronologies were tested for synchrony as described above for the acorn production data, except that sites had to share at least 10 years in common for a correlation coefficient to be calculated.

Results

Statewide Acorn Survey

Kendall rank correlations between the three central coastal California sites were significant for all three species (*lobata*: $\chi^2_6 = 13.0$, $P = 0.043$; *douglasii*: $\chi^2_6 = 12.7$, $P = 0.048$; *agrifolia*: $\chi^2_6 = 14.9$, $P = 0.021$). As an example, results for *Q. agrifolia* are graphed in *figure 2*.

Statewide, data comparing mean acorn crops in 1994 and 1995 are presented in *table 2*. For the four species that require 1 year to mature acorns (*Q. lobata, Q. douglasii, Q. engelmanii*, and *Q. agrifolia*), mean crops for all sites were worse in 1995 than in 1994 with the exception of the single *Q. engelmanii* site. These differences are significant for *Q. lobata, Q. douglasii, Q. agrifolia*, and for all comparisons of 1-year species combined. There was no consistent trend for the two species of oaks (*Q. kelloggii* and *Q. chrysolepis*) that require 2 years to mature acorns.

Literature Survey of Acorn Crop Synchrony

Results of the analysis of acorn crop synchrony based on the literature compilation are presented in *table 3*. Considering only species that require 1 year to mature acorns, crops are highly synchronous ($0.73 < r < 0.93$) between sites up to 500 km apart. Similar results were obtained for species that require 2 years to mature acorns, although mean correlation coefficients were lower ($0.28 < r < 0.59$). Unfortunately, the number of sites available for comparison were, in general, small. However, they at least support the findings of the statewide survey that acorn crops within species of oaks requiring the same number of years to mature acorns are reasonably synchronous at geographic scales on the order of at least 500 km.

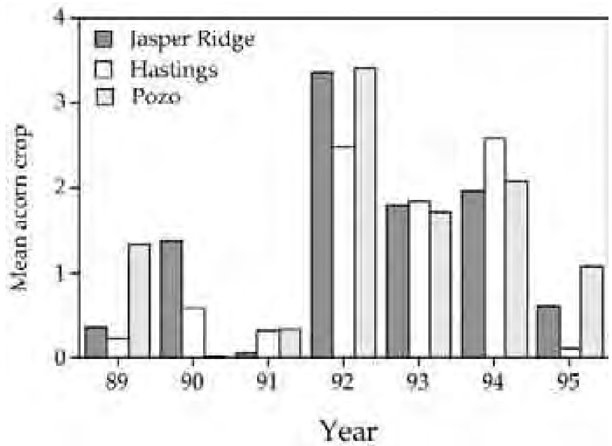

Figure 2—The mean annual acorn crop (log-transformed) of coast live oak Q. agrifolia as measured by visual surveys at Jasper Ridge (San Mateo County), Hastings Reservation (Montery County), and Pozo (San Luis Obispo County) in central coastal California between 1989 and 1995. Values are significantly concordant among years (Kendall coefficient of concordance, $X^2_6 = 14.8$, $P = 0.021$).

Table 2—Comparison of the 1994 and 1995 acorn crops based on surveys of 34 populations at 14 different sites throughout California[1]

Species	Number of sites for which		
	1995 better	1995 worse	*P* -value
1-year species			
Q. lobata	0	6	<0.05
Q. douglasii	0	9	<0.01
Q. engelmannii	1	0	—
Q. agrifolia	0	6	<0.05
2-year species			
Q. kelloggii	2	4	ns
Q. chrysolepis	2	4	ns
All 1-year species combined	1	21	<0.001
Both 2-year species combined	4	8	ns

[1] Listed are the numbers of sites for which a particular species or group of species produced a larger or smaller crop in 1995 compared to 1994. *P*-value from 2-tailed binomial tests; ns = $P > 0.05$.

Table 3—Mean correlation coefficients of annual acorn crops over seven geographic scales for species that require 1 and 2 years to mature acorns[1]

Statistics	Distance category (km/1000)						
	<0.01	0.01-.1	0.1-.5	0.5-1	1-2.5	2.5-5	>5.0
1-year species only							
Mean	0.82**	0.93**	0.73**	-0.13	-0.05	0.03	0.20
SD	0.02	0.04	0.07	0.09	0.10	0.13	0.13
N pairs	31	11	82	6	52	37	115
N independent pairs	15	3	11	2	6	5	11
2-year species only							
Mean	0.59**	0.46*	0.28*	0.10	0.02	0.01	—
SD	0.06	0.22	0.06	0.22	0.17	0.19	—
N pairs	54	23	155	19	38	29	—
N independent pairs	18	3	15	4	4	3	

[1]Total pairwise combinations available was 334 for 1-year species (mean number of years per correlation = 5.8) and 318 for 2-year species (mean number of years per correlation = 5.0). For details of analysis, see text. (** = $P < 0.01$; * = $P < 0.05$; other $P > 0.05$)

Tree-Ring Analyses

Results from analyses involving the 1-year species of oaks worldwide and the California conifers are presented in *table 4*. Among 1-year species of oaks, there is statistically significant synchrony in tree-ring growth between sites up to 2,500 km apart. Among California conifers, synchrony as defined here is evident among sites up to 1,000 km apart.

Table 4—Mean correlation coefficients of tree-ring growth over seven geographic scales for oaks worldwide (1-year species only) and for Califoria conifers[1]

	Distance category (km/1000)						
	<0.01	0.01-.1	0.1-.5	0.5-1	1-2.5	2.5-5	>5.0
Oaks worldwide							
Mean	0.54**	0.38**	0.28**	0.14**	0.07**	0.00	0.01
SD	0.01	0.01	0.02	0.01	0.01	0.05	0.01
N pairs	18	132	1665	2120	2204	30	4869
N independent pairs	16	53	76	68	54	4	51
California conifers							
Mean	0.55**	0.33**	0.25**	0.11**	—	—	—
SD	0.01	0.03	0.02	0.01	—	—	—
N pairs	4	49	662	504	—	—	—
N independent pairs	2	8	24	21	—	—	—

[1] Total pairwise combinations 11,038 for oaks (mean number of years per correlation = 205) and 1,219 for California conifers (mean number of years per correlation = 250). For details of analysis, see text. (** = $P < 0.01$; * = $P < 0.05$; other $P > 0.05$)

Discussion

Results presented here suggest that spatial autocorrelation of both reproduction and growth of oaks within California may be significant over most, if not all, of the state. Data supporting this hypothesis come directly from our statewide acorn survey and indirectly from analysis of published acorn crop data and tree-ring chronologies from oak species worldwide and California conifer species.

Our data are currently limited but suggest that synchrony in acorn production is significant within a range of at least 300 km in the California coast between Jasper Ridge in San Mateo County and Pozo in San Luis Obispo County. Although our statewide survey has been conducted for only 2 years, these data suggest that synchrony may be present on a much larger geographic scale, possibly encompassing most, if not all, of the state for blue oaks and for 1-year species of oaks combined *(table 2)*. No clear pattern emerged for either *Q. kelloggii* or *Q. chrysolepis*, the species surveyed that require 2 years for to mature acorns. Analysis of annual acorn crop data from published sources indicates that acorn crops vary synchronously over relatively large areas on the order of at least 500 km *(table 3)*.

Stronger conclusions can be drawn from the more extensive tree-ring data. Using all 1-year species, statistically significant synchrony between annual growth rates of oaks is detectable between sites up to 2,500 km apart *(table 4)*. Within California, no long-term tree-ring data are available for oaks. However, using tree-ring chronologies from four genera of California conifers, spatial autocorrelations are significant for sites up to 1,000 km apart *(table 4)*.

Thus, all three data sets indicate that the reproduction and growth of oaks are statistically correlated, in the sense that $r > 0$, over distances of at least 500-1,000 km, and possibly up to 2,500 km, when considering only species that require the same number of years to mature acorns. Although we are aware of no attempt to address the question of geographic synchrony in life-history strategies of oaks on this scale, prior work using "signature years" by Kelly and others (1989) found evidence of synchrony among tree-ring growth patterns of a series of oaks located over a distance of approximately 1,000 km throughout the United Kingdom and western Europe.

These findings have several important implications. First, because tree-ring chronologies are considered good proxy measures of climatic variables such as rainfall or temperature (e.g., Fritts 1976, Hughes and others 1982, Mann and others 1995), the patterns of spatial autocorrelation among these variables are probably similar to those found here for tree-ring growth patterns. Some evidence supporting this are presented by the analyses of rainfall patterns in different regions of California by Goodridge (1991). More surprising is the finding that geographic synchrony of acorn production is apparently almost as extensive as that for tree-ring growth. This result is consistent with the hypothesis that weather patterns play an important role in determining acorn crops on a large geographic scale.

Second, both growth and reproduction appear to be more or less geographically synchronized (although not necessarily with each other) within California when considering species that require the same number of years to mature acorns. Consequently, the probability of experiencing a near or total acorn crop failure may be more closely correlated to the presence of both 1- and 2-year species within a site than the diversity or number of oak species present per se.

Third, sites experiencing a near or total crop failure are likely to be geographically widespread. This has potentially important implications to wildlife and even to the understanding of the economy of California's Native Americans prior to European influence. For Native Americans, extensive travel was likely to have been required in order to find good acorn-producing stands during bad years. Poor crops would also have affected wildlife populations relatively synchronously over large geographic areas, except insofar as 2-year and 1-year species of oaks were simultaneously available and asynchronous.

Numerous questions and potential analyses remain. Of particular interest is the potential for using spatial synchrony of tree-ring growth to detect long-term changes in global climate patterns. Currently the data available to perform such analyses are primarily derived from boreal forests (Koenig and Knops 1996). Comparable data from California oaks could yield considerable insights into the factors correlating with the poor regeneration and human-induced changes of California's vast oak woodlands.

Acknowledgments

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References

Fritts, H.C. 1976. **Tree rings and climate**. New York: Academic Press; 567 p.

Goodridge, J.D. 1991. **One hundred years of rainfall trends in California.** In: Betancourt, J.L.; Tharp, V.L., eds. Proceedings of the seventh annual Pacific Climate (PACLIM) workshop. Interagency Ecological Studies Program Technical Report 26. California Department of Water Resources; 109-114.

Graves, W.C. 1980. **Annual oak mast yields from visual estimates**. In: Plumb, T.R., technical coordinator. Proceedings of the symposium on the ecology, management and utilization of California oaks; 1979 June 26-28; Claremont CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 270-274.

Hughes, M.K.; Kelly, P.M.; Pilcher, J.R.; LaMarche., V.C., Jr., eds. 1982. **Climate from tree rings.** Cambridge, England: Cambridge University Press.

Kelly, P. M.; Munro, M.A.R.; Hughes, M.K.; Goodess, C.M. 1989. **Climate and signature years in west European oaks**. Nature 340: 57-60.

Koenig, W.D.; Knops, J.M.H. 1996. **Long-term trends in synchrony of tree-ring growth patterns over multiple spatial scales**. Unpublished manuscript.

Koenig, W.D.; Knops, J.M.H.; Carmen, W.J.; Stanback, M.T.; Mumme, R.L. 1994a. **Estimating acorn crops using visual surveys**. Canadian Journal of Forest Research 24: 2105-2112.

Koenig, W.D.; Knops, J.M.H.; Carmen, W.J.; Stanback, M.T.; Mumme, R.L. 1996. **Acorn production by oaks in central coastal California: influence of weather at three levels**. Canadian Journal of Forest Research 26: 1677-1683.

Koenig, W.D.; Mumme, R.L.; Carmen, W.J.; Stanback, M.T. 1994b. **Acorn production by oaks in central coastal California: variation within and among years.** Ecology 75: 99-109.

Mann, M.E.; Park, J.; Bradley, R.S. 1995. **Global interdecadal and century-scale climate oscillations during the past five centuries**. Nature 378: 266-270.

Siegel, S. 1956. **Nonparametric statistics for the behavioral sciences**. New York: McGraw-Hill; 312 p.

Patterns and Processes of Adaptation in Blue Oak Seedlings[1]

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Abstract: *Reciprocal transplant studies examined the contribution of genetic differentiation and phenotypic plasticity to intraspecific variation in blue oak (*Quercus douglasii*) seedling survival and growth. A nested, mixed model design partitioned seedling survival and growth responses into between-population effects, within-population (among family) effects, and environmental effects. Significant between-population differences in seedling survivorship and growth were observed at both sites. Interactions between population source and planting block suggest local scale adaptation. Differences among maternal families in survival and growth were significant. Phenotypic variation in seedling performance may be related to indices of acorn quality such as embryo dry weight.*

Although blue oak (*Quercus douglasii* Hook. & Arn.) is found only in California, it has a wide geographic distribution within the state. In wide-ranging plant species, it is often assumed that natural selection has resulted in the formation of genetically differentiated populations adapted to local environmental conditions. For example, provenance testing in many conifer species has indicated that there is often adaptive differentiation in response to environmental clines existing along elevational gradients (Campbell 1979, Conkle 1973, Libby and others 1969). Although it is true that natural selection can be a very powerful force in shaping the genetic structure of a species, it has also been demonstrated that gene flow, if of sufficient magnitude, can overwhelm the force of natural selection. Thus, even fairly strong natural selection may not create locally adapted populations if gene flow is very high. Gene flow is typically higher in wind pollinated, outcrossing species like blue oak. The genetic structure of a wind pollinated, outcrossing plant species is usually characterized by relatively large amounts of genetic variation within populations but relatively little genetic differentiation among populations (Hamrick 1979, 1983). Thus, all else being equal, one would expect that local adaptation would be less likely to occur in an outcrossing species.

Previous electrophoretic surveys of blue oak populations at various locations in the State have confirmed expectations that blue oak is highly outcrossing (Riggs and others 1991). In general, the allozyme markers indicated that there was little electrophoretic differentiation among populations and no evidence for the formation of geographically distinct subpopulations. If the allozyme variation described by Riggs and others (1991) also reflects patterns of genetic variation in traits with potential adaptive significance (i.e., quantitative traits), then one might argue that there is little indication of local adaptation in blue oak. This conclusion would have obvious implications on strategies for restoring blue oak populations through planting efforts. If local adaptation is not occurring in blue oak, then one would not need to be concerned about the source used in planting projects. In a very real sense one might conclude that "When you have seen one blue oak population, you have seen them all!"

However, a problem arises in trying to use patterns of variation in allozyme markers to predict patterns of variation in traits of ecological and adaptive significance. Allozyme markers are excellent markers for measuring evolutionary processes such as drift and gene flow because these markers are generally thought to be neutral to the effects of selection. Thus, patterns of allozyme

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variation can be used as indices of patterns of gene dispersal and migration unaffected by selective forces. This neutrality to selection is precisely the reason why these types of markers may not be good indicators of local adaptation. An increasing number of studies have shown that patterns of genetic structure within a species can often depend on the type of genetic marker used and that electrophoretic patterns and patterns of variation in potentially adaptive traits can differ markedly. This discrepancy may result if localized, strong selection on a quantitative trait is able to override the potential swamping effects of the gene flow indicated by allozyme markers. The potential for selection to produce locally adapted populations in spite of significant gene flow has been documented for several plant species (Endler 1977, Jain and Bradshaw 1966, McNeilly and Bradshaw 1968, Mopper and others 1991).

Reciprocal transplanting, which involves collecting germplasm from sites across an environmental gradient and then planting the material together in replicated common gardens at those sites, is the most common experimental approach used to evaluate local adaptation. Introduced by Turesson (1922) and used in classic studies by Clausen and others (1940), this technique remains the most effective method to detect the occurrence of local adaptive response in plant populations. In oaks, one of the few demonstrations of localized adaptation is provided by a reciprocal transplant study conducted on northern red oak (*Quercus rubra*). Within a 4-ha plot, Sork and others (1993) reciprocally transplanted acorns from sub-populations occupying slopes with different aspects. Using leaf damage by insect herbivores as a measure of fitness, they found that seedlings exhibited the lowest leaf damage in the sites of their maternal parent. They argued that local adaptation in this species occurred as the result of strong selection by leaf herbivory of sufficient magnitude to override effects of gene flow. The authors noted that these results, indicating very localized adaptation, were rather unexpected because northern red oak is a widely outcrossing species.

Given that the electrophoretic studies by Riggs and others (1991) have indicated substantial gene flow in blue oak, we initiated a series of reciprocal transplant experiments in order to determine whether selection during the early stages of seedling establishment might be strong enough to result in local adaptation. The study used a hierarchical design to examine adaptive differentiation at both the between- and within-population scale. Acorns from trees at two different geographic locations were planted in common gardens at each of the sites in order to detect local adaptation on a regional scale (i.e. between planting sites). By incorporating the maternal family origin of each acorn into the nested design, we were also able to estimate the amount of within-population genetic variation for adaptive traits. This within-population variation represents the evolutionary potential of a population to respond to new selective pressures.

Methods and Materials

In fall 1991, acorns were collected from blue oak populations at the University of California Hopland Research and Extension Center in Mendocino County and the University of California Sierra Foothill Research and Extension Center in Yuba County. Average annual rainfall at the Hopland site is about 95 cm while the Sierra site is somewhat drier with about 70 cm of rainfall per year. To assure good sampling of the genetic variation at each of the geographic locations, acorns were collected from at least 10 different trees located at various locations within each site. Trees were sampled without regard to tree size or health. Acorns were considered to be ready for harvest from a tree when (1) they detached very easily from their cups, (2) there was no tissue damage when the acorns were removed from their cups, (3) the attachment tissue at the base of the acorn had dried, and (4) the acorns were turning yellow to orange-brown. Acorns with weevil damage were not collected. Although the experimental design required at least 80 acorns from each tree, because of high acorn production in 1991 there was ample seed to complete the experimental design. After collection, acorns were placed within plastic bags and stored for approximately 2 weeks at 3 °C. Acorns were then placed outdoors into a germination bin filled with sand that was shaded and periodically irrigated. At both Hopland and Sierra, a series of 10 planting blocks (10 m by 20 m) were established across a range of microhabitats differing in elevation, slope, and aspect. The goal was to use the widely distributed blocks to sample the regional environment of each field station so that results could be properly extrapolated to the regional scale. Within each of the planting blocks, four germinating acorns from each of the 10 maternal families from each site were planted in fall 1991, yielding a total of 80 acorns planted per block. Before planting, the fresh weight of each acorn was recorded and used as a covariate in the analysis. Within each block, acorns were planted at random with respect to family and population. Acorns were planted at a depth of 5 cm and were covered by protective netting ("Hopland tents"). Although only germinating acorns were used in the field planting, acorn germinability and viability were checked for each maternal family and used in calculating overall survival. Demographic monitoring of the reciprocal transplants began in spring 1992 and took place in April, June, and September. Within each planting block, seedlings were scored for survival and growth (i.e., height). Using the GLM procedure in the SAS statistical package, survival and growth data were analyzed as a hierarchical ANOVA with population (Hopland vs. Sierra) as a fixed effect and block and maternal family as random effects. To estimate the relative importance of the random effects (block and family) on seedling performance, variance components were estimated using the VARCOMP procedure in SAS.

A random subsample of 25-50 acorns from each of the maternal family collections from the field planting were used to examine variation in acorn size parameters at the between- and within-population (i.e., family) level. After taking fresh weights, acorns were placed in 65 °C drying ovens until no change in weight was detected. Acorns were then re-weighed to obtain dry weights and then "hulled" in order to obtain an estimate of embryo dry weight. The effects of both population source and maternal family on acorn size parameters were analyzed using the GLM and VARCOMP procedures in SAS.

Results and Discussion

Evidence for Local Adaptation

Overall, the survival of seedlings was higher at the Hopland planting site ($P < 0.01$) throughout the course of the study. Gopher and squirrel predation at Sierra were important factors contributing to lower seedling survival at this site. Using first-year seedling survival as an index of fitness, local adaptation is indicated by the results at the Sierra site (*fig. 1a*). At the Sierra site, the local Sierra germplasm had significantly higher survival than the non-local Hopland seedlings. This significant ($P < 0.05$) "home" advantage for the Sierra seedlings also occurred during the second and third years of the study (data not shown) but did not persist into the fourth year (*fig. 1b*). Low overall survival to the fourth year at the Sierra site (< 5 percent) regardless of acorn source was probably the major factor eliminating the home advantage for the Sierra source. In contrast to the results for the Sierra populations, the survival results for the Hopland population indicate relative maladaptation. This somewhat unexpected result is indicated by the poorer survival of the Hopland seedlings at their home site throughout

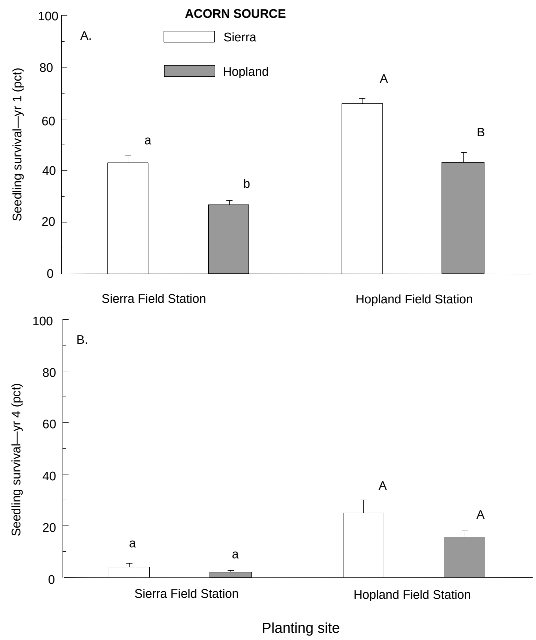

Figure 1—Interactive effects of population source and planting site on percent seedling survival after one and four growing seasons. Within a planting site, survival percentages (±1 standard error) with different superscripts are significantly different ($P < 0.05$).

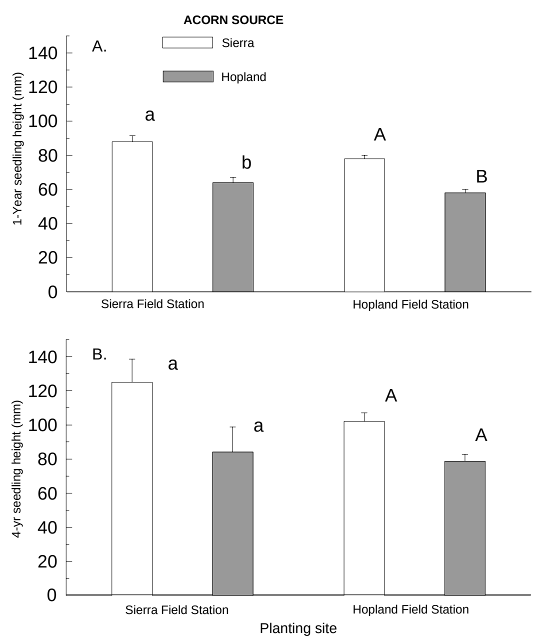

Figure 2—Interactive effects of population source and planting site on average height in 1- and 4-year-old seedlings. Within a planting site, average heights (±1 standard error) with different superscripts are significantly different ($P < 0.05$).

the course of the study (*figs. 1a* and *1b*). Similar results are indicated in an analysis of seedling "size" as measured by seedling height (*fig. 2*). Local adaptation is indicated for the Sierra population at its "home" site while local maladaptation is indicated for the Hopland source at its "home" site. It is interesting to note that one might argue that the data on both seedling survival and size indicate that the Sierra germplasm is "better" overall. We would caution against such an interpretation because (1) these data address only differences among seedlings at a relatively early stage, (2) differences among sources in seedling performance appear to diminish as time goes by (e.g., no differences in seedling survival or growth at both sites by the end of the study), and (3) a much larger array of germplasm sources would need to be tested before robust conclusions could be made regarding the overall superiority of the Sierra germplasm. Long-term monitoring at both sites is planned in order to determine whether these patterns of adaptation (and maladaptation) persist.

In addition to these population comparisons, localized adaptation was also indicated by rank correlation analysis that indicated that family performance was highly site-specific. In other words, seedlings from one tree might exhibit high survival or growth at one site but typically performed relatively poorly at another site. Further evidence for very localized adaptation in blue oak is provided by a comparison of population performance among different planting blocks located within a regional site. In practice, one examines whether there is a statistically significant population source by planting block interaction. At both regional sites, this interaction component was highly significant ($P < 0.01$), suggesting a potential adaptive response to the variation in light, moisture, and soil nutrients that we have observed to occur among planting blocks within sites (unpublished data)[4].

[4]Unpublished data on file at 161 Hunt Hall, Department of Agronomy and Range Science, University of California, Davis, CA 95616

Analysis of acorn size parameters may offer some explanation for variation in seedling survival and growth. At both the population and family level, acorn dry weight and embryo allocation were found to be positively correlated ($P < 0.05$) with seedling survival and growth. Variance component analysis indicated that much of the variation in acorn dry weight and embryo allocation was caused by differences among maternal trees in the initial collection ($P < 0.01$). This suggests at least some genetic control of acorn size. Similar patterns of strong differences in seed weight among trees and weaker but still significant differences among populations have been found for ponderosa pine (Ager and Stettler 1983). Ager and Stettler (1983) proposed that the large differences in seed size among ponderosa pine trees reflect a local selective regime that is highly heterogeneous in space and time. Before we can contemplate similar explanations for the observed between-tree variation in blue oak acorn size, we need to obtain better estimates of the magnitude of genetic control of acorn size parameters. We are currently trying to understand the relative contribution of environmental and genetic factors to variation in these size parameters by analyzing differences among maternal trees across multiple years. The rationale for this analysis is that if acorn size parameters for a given tree remain relatively constant across years varying widely in acorn production, it is more likely that acorn size has a significant genetic component.

Evolutionary Potential Within Populations

Within-population differences among trees (maternal families) in both survival and growth are significant for both populations examined (*table 1*). These inter-family measurements allow us to examine the genetic variation within a population and thus its evolutionary potential for further adaptive change. Variance component analyses indicated that in spite of the large environmental effects indicated by the between-block and within-family (error) terms, variation among maternal families within a population was a significant contributor to phenotypic variation in seedling growth and survival. This inter-family variation was relatively strong for seedling growth parameters (e.g., height) and slightly less pronounced for survival. The lower inter-family variation in survival might be expected because factors reducing survival (e.g., small mammals) are often spatially stochastic and thus less likely than factors affecting individual seedling growth to involve genetic differences among families. Overall, the significant variation among families indicates that there is genetic variation within both populations for seedling growth and survival; genetic variation that can allow these populations to adapt to new evolutionary challenges.

Within-family (error) variation reflects a combination of genetic variation, microenvironmental variation, and an interaction of both genetic and

Table 1—Variance component analysis of the percent contribution of among-family,among-block, block by population, and within-family (error) variance to total phenotypic variance in seedling survival and height at both planting sites

Variance component	Seedling survival (by year)				Seedling height (by year)			
	Hopland		Sierra		Hopland		Sierra	
	1992	1995	1992	1995	1992	1995	1992	1995
	Percent of total variance				*Percent of total variance*			
Family	23.4	10.3	16.6	6.1	25.4	10.3	19.8	4.5
Block	14.9	19.5	14.8	6.2	15.5	9.3	8.6	13.4
Block x population	2.2	8.2	0.7	0.9	3.2	9.6	15.7	16.8
Within-family (error)	59.5	62.0	67.9	86.9	55.8	70.9	55.9	65.3

environmental factors. Although we cannot estimate the effects of microenvironmental variation directly, we suspect that a large amount of the within-family variation was caused by substantial microenvironmental variation within a block. Highly localized microenvironmental variation within a block would not be surprising because we have found that physical parameters including soil depth, soil nutrients, soil moisture, relative humidity, and light vary widely within a block (unpublished data)[5]. The relative importance of inter-family variation in explaining phenotypic variation in seedling growth and survival appeared to decline over the course of the study. For example, in 1992, inter-family variation accounted for 25 percent of the variation in seedling height at the Hopland planting site. In 1995, the proportion of the variance explained by differences among families has dropped to about 10 percent. This result suggests that potential importance of genetic effects on seedling performance may be most pronounced during the first years of establishment. In addition, there was a significant site effect in that the importance of inter-family variation was less at the Sierra planting site for all 4 years of the study. This site difference may reflect the stochasticity of small mammal predation that was so predominant at the Sierra site.

[5]Unpublished data on file at 161 Hunt Hall, Department of Agronomy and Range Science, University of California, Davis, CA 95616

Conclusions

Despite strong evidence for significant gene flow among populations of blue oak (Riggs and others 1991), our reciprocal transplant studies indicate that regional populations represent genetically distinct entities. Further, results suggest that local adaptation has occurred within at least one of the regional populations examined. These results for blue oak challenge the assumption that wind-pollinated, outcrossing trees with nearly continuous geographic distributions are always characterized by high genetic variation within populations and by low genetic diversity between populations (Hamrick 1979, 1983; Hiebert and Hamrick 1983). Our study is not unique in this conclusion; other studies that have tried to examine the potential for strong selection to form locally adapted populations in trees have also detected significant differences between populations. In addition to the work on red oak discussed above (Sork and others 1993), studies on regional differentiation in lodgepole pine (Yeh and others 1986), elevational variation in ponderosa pine (Conkle 1973) and Douglas-fir (Campbell 1979), and local adaptation in pinyon pine populations (Mopper and others 1991) have also found differentiation between populations despite potentially high gene flow. This is not to say that within-population genetic diversity of outcrossing tree species is low. Results from our analyses of inter-family differences indicate that there is significant genetic variation within both blue oak populations for traits such as acorn size and seedling survival and growth. This diversity within each population may indicate that high gene flow within each population may limit scales of adaptation in blue oak to "coarse grained" regional populations. On the other hand, our study was not designed to examine microhabitat scale adaptation as found in red oak (Sork and others 1993). It is possible that the inter-family differences that we detected result from our sampling strategy to use widely distributed maternal trees from a variety of microhabitats. Instead of just representing within-region genetic diversity, differences among these trees may indicate that a large number of sub-populations are locally adapted to a variety of microhabitats. Taken together, these results suggest a complex genetic architecture for blue oak and thus argue for a serious consideration of genetic issues when restoration of blue oak populations involves a significant planting effort.

References

Ager, Alan A.; Stettler, R.F. 1983. **Local variation in seeds of ponderosa pine.** Canadian Journal of Botany 61: 1337-1344.

Campbell, Robert K. 1979. **Genecology of Douglas-fir in a watershed in the Oregon Cascades.** Ecology 60: 1036-1050.

Clausen, J.; Keck, D.D.; Heisey, W.M. 1940. **Experimental studies on the nature of species. I. The effect of varied environments on western North American plants.** Publication 520. Washington, DC: Carnegie Institution of Washington.

Conkle, M. Thompson. 1973. **Growth data for 29 years from the California elevational transect study of ponderosa pine.** Forest Science 19: 31-39.

Endler, John A. 1977. **Geographic variation, speciation, and clines.** Princeton, NJ: Princeton University Press; 246 p.

Hamrick, James L. 1979. **Genetic variation and longevity.** In: Solbrig, O.; Jain, S.; Johnson, G.; Raven, P., eds. Topics in plant population biology. New York: Columbia University Press; 84-113.

Hamrick, James L. 1983. **The distribution of genetic variation within and among natural plant populations.** In: Schoenwald-Cox, C.M.; Chambers, S.M.; MacBryd, B.; Thomas, W.L., eds. Genetics and conservation, a reference for managing wild animal and plant populations. Menlo Park, CA: W.A. Benjamin Inc.; 335-348.

Hiebert, Ronald D.; Hamrick, J.L. 1983. **Patterns and levels of genetic variation in great basin bristlecone pine, *Pinus longaeva*.** Evolution 37: 302-310.

Jain, S.K.; Bradshaw, A.D. 1966. **Evolutionary divergence among adjacent populations: I. The evidence and its theoretical analysis.** Heredity 21: 407-441.

Libby, W.J.; Stettler, R.F.; Seitz, F.W. 1969. **Forest genetics and forest tree breeding.** Annual Review of Genetics 3: 469-494.

McNeilly, Thomas; Bradshaw, A.D. 1968. **Evolutionary processes in populations of copper tolerant *Agrostis tenuis* Sibth.** Evolution 22: 108-118.

Mopper, Steven; Mitton, J.B.; Whitham, T.G.; Cobb, N.S.; Christensen, K.M. 1991. **Genetic differentiation and heterozygosity in pinyon pine associated with resistance to herbivory and environmental stress.** Evolution 45: 989-999.

Riggs, Lawrence A.; Millar, Constance I.; Delany, Diane L. 1991. **Genetic variation sampled in three California oaks.** In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 233-234.

Sork, Victoria L.; Stowe, Kirk A.; Hochwender, Cris. 1993. **Evidence for local adaptation in closely adjacent subpopulations of northern red oak (*Quercus rubra* L.) expressed as resistance to leaf herbivores.** American Naturalist 142: 928-936.

Turesson, G. 1922. **The species and variety as ecological units.** Hereditas 3: 100-113.

Yeh, F.C.; Kahlil, M.A.K.; El-Kassaby, Y.A.; Trust, D.C. 1986. **Allozyme variation in *Pices mariana* from Newfoundland: genetic diversity, population structure, and analysis of differentiation.** Canadian Journal of Forestry Research 16: 713-720.

Genetic Variation in Shoot Growth, Phenology, and Mineral Accumulation of Northern and Central Sierra Nevada Foothill Populations of Blue Oak[1]

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Abstract: *Genetic variation of three traits of blue oak (*Quercus douglasii*) was studied in a common garden experiment at the Sierra Nevada Foothills Field Station, Browns Valley, California. Preliminary observations over a period of 3 years suggest that some genetic variation in blue oak populations studied is expressed as differences in shoot growth, phenology, and mineral accumulation. This variation appears to be typical of neither ecotypic nor ecoclinal variation. Interpretation of results for the development of seed transfer rules is premature at this phase of the study. A longer period of observation encompassing the adult growth phase will be required before definitive recommendations can be made.*

In California, extensive clearance of blue oak (*Quercus douglasii)* from rangelands and the urbanization of blue oak-dominated vegetation types have led to a concern for the loss of biological diversity in this species and its vegetation types. Jones and Stokes Associates (1987) estimated that 591,000 acres, or 7 percent of the area supporting the Valley and Foothill Woodland type, had been completely lost between 1945 and 1980; blue oak is a major component of this Valley and Foothill Woodland type. Since 1980 urbanization has caused additional losses of blue oak woodlands and savannas, while rangeland clearance and agricultural conversion of blue oak-dominated landscapes have had less impact.

The potential impact on biodiversity caused by the loss of blue oak-dominated vegetation is threefold: first, the loss of ecosystems and ecosystem processes; second, the loss of species; and third, the loss of genetic variability (McNeely and others 1990). Losses of all three of these types of biodiversity are significant and warrant the development and application of appropriate management and planning strategies to conserve biodiversity. The research reported here addresses the genetic architecture of blue oak. Understanding the degree and geographical pattern of genetic variation is essential in evaluating the significance of the loss of local populations of a species and can serve as the basis for the development of seed source acquisition rules and gene conservation strategies.

Seed source acquisition rules are guidelines that consider the complex and irregular ways in which individual species vary genetically over the landscape. These rules are used to define geographic seed collection zones for restoration projects. Long-term seed storage, the most common *ex situ* gene conservation strategy, is not applicable to blue oak because acorns of blue oak cannot be maintained for a long time in storage facilities. Therefore, the maintenance of genetic diversity in blue oak depends on *in situ* programs combined with the *ex situ* maintenance of trees in botanical gardens.

Research on the genetic variation in blue oak has been limited to allozyme analysis of a few populations and some linkage of ecological characteristics to population variation. Both approaches indicated high within-population variation (Millar and others 1990, Rice and others 1991, Riggs and others 1991). These studies have not provided sufficient information to define the geographical pattern of genetic variation in blue oak. Research reported here was designed to

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues. March 19-22, 1996, San Luis Obispo, Calif.

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examine genetic variability in blue oak by investigating a larger number of populations than had previously been studied.

Our study used the common garden method to characterize the geographic pattern of genetic variation in blue oak. The common garden method grew from the early reciprocal transplant experiments of Bonnier (1895) in the Pyrenees and the transplant garden experiment of Kerner (1895) in the Tirol Mountains. Turreson (1922) working in Denmark, Clausen and others (1939) working in California, and Gregor (1946) working in Scotland used the common garden method to investigate genetic variability in wild species. The method was adopted by forest geneticists for provenance testing of forest trees and by agronomists for evaluating genetic strains of crop species (Zobel and Talbert 1991). The common garden method is based on the premise that genetic variability within a species will be expressed as differences in growth, morphology, physiological characteristics, and phenology when plants, cuttings, or seeds collected over the range of a species are raised in a uniform environment.

Use of common garden experiments declined after the 1960's with the advent of biochemical techniques to characterize genetic variability. The high cost of maintaining common gardens also played a role in the decline of common garden experiments. Various nucleic acid and allozyme methods developed in the past 30 years have yielded rapid and precise information at the gene and gene product level. However, as Millar and Libby (1991) pointed out, common garden experiments over several years of study provide more information on traits directly related to adaptation than biochemical studies. Hamrick and others (1991) further contend that dependence on biochemical techniques has not usefully demonstrated positive association among different adaptive traits and genetic variation in outcrossing species with wide geographic ranges. One must be cognizant that genetic variation in trees that affects morphological and physiological expression can be expected to involve multiple gene interaction (Namkoong and others 1988). These interactions are expressed through the physiological and developmental processes that are impossible to observe out of the environmental context in which the organism operates. The common garden can serve as an environment to observe the various outcomes of these multiple gene interactions. It can provide, in combination with various nucleic acid and allozyme methods, a successful approach to understanding genetic variability within a species.

Establishment of the Common Garden

A common garden for blue oak plantings was established at the Sierra Foothill Field Station in spring 1992 on a site within the natural range of the species. Seed collections for this common garden were made at 15 locations in the foothills of the Sierra Nevada. Collection sites were established along four west-to-east transects located approximately 100 km apart in the northern and central Sierra Nevada foothills. Collections were made in 1990 at elevations of approximately 150, 300, 600, and 900 m along these transects, with the exception of transect number 2 where collections were made at 150, 450, and 750 m (*table 1*).

At each site approximately 150 to 200 acorns were collected from each of 10 trees. Trees used in the collection occurred within 30 m of the chosen elevation (e.g., 150, 300, 600, 900 m) but were separated from each other by at least 100 m. Acorns first were subjected to a float test. Those that floated were held for 24 hours in a mist bed and float-tested a second time because a majority of acorns that did not sink in the initial test appeared to be sound. One hundred acorns representing the size distribution of the acorns that sank in the float test were selected for each tree. The sets of 100 acorns, from each of the 10 trees used for collection at the various elevations along the transects, were then bulked. These bulked samples were dried in open trays to near 25 percent on a dry weight basis. During the drying process they were sequentially exposed to temperatures of 20, 15, 10, and 5 °C over a period of 2 weeks. After drying, the acorns were placed in air-tight polyethylene bags for storage at 1 °C until they were planted. Before planting they were soaked for 24 hours in aerated tap water.

Acorns from the 15 seed sources collected in 1990 were sown at the Magalia Nursery, California Department of Forestry and Fire Protection, Magalia, Calif., in January 1991. Seedlings were lifted from the nursery beds and planted in the common garden at the Sierra Nevada Foothill Station in March 1992.

The plantation planting design used in the common garden consisted of 10 major blocks each with 15 minor plots per seed source. Each of the minor plots had nine planting spots on 1.2-m centers. Seedlings were planted in holes dug to 45 cm with a power auger. Two bare-root seedlings were planted in each augered planting spot. Weeds were controlled before planting with a glyco-phosphate herbicide. After planting weeds were killed by a combination of hand weeding and herbicide application. Approximately 10 percent of the seedlings needed replacement during the first growing season because of predation by voles and pocket gophers. Replacement seedlings were grown outside in Berkeley, California, in 8-cm-diameter by 30-cm-deep containers. These were planted in January 1992 at Berkeley and used for replacement of seedlings in the Sierra Nevada Foothills common garden during the first growing season. Seedlings were thinned to one per spot in January 1993.

Analysis of soil conditions in the common garden indicated a uniformity of soil characteristics. Soil samples were collected from six randomly located sample spots in the common garden and were analyzed in spring 1995. Soil was collected at depths of 10, 30, and 60 cm at each sample location. Soil samples were air dried and sifted to remove particles of >2 mm. The pH of each sample was determined on a saturation paste, total carbon by combustion, total nitrogen by macro-kjeldahl, cation exchange capacity by ammonium acetate extraction, phosphorus by sodium bicarbonate extraction, and exchangeable cations by both acetate extraction at pH 7 and potassium chloride (KCl) extraction at the unbuffered pH of the soil. Standard soil moisture contents at pressure plate pressures of 0.03 and 1.5 MPa were also determined.

Table 1—Location of blue oak* (Quercus douglasii) *seed sources

Transect	Geographic location	Latitude	Seed source no.	Elevation
				m
1	Route 36	40° 19′	1A	150
			1B	300
			1C	600
			1D	900
2	Route E21	39° 20′	2A	150
			2B	450
			2C	750
3	Route 50	38° 46′	3A	150
			3B	300
			3C	600
			3D	900
4	Route 120	38° 00′	4A	150
			4B	300
			4C	600
			4D	900

A nutrient analysis showed that the soil is not limiting for plant growth (*table 2*). The soils showed 27 and 12 percent moisture at pressure plate pressures of 0.03 and 1.5 MPa, respectively. Summer soil moisture levels in the common garden were above the permanent wilting point, during each year of the study, because of late spring precipitation and the elimination of herbaceous cover. The soil in the common garden is probably a complex of the Auburn, Los Pasos, and Argonaut series that are derived from greenstone and metamorphic parent material. These soils tend to be well weathered with a red color tending to yellowish in the C horizon at 70-80 cm. Soil bulk densities ranging from 1.20 to 1.32 were measured in the common garden.

Table 2—Soil nutrient characteristic in a common garden at the Sierra Nevada Foothill Field Station[1]

					Milliequivalents/100 g soil						
Depth	pH	C	N	P	Ca	Mg	K	Na	Mn	CEC	Ca/Mg
cm		*pct*	*pct*	*ppm*							
10	6.0	1.05	0.11	17.10	11.05	1.45	0.62	0.13	0.79	14.3	7.6
30	6.1	0.51	0.05	5.10	1.87	2.96	0.41	0.13	0.64	14.1	4.0
60	6.2	0.25	0.04	2.20	15.38	5.08	0.22	0.14	0.34	15.8	3.0

[1]C = carbon; Ca = calcium; CEC = Cation exchange capacity; K = potassium; Mg = magnesium; Mn = manganese; N = nitrogen; Na = sodium; P = phosphorus.

Methods

Plant Growth and Phenology

Basal diameter and length of the longest stem of each plant were measured each year in late winter. Diameter measurements were made using a digital, electronic caliper at a point 3 cm above the soil level. The longest stem was measured using a flexible steel carpenter's tape. Many plants did not develop a central dominant leader, but grew in a more shrubby habit. Wilting of the second flush of growth and attacks of mildew resulted in the mortality of the terminal portion of the main stems of some plants over the 3-year period of measurements; however, this isolated mortality did not result in a disruption in any of the height growth trends shown by the populations.

Phenology of bud break, leaf expansion, and shoot elongation was followed during the spring shoot development period in 1993; the timing of bud swell, bud break (leaf emergence), and shoot elongation were recorded for the major shoot on all plants.

Plant Tissue Analyses

In spring 1995, eight of the 15 blue oak populations in the common garden were sampled for plant nutrient analysis. Populations were chosen to represent the latitudinal and elevational range of populations planted in the common garden. Three mature leaves were cut from each seedling within each of six randomly selected blocks. Leaves were pooled by block for analysis. Recently matured leaves were used as stable benchmark and to avoid leaves that may be dominated by the transient nutrient fluxes involved in (1) the cell division or osmotic adjustments of expanding leaves or (2) the cell wall thickening and re-transport of nutrients in older leaves. Leaf tissue samples were oven dried at 65 °C, ground to pass through a 20-mesh screen, analyzed for nitrogen by micro-kjeldahl, and suitably prepared for atomic absorption and ICP spectroscopy by nitric acid digest (Bradstreet 1965, Zarcinas and others 1987).

Results and Discussion

Plant Growth

Analysis of diameter and height growth did not reveal a consistent trend in relation to elevation and latitude (*table 3*). Both variables first increase and then

Table 3—Average diameters and heights of blue oak* (Quercus douglasii) *in a common garden at the Sierra Nevada Foothill Field Station in February, 1994

Latitude	Elevation (m):	150	300	600	900	Avg.
				Diameter (*mm*)		
40° 19′		13.6	12.6	12.8	13.2	13.0a[1]
39° 20′		16.2	16.8[2]	15.7[3]	-	16.2b
38° 46′		14.2	17.0	16.0	14.3	15.4b
38° 00′		13.8	16.3	14.3	14.5	14.7b
	Avg.	14.4ab	15.7ab	14.7ab	14.0ab	
				Height (*cm*)		
40° 19′		97	88	100	92	94.2c
39° 20′		104	111[2]	112[3]	-	109.0c
38° 46′		94	123	109	95	105.2c
38° 00′		100	121	89	103	103.2c
	Avg.	98.8c	111.4c	102.5c	97.5c	

[1]Numbers with the same letter are not significantly different at the 0.01 percent level
[2]450-m elevation
[3]750-m elevation

decrease along both gradients. The average diameters and heights were greater in those populations occurring in central latitudes and middle elevations. The term trend is used here with caution because a statistical analysis (a one-way ANOVA; Tukey test for multiple comparison of means) indicated that only the average of the diameters of the northernmost populations was significantly different (0.05 percent level) from the diameters of the other populations averaged by latitude. The trend in greater growth exhibited by the central latitude and mid-elevation populations suggests a better adaptation of the genotypes of these populations to the environment of the common garden at the Sierra Nevada Foothills Station. This location falls within the range of central latitudes and mid-elevation. It is assumed that populations from higher and lower latitudes and higher and lower elevations are not as well adapted to the environment of the common garden. Blue oaks occurring at these higher and lower elevations and latitudes may have evolved a more conservative growth strategy in response to drought-induced desiccation at lower elevations and latitudes and early frost damage at higher elevations and higher latitudes. In either case, limiting growth and entering into dormancy early would be a conservative strategy that results in decreased growth. Mid-elevation and mid-latitude populations would be less vulnerable to either extremes of drought or frost damage. Continued growth of these populations over a longer season may have contributed to their increased diameters and height.

Plant Phenology

A large data set was produced from the observations of the phenology of the different seed sources. We have chosen the percentage of seedlings that were dormant on March 16, 1993 as an indicator of the difference in the phenological development of the various populations. On this date about 60 percent or more of the individuals in each population had experienced bud break. The data show that all individuals from the lower-elevation populations collected along the latitude of the common garden (latitude N39°20") had initiated bud break (*table 4*). Eighty-nine percent of the individuals from the highest-elevation population along this same latitude (latitude N39° 20") had also initiated bud break. Populations collected along latitudes N40° 19" showed an increasing percentage of dormant individuals as elevation increased. At latitudes N38°46" and N38° 00" there was no trend in increasing dormancy and elevation; however, the highest-elevation populations along these two transects exhibited the greatest dormancy percents. An average of the percentages of dormant plants at each elevation across the various latitudes showed an increase in dormancy with increasing elevation. This trend of increasing dormancy with latitude and elevation suggests that release from dormancy may be related to temperature. The fact that nearly all individuals from populations along the latitude of the common garden had broken bud suggests that photoperiod may also be involved. Kramer and Kozlowski (1979) proposed a general model for the control of dormancy and bud break that involved both photoperiod and temperature.

***Table 4**—Percentage of blue oaks that were dormant on March 16, 1993 in a common garden at the Sierra Nevada Foothill Field Station*

Latitude		Percent dormant				
	Elevation (m):	150	300	600	900	Avg.
40° 19′		10	15	38	40	25.8a[1]
39° 20′		0	0[2]	11[3]	-	2.8b
38° 46′		17	26	15	30	22.0a
38° 00′		20	12	18	22	18.0a
	Avg.	11.8a	13.2a	20.5ab	30.6b	

[1]Numbers with the same letter are not significantly different at the 0.01 percent level
[2]450-m elevation
[3]750-m elevation

One would expect that trees at the locations from which the acorns were collected would break bud dormancy in relation to increasing temperature and day length. Trees at the lowest elevation (150 m) along the latitude N38˚00" would be the first to break bud. However, in the common garden at latitude N39˚ 20", 20 percent of the trees from this seed source were still dormant on March 16, 1993. There may be attributes of the common garden used in this experiment that are influencing the bud break of seedlings that are not understood and have resulted in what does not seem to be a logical pattern of bud break.

Plant Tissue Analyses

Leaf tissue analysis showed a greater accumulation of nitrogen, phosphorus, and sulfur in high-elevation populations than in low-elevation populations (*table 5*). This pattern was not apparent in the other nutrients studied. This increased

Table 5—Foliar nutrient content of blue oak in a common garden at the Sierra Nevada Foothill Field Station in 1995

Latitude	Elevation Low (150 m)	Elevation High (900 m)
Nitrogen *(pct)*		
40° 19′	2.28	2.39
39° 20′	2.40	2.37
38° 46′	2.31	2.44
38° 00′	2.35	2.45
Avg.	2.33a[1]	2.41a
Phosphorus *(ppm)*		
40° 19′	1772	1987
39° 20′	1739	1946
38° 46′	763	1908
38° 00′	1761	1918
Avg.	1758.8b	1939.8c
Sulfur *(ppm)*		
40° 19′	1603	1668
39° 20′	1681	1748
38° 46′	1649	1662
38° 00′	1571	1695
Avg.	1626.0d	1693.2d
Calcium *(pct)*		
40° 19′	1.15	0.96
39° 20′	1.29	1.04
38° 46′	1.04	1.23
38° 00′	1.09	1.23
Avg.	1.14e	1.12e
Magnesium *(pct)*		
40° 19′	0.25	0.20
39° 20′	0.23	0.22
38° 46′	0.23	0.22
38° 00′	0.22	0.23
Avg.	0.23f	0.22f
Potassium *(pct)*		
40° 19′	0.48	0.56
39° 20′	0.51	0.55
38° 46′	0.52	0.50
38° 00′	0.54	0.54
Avg.	0.51g	0.54g
Manganese *(ppm)*		
40° 19′	606	556
39° 20′	605	582
38° 46′	477	628
38° 00′	488	586
Avg.	544h	588h
Iron *(ppm)*		
40° 19′	108	119
39° 20′	100	93
38° 46′	113	99
38° 00′	96	101
Avg.	104i	103I
Calcium/Magnesium		
40° 19′	4.61	4.85
39° 20′	5.69	4.95
38° 46′	4.39	5.87
38° 00′	5.03	5.29
Avg.	4.93j	5.24j

[1]Numbers with the same letter are not significantly different at the 0.01 percent level

concentration of these macronutrients may be an indication of more effective mineral accumulation by seed sources from high elevations. We hypothesize that the shorter growing seasons and the trend toward less nutrient-rich soils, with increasing elevation, may have been selective forces for a greater capacity for absorption in higher-elevation populations.

Conclusions

The basic approach of common garden studies is to observe the phenotypic expression of survival, growth, and development over time. Phenotypic expression may indicate a stepwise change in genetic variation associated with distinct ecotypes or a gradual variation typical of ecoclines (Heslop-Harrison 1964). Our data have not demonstrated either stepwise or gradual variation. Few of the characteristics of the plants measured have been statistically definitive for delineating the geographic pattern of genetic variation in blue oak. Genetic variation in blue oak may be sufficiently large within local populations to obscure statistical delineation of either ecotypes or ecoclines. It is possible that genetic variation between populations, selected at the intervals of latitude and elevation studied in this report, is slight and that neither ecotypes nor ecoclines occur in the area studied. We, therefore, cannot at this time suggest definitive seed source transfer rules that could be used in restoration projects. We intend to follow these populations over the next decade to see if a more definitive characterization of the geographic variation within blue oak can be achieved.

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References

Bonnier, G. 1895. **Recherches expérimentales sur l'adaptation des plants au climat alpin.** Annales des Sciences Naturelles Botanique, 7th ser., 20: 217-358.

Bradstreet, R.B. 1965. **The Kjedahl method for organic nitrogen.** New York: Academic Press; 239 p.

Clausen, J., Keck, D.D.; Heisey, W.M. 1939. **The concept of species based on experiment.** American Journal of Botany 26: 103-106.

Gregor, J.W. 1946. **Ecotypic differentiation.** The New Phytologist 45: 254-270.

Hamrick, J.L.; Gotdt, M.J.W.; Murawaki, D.A.; Loveless, M.D. 1991. **Correlation between species traits and allozyme diversity: implications for conservation biology**. In Falk, D.A; Holsinger, K.E., eds. **Genetics and conservation of rare plants.** New York: Oxford University Press; 75-86.

Heslop-Harrison, J. 1964. **Forty years of genecology.** Advances in Ecological Research 2: 159-247.

Jones and Stokes Associates. 1987. **Sliding toward extinction: the state of California's natural heritage, 1987**. San Francisco: The Nature Conservancy; 106 p.

Kerner, A. 1895. **The natural history of plants, their forms, growth, reproduction, and distribution**. Translated by F. W. Oliver. London: Blackie; 326 p.

Kramer, P.J.; Kozlowski, T.T. 1979. **Physiology of woody plants**. New York: Academic Press; 811 p.

McNeely, Jeffrey, A.; Miller, K.R.; Reid, W.V.; Mittermeir, R.A.; Werner, T.B. 1990. **Conserving the world's biological diversity**. International Union for the Conservation of Nature. Gland, Switzerland: World Resources Institute, Conservation Institute, World Wildlife Fund-United States, and the World Bank, Washington, DC 193 p.

Millar, C. I.; Delany, Diane L.; Riggs, Lawrence A. 1990. **Genetic variation in California oaks**. Fremontia 18: 20-21.

Millar, C. I.; Libby, W.J. 1991. **Strategies for conserving clinal, ecotypic, and disjunct population diversity in wildland species**. In: Falk, D.A.; Holsinger, K.E., eds. Genetics and conservation of rare plants. New York: Oxford University Press; 149-170.

Namkoong, G. and others. 1988. **Tree breeding: principles and strategies**. New York: Springer-Verlag; 439 p.

Rice, Kevin J.; Gordon, Doria R.; Hardison, Jeanine L.; Walker, Jeffrey M. 1991. **Intraspecific phenotypic variation and ecological genetics of blue oak *(Quercus douglasii* Hook. & Arn.).** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 59-63.

Riggs, Lawrence A.; Millar, Constance I.; Delany, Diane L. 1991. **Genetic variation sampled in three California oaks**. USDA Forest Service Gen. Tech. Rep. Pacific Southwest Forest and Range Experiment Station-126.

Turresson, Gote. 1922. **The genotypic response of plant species to the habitat**. Hereditas 3: 211-350.

Zarcinas, B.; Cartwright, B.; Spouncer, L.R. 1987. **Nitric acid digestion and multi-element analysis of plant material by inductively coupled plasma spectrometry**. Communication in Soil Science-Plant Analysis 18(1): 131-146.

Zobel B.; Talbert, J. 1991. **Applied forest tree improvement**. Chicago, IL: Waveland Press; 505 p.

Gene Flow Among Populations of Three California Evergreen Oaks[1]

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Abstract: *Intraspecific variability within the oak genus has been the source of considerable taxonomic confusion. In part, this variability seems to arise from the relatively facile hybridization of oak species. Our biochemical data suggest that coastal populations of* Quercus wislizenii *should be ascribed to* Q. parvula *and that, in restricted regions, hybridization between this species and* Q. agrifolia *accounts for difficulty in their separation. Low levels of interspecific gene flow occurring over a wider geographic range may account for morphological variability in the species.*

Oak species are characterized by unusually high levels of morphological variability which often pose serious taxonomic problems. This variation may be attributed to high intrinsic levels of genetic variation, to high levels of phenotypic plasticity, and to high potential gene flow among species. Undoubtedly, all three sources of variation are important. Reports of unusually high levels of genetic variation at the species level (Dodd and others 1993a; Guttman and Weight 1989; Rafii 1988; Schnabel and Hamrick 1990; Schwarzmann and Gerhold 1991) are as expected for species of late seral stages, which are predominantly outcrossed and long-lived (Hamrick and Godt 1990). Relatively little is known about the genetic controls of phenotypic plasticity, particularly in the genus *Quercus*. However, the high degree of within-tree morphological variability suggests that phenotypic plasticity is an important source of variation in oaks.

It is the third source of variation, gene flow among species, that is the focus of this paper. Although many oak species are sufficiently distinct that identification presents no great problems, there are instances in which morphological convergence results in taxonomic confusion. This is particularly true in regions of sympatry, where the separation of species is sometimes problematic. In these instances, hybridization has commonly been cited as the source of morphological confusion. Reports of hybrids in oaks have usually taken one of two forms: (1) infrequent individuals that are intermediate between parental forms or (2) populations in which individuals show a range of morphological variation including characteristics of either parents and all levels of intermediacy. Because genetic incompatibility is believed to be absent or infrequent in *Quercus* (Stebbins 1950), the potential for interspecific crossing should be relatively high. It is, therefore, the absence, or low frequency, of hybrids that is perhaps more remarkable under conditions of sympatry.

Reports of low levels of hybridity in nature may be more apparent than real because of the difficulty of identifying crossed individuals. Anderson (1948) pointed out that F1 hybrids are generally morphologically intermediate between either parent, but future generations of hybrids and backcrosses include high proportions of individuals that closely resemble either one or the other parent. Because of high levels of morphological variation within parental taxa, field biologists might fail to recognize individuals as hybrid. The need for more specific genetic markers is essential for the detection of interspecific gene flow. Recently, low levels of gene flow have been demonstrated among morphologically "typical" members of eastern North American white oaks, using chloroplast DNA (Whittemore and Schaal 1991). This evidence, together with molecular studies of parapatric species from other genera, suggests that introgressive gene flow may be more prevalent than previously thought.

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Evaluation of the role of hybridization in evolution depends on an adequate means for identifying gene flow and on an understanding of the ecological preferences of parental species and the occurrence of ecological gradients in sympatric zones. To shed some light on these processes, we have been studying intraspecific variation in natural allopatric and sympatric populations of evergreen oaks in California (Dodd and others 1993a, b) and in the Mediterranean Basin (Rafii and Dodd 1992; Rafii and others 1993). Earlier work using acorn steroids and acorn fatty acids as biochemical markers provided strong evidence to support field observations of hybridization between *Q. wislizenii* and *Q. agrifolia* and at the same time indicated significant differentiation between Sierra Nevadan and coastal populations of the former species. To further investigate diversity in these species we have analyzed epicuticular wax composition of a wider geographic range of populations of the two species, together with individuals of *Q. parvula*, including some from the type locality of variety *shreveii*, which was formerly attributed to *Q. wislizenii*.

Methods

Foliage was collected from approximately 10 individuals from each of 26 populations of *Q. agrifolia* and seven populations of *Q. wislizenii*. Sampled individuals of the latter species included five Sierra Nevadan populations (allopatric from *Q. agrifolia*), a Central Valley population from Roseville (near Sacramento), and a coastal population from Ornbaum (near Gualala). Because *Q. wislizenii* and *Q. parvula* have commonly been treated as synonymous, individuals from the type locality of *Q. parvula* var. *shreveii* at Palo Colorado Canyon and from nearby locations at Santa Cruz and Pfeiffer Big Sur and individuals of *Q. parvula* var *parvula* from the Purisima Hills were included in the analyses. In addition, three putative hybrid populations from Hopland, Yorkville, and Santa Cruz were included. Population locations are numbered in *fig. 1*, and numbers correspond to the population names in *tables 1, 2, 3*.

Within each population, mature trees at least 50 m apart were selected, and foliage from different sides of the outer crown was sampled. Sampling was carried out after late summer, and further analyses were carried out only on mature foliage. Epicuticular waxes were extracted by submerging a random sample of 10 whole leaves (to avoid extraction of internal lipids) per tree in 10 ml of hexane for 3 minutes. Hydrocarbons were separated from other wax constituents by filtering the extract through a mini-column packed with 0.5 g of 70-230 mesh silica gel. The hydrocarbon extract was analyzed on an HT-5 (0.25 mm internal diameter; 25 m length) column in a Varian 3400 gas chromatograph equipped with a flame ionization detector. Alkanes were identified by comparing

Table 1—Percentage occurrence of low, medium, and high levels of hentriacontane in foliar wax extracts of Quercus parvula *and of hybrid populations of* Q. agrifolia *and* Q. wislizenii

Collection locality	Low	Medium	High
P1 Palo Colorado	0	50	50
P2 Pfeiffer Big Sur	0	50	50
P3 Purisima Hills	0	0	100
P4 Santa Cruz	0	0	100
Hybrid Populations			
H1 Hopland	43	43	14
H2 Yorkville	100	0	0
H3 Santa Cruz	88	6	6

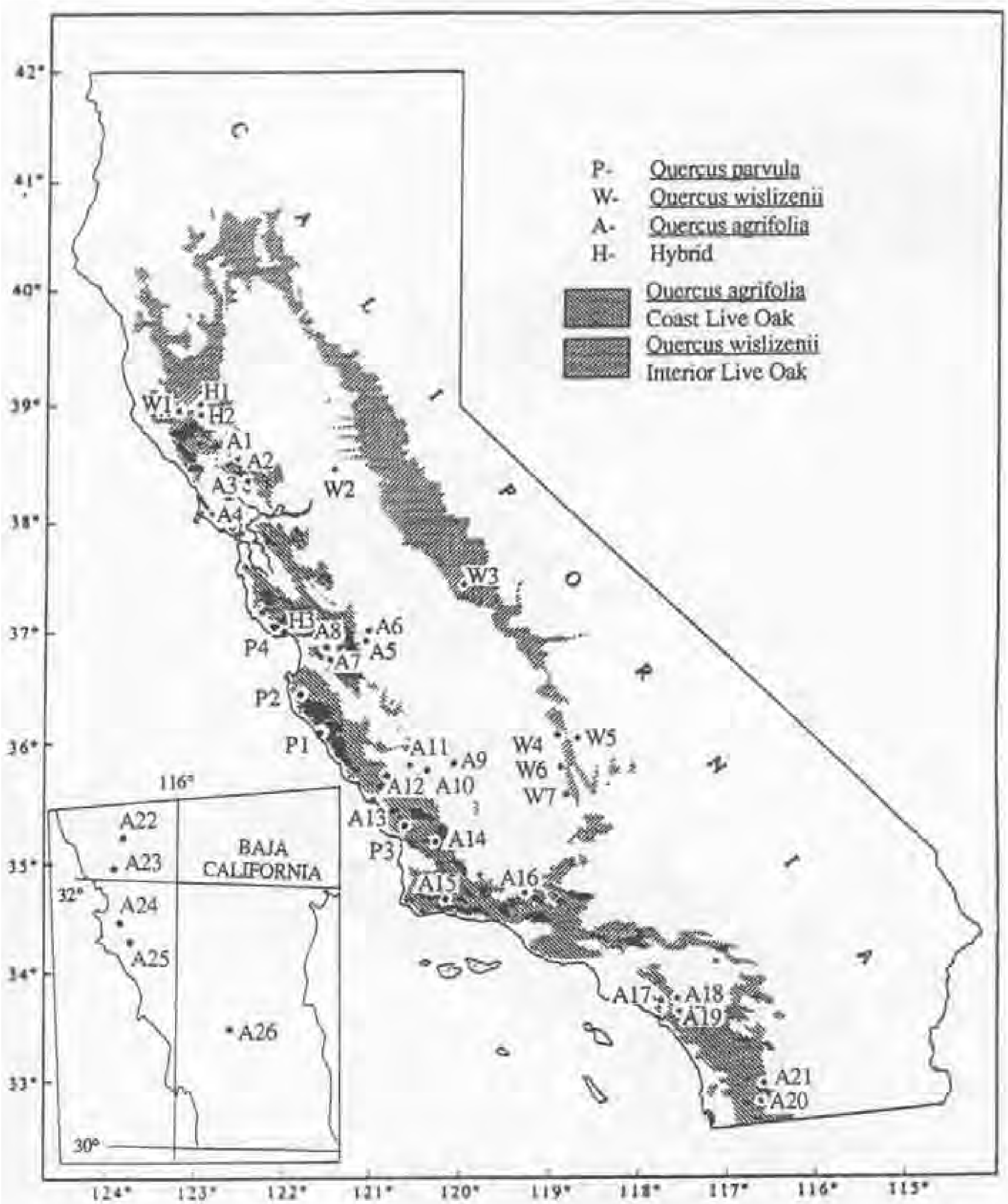

Figure 1—Geographic distribution of *Quercus agrifolia* and *Q. wislizenii* in California and populations sampled in California and Baja California.

retention times with commercial standards and by comparing gas chromatography - mass spectrometric (GC-MS) analyses with a library of mass spectra (D. Henneberg, Max-Planck Inst., Mulheim, Germany). Chromatographic peak areas of identified compounds were expressed as a percentage of the total alkane extract.

Table 2—Percentage occurrence of low, medium, and high levels of hentriacontane in foliar wax extracts of Quercus agrifolia

Collection locality	Low	Medium	High
A1 Cloverdale	90	10	0
A2 Franz Valley	100	0	0
A3 Crane Park	100	0	0
A4 Point Reyes	90	10	0
A5 Pacheco Creek	90	10	0
A6 Pacheco Pass	80	20	0
A7 Fremont Peak	62	38	0
A8 San Juan Road	70	30	0
A9 Parkfield	80	20	0
A10 San Miguel	100	0	0
A11 Paso Robles	89	11	0
A12 Black Mountain	100	0	0
A13 Cambria	90	10	0
A14 Lompoc	100	0	0
A15 Ojai	90	10	0
A16 Valencia	100	0	0
A17 Cleveland 1	100	0	0
A18 Cleveland 2	100	0	0
A19 Fallbrook	100	0	0
A20 Peutz Valley	100	0	0
A21 San Ysabella	100	0	0
A22 Vallecitos Baja California (BC)	100	0	0
A23 San Antonio (BC)	100	0	0
A24 La Mission (BC)	100	0	0
A25 Santo Thomas (BC)	86	14	0
A26 San Pedro Martir (BC)	83	17	0

Table 3—Percentage occurrence of low, medium, and high levels of hentriacontane in foliar wax extracts of Quercus wislizenii

Collection locality	Low	Medium	High
W1 Ornbaum	30	40	30
W2 Roseville	55	45	0
W3 Mariposa	100	0	0
W4 California Hot Springs	90	10	0
W5 Kernville	90	10	0
W6 Wofford Heights	100	0	0
W7 Kern River	100	0	0

Results

A total of 11 alkanes, with carbon chain lengths ranging from C_{20} to C_{33}, were detected in the filtered wax extract. Frequency distributions of the percentage composition of these alkanes (from the more than 400 individuals) were heavily skewed, as shown most strikingly for hentriacontane (C_{31}), in *fig. 2*. This distributional pattern may be explained by the presence of three chemotypes comprising low levels of hentriacontane (up to 10 percent of total hydrocarbons), medium levels (11-36 percent), and high levels (39-60 percent). This trimodal pattern is suggestive of two alleles at a single locus specifying high and low levels of the compound, respectively.

For all individuals combined, the low C_{31} chemoytpe was the most common, followed by medium and then high C_{31} chemotypes. An interesting pattern emerged for the frequency of the different chemotypes among populations. High C_{31} was the most common chemotype in all individuals from the type locality of *Q. parvula* var *shreveii* at Palo Colorado and from nearby populations at Pfeiffer Big Sur, Santa Cruz, and in the Purisima Hills population of *Q. parvula* var *parvula* (*table 1*). For these individuals the low C_{31} chemotype was entirely absent.

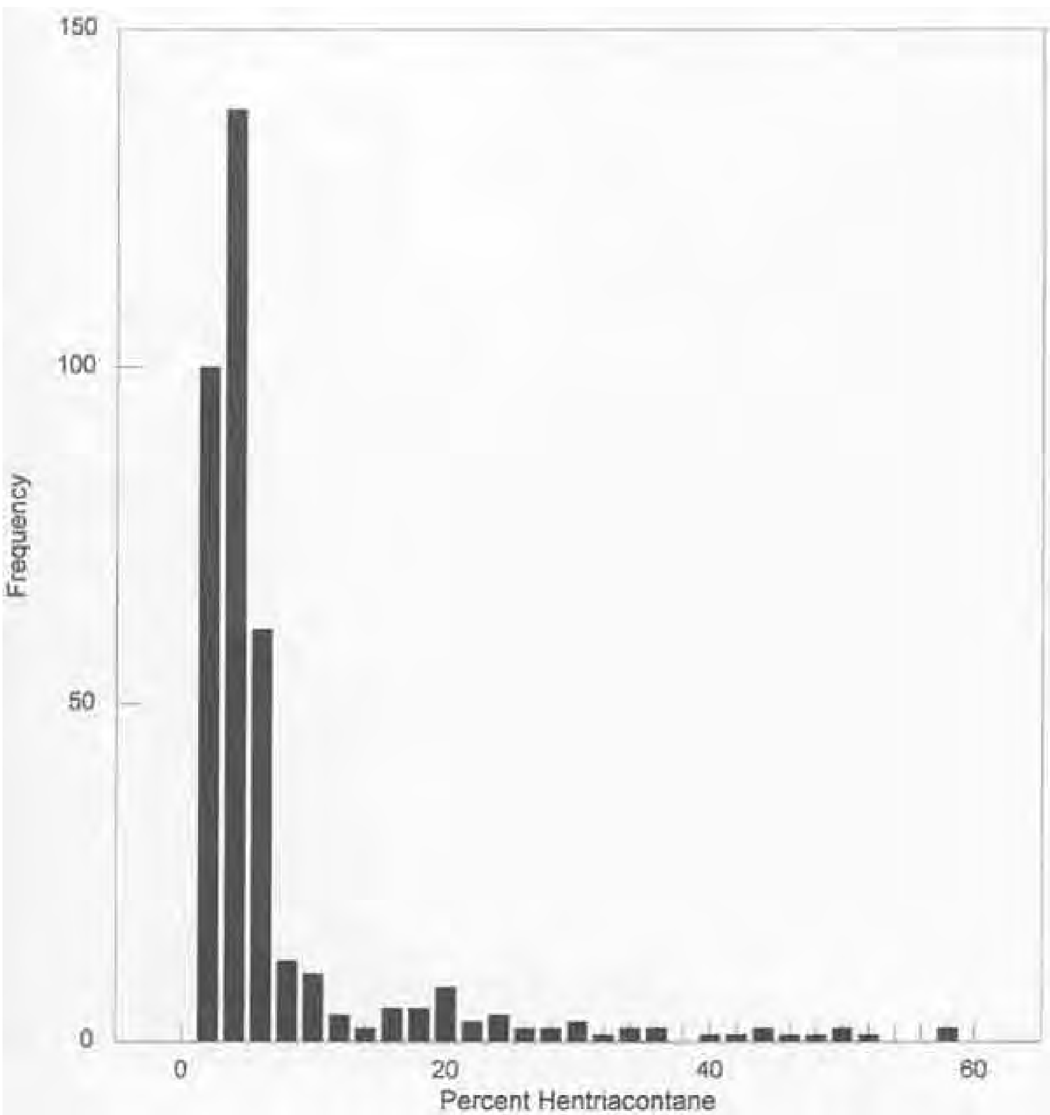

Figure 2—The frequency distribution of the percentage abundance of hentriacontane in wax extracts of leaves of *Quercus agrifolia*, *Q. wislizenii*, and *Q. parvula*.

By contrast, high C_{31} chemotypes were absent in *Q. agrifolia* (*table 2*), and the medium C_{31} chemotype occurred occasionally. Occurrence of the latter chemotype was restricted to populations from Cloverdale, in the north, to Ojai, in the south, and in two outlying populations in Baja California. In most of these populations, the incidence of medium C_{31} chemotypes was at, or below, 10 percent, but increased to 30 percent in a region east of Monterey-Santa Cruz (Pacheco, Fremont Peak, San Juan Road). The occurrence of the medium C_{31} chemotype in central California, in the probable range of *Q. parvula* var *shrevei*, is highly suggestive of gene flow between these two species.

In Sierra Nevadan populations of *Q. wislizenii*, the high C_{31} chemotype was absent (*table 3*), and the medium chemotype occurred in only two individuals (a frequency of less than 4 percent). This marked biochemical differentiation from *Q. parvula* serves to underline the differentiation of these two taxa. Interestingly, the coastal population from Ornbaum included almost equal numbers of the three chemotypes (*table 3*), raising the question as to whether this population might be better ascribed to *Q. parvula*, or to hybrids between the two species. Similar reasoning may apply to the Central Valley population at Roseville, in which 45 percent of individuals were of the medium C_{31} chemotype.

Among the three populations identified as hybrid in the field, medium and high C_{31} chemotypes were recorded in both the Hopland and Santa Cruz populations, but only low C_{31} chemotypes were identified at Yorkville (*table 1*). Our data from steroid chemistry and morphology suggested highest levels of hybridization at Hopland followed by a decline from Yorkville to Santa Cruz (Dodd and others 1993a). In this earlier work, hybridization was assumed to be between *Q. agrifolia* and *Q. wislizenii*. However, presence of medium and high C_{31} chemotypes at Hopland suggest that *Q. parvula* is involved in hybridization rather than *Q. wislizenii*. Consistent with our earlier findings, hybridization at Santa Cruz is probably low, since the medium and high chemotypes were individuals identified in the field as *Q. wislizenii* type (probably *Q. parvula*). The hydrocarbon data provide no evidence for hybridization between *Q. parvula* and *Q. agrifolia* at Yorkville.

The patterns described above for hentriacontane were repeated by some other hydrocarbons and provide some interesting insights into the diversity of this complex of evergreen oaks. First, *Q. parvula* exhibits a marked genetic differentiation from interior populations of *Q. wislizenii*. Indeed, it is more distinct from *Q. wislizenii* than the latter species is from *Q. agrifolia*, supporting recognition of this taxon (Tucker 1993). Second, the frequency of chemotypes common in *Q. parvula*, but rare in the other two species, increases with increasing proximity to the range of *Q. parvula*, suggesting gene flow over a relatively broad geographic range. Third, chemotypes characteristic of *Q. parvula* appeared in two of the putative hybrid populations, suggesting the presence of hybrids between this species and *Q. agrifolia*, but only at Hopland were these chemotypes common.

In local regions such as Hopland, hybridization between *Q. parvula* and *Q. agrifolia* may be common, constituting a local hybrid swarm. This pattern of local hybrid success may be attributable to specific ecological conditions that favor hybrid progeny. Our biochemical data indicate that interspecific gene flow is not restricted solely to these regions, but that low levels of gene flow may be occurring over a relatively large geographic range.

References

Anderson, E. 1948. **Hybridization of the habitat.** Evolution 2: 1-9.

Dodd, R.S.; Rafii, A.Z.; Bojovic, S. 1993a. **Chemosystematic study of hybridization in Californian live oak: acorn steroids.** Biochemical Systematics and Ecology 21: 467-473.

Dodd, R.S.; Rafii, A.Z.; Zavarin, E. 1993b. **Chemosystematic variation in acorn fatty acids of California live oaks (*Quercus agrifolia* and *Q. wislizenii*).** Biochemical Systematics and Ecology 21: 279-285.

Guttman, S.I.; Weight, L.A. 1989. **Electrophoretic evidence of relationships among *Quercus* (oaks) of eastern North America.** Canadian Journal of Botany 67: 339-351.

Hamrick, J.L.; Godt, M.J.W. 1990. **Allozyme diversity in plant species.** In: Brown, A.H.D.; Clegg, M.T.; Kahler, A.L.; Weir, B.S., eds. Plant population genetics, breeding and genetic resources. Sunderland, MA: Sinauer Associates; 43-63.

Rafii, A.Z. 1988. **Caractéristiques taxonomique, morphologique et isoenzymatique du complexe "chêne vert."** Bulletin de la Société Botanique de France 4: 343-352.

Rafii, A.Z.; Dodd, R.S. 1992. **Mediterranean evergreen oak diversity: morphological and chemical variation of acorns.** Canadian Journal of Botany 70: 1459-1466.

Rafii, A.Z.; Dodd, R.S.; Pelleau, Y. 1993. **Biochemical diversity and systematics of Mediterranean evergreen oak from southeast France.** Biochemical Systematics and Ecology 21: 687-694.

Schnabel, A.; Hamrick, J.L. 1990. **Comparative analysis of population genetic structure in *Quercus macrocarpa* and *Q. gambelii* (Fagaceae).** Systematic Botany 15: 240-251.

Schwarzmann, J.F.; Gerhold, H.D. 1991. **Genetic structure and mating system of northern red oak (*Quercus rubra* L.) in Pennsylvania.** Forest Science 37: 1376-1389.

Stebbins, G.L. 1950. **Variation and evolution in plants**. New York: Columbia University.

Tucker, J.M. 1993. **Fagaceae.** In: Hickman, James C., ed. The Jepson manual: higher plants of California. Berkeley: University of California Press.

Whittemore, A.T.; Schaal, B.A. 1991. **Interspecific gene flow in sympatric oaks.** Proceedings of the National Academy of Science 88: 2540-2544.

Effects of Shade and Clipping on Coast Live and Blue Oak Seedling Mortality and Growth in California Annual Grasslands[1]

Pamela C. Muick[2]

Abstract: *Responses of oak seedlings to shade and clipping treatments were studied in unirrigated, unweeded exclosures at Hastings Reservation, Monterey County, California from 1988 through 1991. Locally collected acorns were planted (December 1988) and a greater number of coast live than blue oak seedlings emerged (84 versus 54 percent), but fewer survived (by Year 3, 10 versus 40 percent). Blue oak benefited from but did not require shade for survival, in contrast with coast live oak. Clipping treatments resulted in greater coast live oak mortality but possibly benefited blue oak. Ultimately, both species established seedlings in annual grasslands during a prolonged drought.*

Livestock ranching is the primary use of many oak habitats in California (Bolsinger 1988). Ranchers and land managers might have greater assurance about management strategies likely to promote oak recruitment if they had more information on the specific effects of biomass removal on oak survival and growth.

Anecdotal evidence abounds on the deleterious effects of livestock grazing on oak regeneration. However, for a variety of political and logistical reasons, there has been little research and therefore a paucity of data about specific effects of livestock grazing and wildlife browsing upon oak seedling establishment, growth, and survival (Allen-Diaz and Bartolome 1992, George and Hall 1991).

Our experiment sought to understand how coast live oak (*Quercus agrifolia* Nee) and blue oak (*Q. douglasii* Hook & Arn.) seedling growth and survival are influenced by herbivory and canopy. Coast live and blue oak dominate almost half of the oak woodlands in the state and offer several interesting points of comparison. Coast live oak is an evergreen species and blue oak deciduous, although as seedlings both often maintain leaves throughout the year. The seedlings are reputed to differ in their ability to survive under tree canopy. Field observations have suggested that tree canopy had an important effect on sapling survival (Muick and Bartolome 1987), and I wanted to investigate its effects on seedlings. Simultaneously, I investigated how different kinds and seasons of herbivory (biomass removal as a first-level proxy for grazing effects) would affect oak seedlings.

The study investigated three hypotheses: (1) Do seedling emergence, growth, and survival in response to shade treatments differ between coast live oak and blue oak in annual grasslands? (2) Do seedling survival and growth in response to clipping treatments differ between coast live oak and blue oak in annual grasslands? and (3) Are there interactions among these treatments and species affecting survival and growth? The results of the first two hypotheses are presented and discussed in this paper (for a full discussion see Muick 1995).

Methods

Research took place at University of California's Hastings Reservation, Monterey County, California, from 1989 to 1991 on three sites within old fields near blue or coast live oak stands. A comparison of the three sites (North Field, Robinson

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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Saddle, and Tire Flat) is presented in *table 1*. At each site an exclosure was constructed, fenced above and below ground, to exclude all vertebrate herbivores. The exclosures were rested for one year after fencing, and remaining rodents were live-trapped and removed.

Table 1—Comparison of site and soil characteristics of the three Hastings sites including data from soils analysis by UC Davis, DANR Soils Laboratory

Characteristic	North Field	Robinson Saddle	Tire Flat
Elevation (ft)	1800	1840	1760
Slope (pct)	0-5	0-5	0-5
Depth to clay pan (ft)	4	5	6
SO_4-S	20	21	21
N (total N; Kjeldahl method)	0.066	0.040	0.063
P (carbonate; Olsen test)	6.4	3.6	4.8
CEC	18.0	9.0	16.5
Percent sand	77	87	76
Percent silt	13	8	14
Percent clay	10	5	10
Hastings sample number	901	902	903

Concerns about effects of fence edge and soil compaction were addressed. To minimize edge effects associated with fences, a 1-m boundary strip was established between the fence and the planting area. Since soil compaction is thought to inhibit oak seedling establishment, the planting areas were protected from treading and mechanical disturbance during trenching and fence construction. Foot traffic was restricted to well-defined paths which were used during all phases of the study.

Each exclosure measured approximately 6 by 8 m and was divided into quarter-plots. Each quarter-plot was further subdivided into 16 cells measuring 30 cm on a side. Cells were separated and positioned to equalize interactions (*fig. 1*). Fifteen cells were planted with acorns, and one was used for herbaceous vegetation observations. Each cell was planted with 16 acorns from a single source, either from one blue oak parent or one coast live oak population.

The experiment was a multifactorial design, and species and treatments were assigned randomly to cells. The resulting design was evaluated for adequate dispersion within the quarter-plot and balanced within each shade treatment and site.

A total of 2880 acorns was planted in this experiment. Acorns were planted on December 18, 1988, at a depth of approximately 5 cm. After planting, the cell received about 200 to 250 ml of water to prevent the acorns, some of which had emerging roots, from drying out before the next rain. This was the only additional water used in the experiment.

Herbaceous vegetation, consisting of annual grasses and forbs, was not modified beyond the disturbance associated with acorn planting. No fertilizer or irrigation was applied to the acorns or seedlings, and no pre-existing oak seedlings were observed.

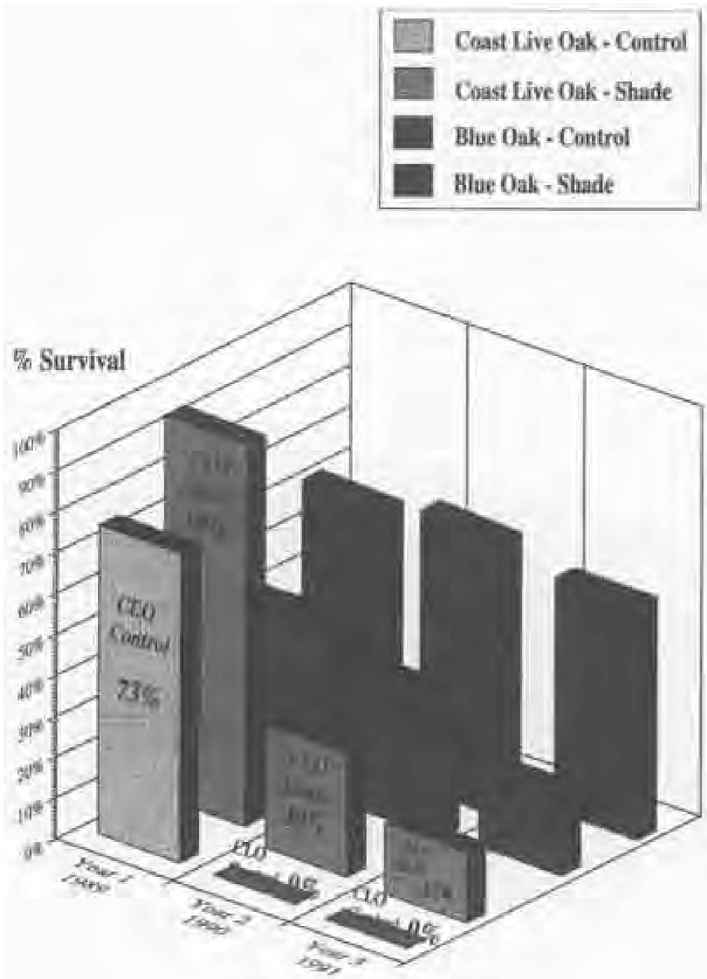

Figure 1—Seedling survival by species and shade treatment across three years of study, 1989 to 1991.

Experimental Treatments

Two intensities of clipping were used to simulate herbivory plus a control: (1) a moderate clipping treatment which removed all leaves, (2) a heavy clipping treatment which removed all stems and leaves at 0.5–1.0 cm above ground level, and (3) a control, no clipping. Seedlings were clipped on May 1, 1989.

Moderate clipping represented defoliation by insects, particularly grasshoppers. Heavy clipping represented browsing by deer, rabbits, woodrats, sheep, and cattle.

Although originally two seasons of clipping, early and late, were planned to investigate seasonality of seedling responses, the drought altered this plan. By July of Year 1, leaves and shoots of many unclipped seedlings of both species were dried and brown. Since there were few green leaves or shoots, it appeared unlikely that they would have been grazed; therefore the late season clipping was eliminated from the plan and clipping was limited to one season.

The shade treatment consisted of shaded and unshaded quarter-plots. One of the four quarter-plots on each site, and the one diagonal to it, were randomly assigned to the shade treatment. The two remaining quarter-plots were unshaded. Shade was produced by a 50 percent shadecloth tarp of Weathashade$_{TM}$, suspended horizontally over a quarter-plot approximately 1 to 1.25 m above the ground.

Data Collection

Observations were made monthly from March 1989 and ended in July 1991. Each month I recorded, by cell, the number of seedlings and leaves, heights of seedlings, and annual vegetation. Annual biomass production was collected in the spring of 1989 and 1990 from a control cell within each quarter-plot.

Seedling emergence was defined as the presence of a shoot or stem with leaves in the spring of 1989. Survival was defined as the presence of a stem with green leaves or a living stem during any of the observation dates in Year 2 or 3. Dieback was defined as the unseasonal presence of brown and dried leaves, shoots or parts of shoots, and was common for both species at all sites. The maximum number of seedlings with green leaves and/or stems observed for a species at a site was used to represent survival for that time interval.

Data Analysis

Data were entered into a database using $Excel_{TM}$ spreadsheet software and were summarized monthly by site, quarter-plots, and treatments over the course of the experiment. $SYSTAT_{TM}$ and $Excel_{TM}$ were used to produce frequencies and other descriptive statistics. The SAS_{TM} general linear model (GLM) for split plot designs was used to evaluate the seedling responses to treatments. Seedling number was square root transformed to increase consistency with the assumptions of the GLM.

Results

Even during the most extreme drought of the century, coast live and blue oak seedlings survived in ungrazed annual grasslands, although patterns of growth and survival would probably have been different under wetter conditions.

Observations are summarized by species for three periods. Year 1 was the first growth period—March through September 1989. Year 2 was the second growth period—October 1989 through September 1990. Year 3 was the final growth period of the study—October 1990 through July 1991.

General Linear Model (GLM) Analysis

The GLM analysis testing of the first hypothesis (*table 2*) demonstrated that the species differed significantly in emergence and survival ($P \geq 0.001$). By Year 2 the shade treatment effects were also highly significant in explaining survival ($P \geq 0.001$).

The second hypothesis "Do seedling survival and growth in response to clipping treatments differ between coast live oak and blue oak in annual grasslands?" was rejected for Year 1, although the clipping treatment resulted in greater mortality among coast live oak than among blue oak seedlings. However,

Table 2—Summary of the general linear model (GLM) analysis of the three hypotheses (Type III model).

	Seedling survival year 2 April 1990				Seedling survival year 3 June 1991			
	Site	Spp	Shade	Clip	Site	Spp	Shade	Clip
Overall Model F	21.30	20.43	20.40	1.21	11.26	21.94	12.20	5.12
P	0.0001	0.0001	0.0001	0.3069	0.0001	0.0001	0.0009	0.0089
Interactions								
(omitted for brevity)								

by Year 3 the clipping treatment began to explain the differences in seedling survival ($P \geq 0.0089$).

Coast Live Oak

Emergence, responses to shade treatment and site—In Year 1, 1215 coast live oak seedlings, 84 percent of 1440 acorns planted, emerged in 4 months. Whereas shaded quarter-plots in North Field and Robinson Saddle were more favorable for seedling emergence than unshaded quarter-plots, an equal number of seedlings emerged on shaded and unshaded treatments at the more mesic Tire Flat. The driest site, Robinson Saddle, exhibited the greatest differences between shade treatments in seedling emergence. There, 90 percent of the acorns planted under shade produced seedlings whereas only 60 percent of the acorns emerged when not shaded. Robinson Saddle also exhibited earlier seedling dieback than North Field and Tire Flat. In Year 1, species was highly significant in explaining the differences in seedling emergence. A summary of coast live oak response by site and treatment is presented in *table 3*.

Table 3—Results of GLM of seedling height in April 1991, Year 3 (Type III model)

	Mean square	*F*	*P*
Main effects			
Site	264.24	39.59	0.0001
Spp	223.81	33.53	0.0001
Shade	339.42	50.84	0.0001
Clip	38.07	5.70	0.0041
Interaction (omitted for brevity)			
Error	6.67		

In Year 2, the population of coast live oak seedlings decreased dramatically, and most survivors were located under shade. Only 17 percent (202) of the original seedlings survived across all three sites, and only one of these grew on an unshaded quarter-plot. In Year 2, shade also became significant in explaining the differences in seedling survival.

By Year 3, 74 percent of the previous year's seedlings survived. However, this represented only 10 percent of the original seedling population established in 1989. Tire Flat, the most mesic site, had four times as many seedlings as North Field. No unshaded coast live oak seedlings survived the third year.

Responses to clipping treatments—Clipping treatments increased seedling mortality. In Year 2, 45 percent of unclipped seedlings survived compared to 16 percent of moderately clipped seedlings and 12 percent of heavily clipped seedlings. By Year 3, only 8 percent of clipped seedlings (both treatments) survived under shade versus 23 percent of unclipped seedlings. Although the hypotheses that clipping has different effects on seedling survival by species was rejected in Year 2, its significance increased in Year 3.

Blue Oak

Emergence, responses to shade treatment and site—By June 1989 in Year 1, 773 blue oak seedlings, or 54 percent of the 1440 acorns planted, emerged (*table 4*). On unshaded quarter-plots, 47 percent of the acorns produced seedlings, with maximum numbers appearing in March and April before dieback and/or dormancy ensued. On shaded quarter-plots, 60 percent of the acorns emerged; most seedlings emerged in April and June, about a month **after** peak numbers on unshaded quarter-plots.

Table 4—Blue oak seedling emergence and survival by shade and clipping treatments and site for April 1989, April 1990, and June 1991
*** no surviving seedlings*

Site	Blue oak unshaded				Blue oak shaded			
	Acorns	89 Seedlings	90 Seedlings	91 Seedlings	Acorns	89 Seedlings	90 Seedlings	91 Seedlings
Unclipped								
North Field	144	82	51	25	160	92	86	84
Robinson Saddle	160	45	**	**	112	65	3	4
Tire Flat	128	63	18	16	144	81	66	66
Subtotal	432	190	69	41	416	238	155	154
Moderate clipping								
North Field	48	20	11	11	48	29	31	24
Robinson Saddle	48	17	**	**	32	20	**	**
Tire Flat	32	28	11	8	64	26	20	22
Subtotal	128	65	22	19	144	75	51	46
Heavy clipping								
North Field	48	23	9	1	32	28	29	27
Robinson Saddle	32	**	**	**	96	60	2	1
Tire Flat	80	46	14	4	32	14	7	9
Subtotal	160	69	23	5	160	102	38	37
Total	720	324	114	65	720	415	244	237

In the spring of Year 2, the relationship between seedling survival and shade treatment was more pronounced. Shaded seedling populations remained relatively stable after Year 1. Shaded seedling survival was higher (58 percent), although some unshaded seedlings did survive (28 percent). In Year 2 species and shade were both significant in explaining the differences in seedling emergence (*table 2*). Almost all the shaded seedlings that emerged in Year 1 survived into Year 3, whereas the numbers of unshaded seedlings declined. Species and shade treatments continued to be significant in explaining differences in seedling survival (*table 5*).

Responses to clipping treatments—The interactions between survival and clipping treatment were most pronounced on the dry Robinson Saddle site where all unshaded blue oak seedlings died. There, in Year 3, only five shaded blue oak seedlings remained alive.

On unshaded North Field and Tire Flat quarter-plots, only moderately clipped blue oak seedlings survived. Unclipped and heavily clipped seedlings continued to die. Shaded blue oak seedlings in North Field appeared to be little affected by clipping. On Tire Flat, mortality of shaded seedlings increased in direct relation to clipping intensity the first 2 years but stabilized after Year 2.

Herbaceous Vegetation

Annual vegetation was measured on each cell, and shaded vegetation was taller (*table 6*). The average height of shaded annual vegetation averaged 24 versus 16 centimeters when unshaded, a pattern that persisted in Years 2 and 3. Annual vegetation was at least twice the height of the average coast live or blue oak seedling during the spring and early summer. There was no apparent difference in vegetation heights on control cells and those with either oak species.

Discussion and Conclusions

Rainfall at Hastings was below average for the year preceding the experiment and the 3 years reported here. Average precipitation for 1987-88 through 1990-91 was 37.3 cm. In contrast, the average precipitation from 1970-71 through 1986-87

*Table 5—Coast live oak seedling establishment and survival by shade and clipping treatments and site for April 1989, April 1990, and June 1991. ** no surviving seedlings*

Site	Coast live oak unshaded			Coast live oak shaded			
	Acorns	89 Seedlings	90 & 91 Seedlings	Acorns	89 Seedlings	90 Seedlings	91 Seedlings
Unclipped							
North Field	192	178	**	128	126	70	21
Robinson Saddle	112	48	**	144	131	1	1
Tire Flat	160	131	**	128	108	85	62
Subtotal	464	357		400	365	156	84
Moderate Clipping							
North Field	16	16	**	64	60	4	**
Robinson Saddle	80	35	**	48	41	**	**
Tire Flat	32	31	**	48	39	18	12
Subtotal	128	82		160	140	22	12
Heavy Clipping							
North Field	32	29	**	48	46	1	1
Robinson Saddle	48	18	**	48	44	**	**
Tire Flat	48	39	**	64	54	16	11
Subtotal	128	86		160	144	17	12
Total	720	525		720	649	195	108

was 57 cm. At the outset of the study, I decided not to irrigate the oak seedlings regardless of precipitation. My primary objective was to obtain results applicable to landscape and ecosystem levels of management; irrigation is not a practical technique at those scales.

Although patterns of growth and survival would probably have been different under wetter conditions, without a comparable study in wetter years, the extent to which results were influenced by drought is unknown.

Comparison of Species' Responses to Treatments

Coast live oak and blue oak seedlings were similar in their positive response to the shade treatment. The two species differed in the number of seedlings established, timing of emergence, percent survival, and the extent of the positive responses to shade and clipping treatments.

Coast live and blue oak seedlings responded favorably to shade and both experienced higher mortality without it. Both coast live and blue oak had more and taller seedlings when shaded. On the driest site, Robinson Saddle, neither

Table 6—Heights of herbaceous vegetation (cm) at the three sites.

	Apr-89	Apr-90		Jun-91	
	Annual vegetation*	Grasses	Forbs	Grasses	Forbs
Unshaded					
North Field	19.57	36.18	18.82	47.77	12.26
Robinson Saddle	10.11	20.13	20.24	21.01	9.98
Tire Flat	16.55	25.90	22.35	19.8	12.33
Mean height	15.41	27.40	20.47	29.53	11.52
Shaded					
North Field	30.14	50.40	22.56	56.27	9.51
Robinson Saddle	15.49	29.65	22.64	52.73	15.39
Tire Flat	22.86	40.13	25.96	28.89	13.45
Mean height	22.83	40.06	23.72	45.96	12.78

* In 1989 measurements were averaged between grasses and forbs, then separated in 1990 and 1991.

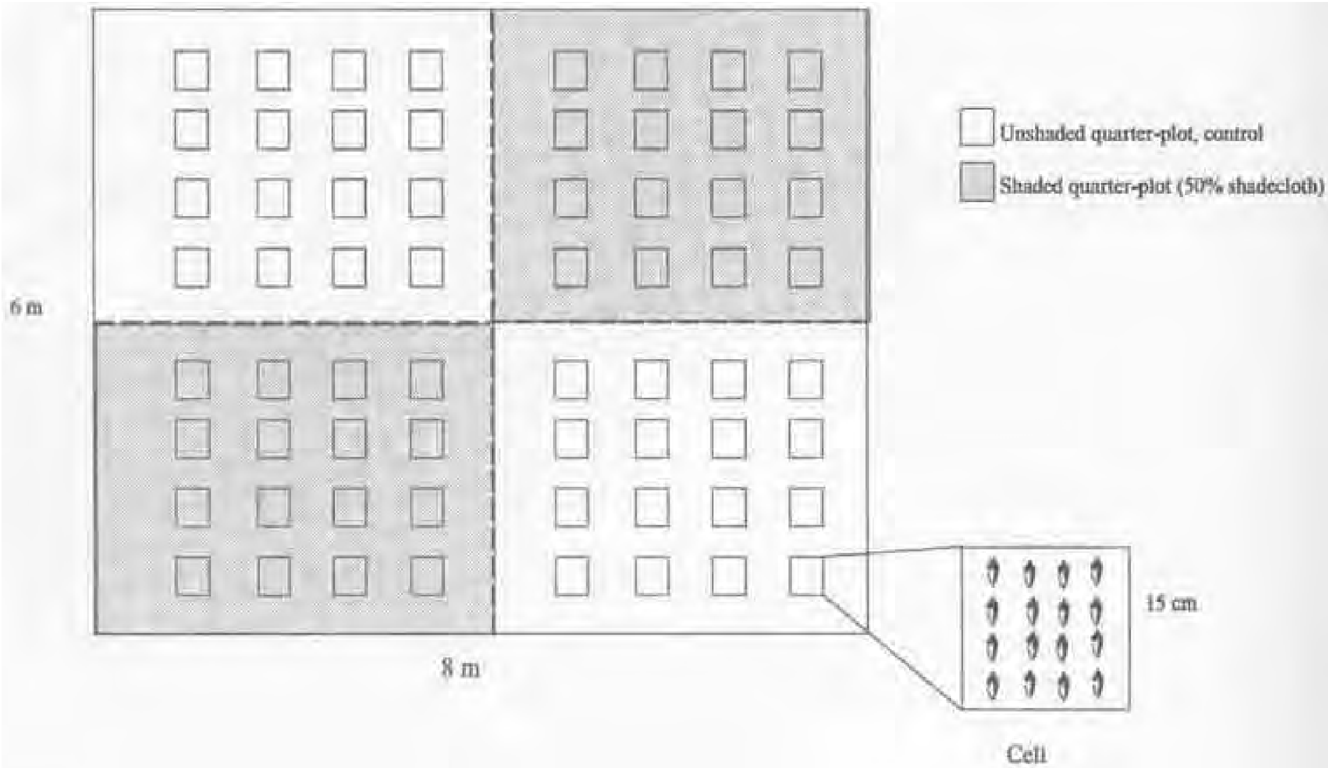

Figure 2—Planting diagram for one site containing four quarter-plots and sixteen cells per quarter plot.

species was able to survive without shade. Even then, only one coast live oak and five blue oak seedlings survived under shade after the first year. A comparison of species' survival in response to shade treatments is summarized in *figure 2*.

Seedling establishment—Despite identical handling, storage, planting, and allocation among sites and treatments, 84 percent of coast live oak acorns established seedlings in comparison with only 54 percent of blue oak acorns. At the time of planting, many blue oak acorns had emerging radicles (an uncontrolled variable), and this may have influenced establishment and survival. Since no laboratory germination tests were undertaken, it is not known if acorn viability was the same for both species. No other causes of acorn mortality or germination inhibition were determined.

Timing of shoot emergence—Blue oak exhibited delayed shoot emergence under some conditions. Although coast live oak is known to germinate late and blue oak is known to germinate early (Griffin 1971, Matsuda and McBride 1989), and blue oak hypocotyls are often visible emerging from the split tips of acorns still on the tree, the relative timing of shoot emergence has not been noted previously.

Seedling Survival and Mortality

Dieback and clipping treatments—Coast live oak experienced higher mortality than blue oak after dieback and clipping treatments. For coast live oak, seedling dieback often resulted in mortality (Griffin 1971, Jepson 1910, Snow 1973). A high proportion of seedling biomass is located in coast live oak's shoots and leaves, whereas more of blue oak's is located in roots (Matsuda and McBride 1989). When the aboveground portion of the coast live oak seedling dies or is removed, there are few reserves elsewhere for use in generating new shoots or leaves.

Despite the benefits of shade, by the final year, most of the surviving coast live oaks were those that had never been clipped. This lack of sprouting by seedling coast live oak contrasts with the documented vigorous sprouting of saplings and tree-sized individuals. Sprouting is so predictable in coast live oak stands that they have been successfully managed as coppices (Pillsbury and others 1987).

If the rate of seedling mortality observed in this study is indicative of rates in wild populations, larger size classes of coast live oak play a greater role in regeneration and recruitment. The poor ability of year-old coast live oak seedlings to sprout and recover from clipping has not previously been noted, though drought effects must be considered.

More blue oak seedlings sprouted and survived across the range of sites and treatments. A small number of unshaded seedlings, 15 percent of moderately clipped and 3 percent of heavily clipped, survived through Year 3, in contrast with no survival among clipped coast live oak seedlings.

Effects of the drought—Although the difference in rates of species' survival was not anticipated, a possible explanation emerges when drought effects are considered. Blue oak's ability to survive unseasonal leaf drop and stem dieback and its vigorous sprouting and adaptive morphology (including waxy leaf coating and substantial biomass allocation to roots) undoubtedly enhanced its survival during the longest drought of the century. Because more of the unshaded, moderately clipped blue oak seedlings survived, this suggests that seedlings may even have benefited from leaf removal on unshaded treatments. However, other explanations may be possible.

Acorns were planted at a density of 16 per square foot. The effects of seedling competition for moisture within cells and quarter-plots cannot be eliminated and may have affected seedling establishment, growth, survival, and responses to treatments. Although no measurements of soil or plant moisture were taken, it is reasonable to assume that competition for soil moisture occurred both among oaks and between oaks and annual species. Since the larger, longer, and fleshier tap roots of blue oak seedlings appear better able to obtain and store soil moisture than the thinner, shorter, and wiry roots of coast live oak seedlings, this may have afforded blue oak an advantage during the drought.

It is unlikely that seedling competition with annual herbaceous vegetation was as deleterious as exposure to full sun since shaded quarter-plots had taller annual vegetation and more and taller oak seedlings than unshaded quarter-plots.

Shade—For both species, shade was highly significant in explaining seedling height and survival ($P > 0.001$), despite the fact that coast live oak is considered shade-tolerant and blue oak is considered shade-intolerant (Sudworth 1908). The shade treatment may have ameliorated the effects of low soil moisture since shadecloth typically reduces soil temperatures which can result in higher soil moisture or reduced evapotranspiration. Perhaps the benefit of shadecloth on blue oak survival is more pronounced during drought years, although seems unlikely given the results of a greenhouse study using the same seed stock (Muick[4;] see also Muick 1995).

For both species, seedlings experienced massive dieback and/or mortality between June and August in 1989 and June and July, in 1990 on all unshaded quarter-plots and on two-thirds of the shaded quarter-plots. For example, on North Field, 143 coast live oak seedlings had green shoots or leaves in July and none were visible in August. On Robinson Saddle, 89 blue oak seedlings were alive in June, and only one seedling had leaves in July. For both species, critical sprouting periods were between March and April in 1990, and March and June in 1991.

The greatest mortality of coast live oak seedlings probably occurred in July of the first year when only about a fifth of the seedlings survived. Clipping treatments increased the mortality rates to such a degree that, by the final year, only one-third of the clipped seedlings survived in comparison with two-thirds of the unclipped seedlings.

4 Unpublished data on file at 2660 Gulf Drive, Fairfield, CA 94533.

The greatest mortality of blue oak was observed during the acorn to seedling stage when less than half of the blue oak acorns grew into seedlings. Blue oak seedlings usually emerged later and were shorter than coast live oak. However, once established, blue oak seedlings demonstrated remarkable persistence (perhaps enhanced by lower density) and became the dominant species on each quarter-plot and treatment by the end of the study.

Deer Browsing and Livestock Grazing

One study directly examining the effects of livestock grazing on blue oak seedling survival concluded that seasonal grazing was compatible with oak regeneration (George and Hall 1991). However, the study, which used container-grown seedlings, lasted only one year. The results of this study support findings of compatibility between blue oak seedling survival and grazing by demonstrating the ability of blue oak seedlings to sprout after clipping.

Findings and Recommendations

Coast Live Oak

Findings

Both shade and protection from herbivory enhanced coast live oak seedling establishment, growth, and survival.

The greatest mortality of coast live oak seedlings resulted from dieback, desiccation, and clipping treatments during the first year.

Unlike older seedlings, 1- to 3-year-old coast live oak seedlings are not vigorous sprouters and appear to be vulnerable to both desiccation and herbivory.

Recommendations

- For habitat restoration projects coast live oak seedlings should be shaded and protected from herbivory.
- For ranchers, land managers and researchers, established seedling populations should be protected from herbivory to facilitate growth and survival.

Blue Oak

Findings

The greatest mortality of blue oak was observed at the acorn-to-seedling stage when less than half of the blue oak acorns produced seedlings, even though many of the blue oak acorns planted had emerging radicles.

Shade and protection from herbivory were of positive benefit to blue oak seedling establishment, growth, and survival, but neither was completely limiting.

First-year blue oak seedlings sprouted new stems and leaves in response to clipping—simulated herbivory—more vigorously than first-year coast live oak seedlings.

Blue oak seedlings emerged later than coast live oak seedlings on most sites under both shaded and unshaded conditions.

Both unclipped and clipped blue oak seedlings were shorter than comparably treated coast live oak seedlings, indicating slower aboveground growth.

Once established, blue oak seedlings demonstrated remarkable persistence, both in relation to shade treatments and site.

Recommendations

- For habitat restoration projects blue oak seedlings should be shaded and protected from herbivory.
- For ranchers and researchers, established seedling populations should be protected from herbivory to facilitate growth and survival. This study supports the possibility that, under certain conditions, blue oaks may be able to tolerate some types of herbivory.

Both Coast Live and Blue Oak

First-year dieback is common to both species. Seedlings typically responded to precipitation within 2 weeks with new shoots, leaves, or basal sprouts. Based on these observations, I offer the following cautionary advice. In dry years and at dry locations, seedling surveys conducted after June are likely to under-represent populations of 1- to 3-year-old seedlings since leaves and stems may have died back and are not visible.

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References

Allen-Diaz, B.; Bartolome, James W. 1992. **Survival of *Quercus douglasii* (Fagaceae) seedlings under the influence of fire and grazing.** Madroño 39(1): 47-53.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas.** Resource Bulletin PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

George, Melvin R.; Hall, Lillian M. 1991. **Grazing compatible with blue oak regeneration**. Contract 8CA84964. Sacramento, CA: California Department of Forestry and Fire Protection; 32 p.

Griffin, James R. 1971. **Oak regeneration in the Upper Carmel Valley, California.** Ecology 52(5): 862-868.

Jepson, Willis L. 1910. **The silva of California**. Berkeley, CA: University of California Memoirs 2: 1-480.

Matsuda, Kozue; McBride, Joe R. 1989. **Germination characteristics of selected California oak species.** American Midland Naturalist 122(1): 66-76.

Muick, Pamela C. 1995. **Effects of shade and simulated herbivory on seedling emergence, survival and growth for two California oaks: Coast Live Oak (*Quercus agrifolia* Nee) and Blue Oak (*Quercus douglasii* Hook & Arn.).** Berkeley: University of California; 104 p. Ph.D. dissertation. Also available through UMI, Ann Arbor, MI. (1-800-521-0600).

Muick, Pamela C.; Bartolome, James W. 1987. **Oak regeneration in California: a report of the 1984-5 statewide survey.** Sacramento: California Department of Forestry; 100 p.

Pillsbury, Norman H.; DeLasaux, Michael J.; Plumb, Timothy R. 1987. **Coast live oak thinning study in the Central Coast of California.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources: November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 92-97.

Snow, Gerald Eldon. 1973. **Some factors controlling the establishment and distribution of *Quercus engelmannii* and *Quercus agrifolia* in certain Southern California woodlands.** Corvallis, OR: University of Oregon; 105 p.

Sudworth, George B. 1908. **Forest trees of the Pacific slope.** Washington, DC: U.S. Department of Agriculture; 441 p.

Stand-Level Status of Blue Oak Sapling Recruitment and Regeneration[1]

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Christiana Drake[3]

Abstract: *We assessed blue oak (*Quercus douglasii*) sapling recruitment and regeneration at 15 locations distributed throughout the range of blue oak. Overall, 15.3 percent of the 1500 plots surveyed contained blue oak saplings. Four locations had moderate numbers of saplings, and the remaining locations had few to no saplings. Seedling-origin saplings were far more common than stump-sprout saplings. Most saplings were shorter than the browse line (1.4 m). At 13 of the 15 locations, sapling recruitment is inadequate to offset recent losses in blue oak density and canopy cover.*

There is a widespread belief that blue oak (*Quercus douglasii* Hook. & Arn.) is not regenerating well over much of its range. Several researchers have shown that flushes of blue oak recruitment coincided with the influx of settlers into California in the period from the 1850's through the 1890's (McClaran and Bartolome 1989, Mensing 1992, Vankat and Major 1978), but that little recruitment has occurred in the latter half of this century. Data from two surveys (Bolsinger 1988, Muick and Bartolome 1987) have been interpreted to indicate that blue oak sapling populations are insufficient to maintain current stand densities. However, these surveys do not provide a clear picture of recent recruitment, because they include blue oaks up to 12.7 cm diameter at breast height (DBH) in the sapling size class. Oaks of diameters approaching 12.7 cm are functionally in the tree size class and could easily range from 30 to more than 90 years old (McClaran 1986).

We conducted a study to examine the distribution of small blue oak saplings at the stand level and assess net blue oak regeneration in these stands. We studied oaks in the transitional stage between seedling and small-diameter tree, during which height growth can be limited by browsing animals. No previous surveys of California oak woodlands have focused on oaks in this size class. We sampled many plots spread over a large area in each stand to determine how sapling recruitment and regeneration are distributed at the landscape level. Previous blue oak surveys are based on data collected from single plots or clusters of up to five subplots at widely separated locations (Bolsinger 1988, Muick and Bartolome 1987) and do not show how saplings are distributed at the stand or landscape level. Additional results of this project are presented elsewhere (Swiecki and others 1993, Swiecki and others, these proceedings).

Methods

We selected 15 locations, geographically stratified throughout the range of blue oak, for study (*table 1*). Candidate study locations had to have at least 61 ha of mostly contiguous woodland dominated by blue oak and a known history of grazing, fire, clearing, and other management practices for the 30 years before 1992. Clearing history had to be extended back 42 years because of uncertainty about when tree cutting occurred at one of the locations. We selected locations without prior knowledge of the amount of sapling recruitment present.

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Table 1—Blue oak seedling-origin recruitment by location

Location		County	Live seedling-origin saplings (pct of plots)	Dead seedling-origin saplings (pct of seedling-origin saplings)	S0 seedlings[1] present (pct of plots)
1	Wantrup Wildlife Sanctuary	Napa	31	2	33
2	Black Butte Lake	Glenn	0	—	0
3	Pinnacles National Monument	San Benito	40	8	30
4	Sierra Foothills Research & Extension Center	Yuba	39	21	23
5	Hopland Field Station	Mendocino	0	—	0
6	Sequoia National Park	Tulare	13	5	10
7	Dye Creek Preserve	Tehama	15	21	1
8	Pardee Reservoir	Amador	3	14	1
9	Pozo (private ranch)	San Luis Obispo	8	45	1
10	Lake San Antonio	Monterey	15	27	0
11	Hensley Lake (private ranch in part)	Madera	0	—	0
12	Henry W. Coe State Park	Santa Clara	0	—	1
13	Mt. Diablo State Park	Contra Costa	2	25	1
14	California Hot Springs (private ranch)	Tulare	5	40	0
15	Jamestown (private ranch)	Tuolumne	19	3	13

[1]Presapling seedlings—plants at least 25 cm tall with a basal diameter of less than 1 cm.

For each location, we used aerial photography, vegetation cover maps, and topographic maps to determine the portion of each study location that was dominated by blue oaks. We designated sample plot locations by superimposing a rectangular sampling grid over a map of the area, placing the origin of the grid at a randomly selected starting point. We oriented the grid along the four cardinal directions in a predetermined order and selected the first orientation that provided at least 100 plots in areas dominated by blue oak. If no orientation met these criteria, we selected a new random point and repeated the process.

The sampling grid included an area 1,520 m by 900 m (136.8 ha). Plots in the grid were arranged in 10 parallel transects spaced 100 m apart. Plot centers within transects were spaced 80 m apart. The grid provided 200 plot locations, at a density of one plot per 0.8 ha. We selected this plot spacing to minimize the possibility that recruitment in one plot would directly affect the likelihood of recruitment in an adjacent plot.

We surveyed 1,500 plots between July and early November of 1992. At each location, we started at the first accessible plot on the grid and surveyed plots sequentially along the transects, skipping ineligible or inaccessible plots, until we had collected data from 100 plots. Deviations from the target sample size occurred only at Pinnacles (99 plots) and Sierra (101 plots). Plots were considered ineligible for sampling if they were more than 80 m from the nearest blue oak. We navigated between plots using a compass and an optical rangefinder, and ground positions were verified through the use of topographic maps, aerial photos, and a Global Positioning System (GPS) receiver (Garmin GPS 100 SRVY) operating without differential correction.

Plots were circular, with a 16-m radius and an area of 0.08 ha. In each plot, we counted the number of dead and live blue oak saplings and classified each sapling by size class and origin class, either seedling-origin or sprout-origin. We inspected the base of each sapling and designated saplings as sprout-origin if they arose from stumps or topkilled trees with a basal diameter of at least 8 cm.

We also noted the position of each sapling relative to tree canopy (open, canopy edge, under canopy).

We defined saplings as oaks with a basal diameter (BD) of at least 1 cm and no stem with a DBH (diameter at 140-cm-height) of more than 3 cm. Sapling size classes we used were:

Sapling size class:	*Size range*
S1	BD≥1 cm, <140 cm tall
S2	BD≥1 cm, ≥140 cm tall, DBH <1 cm
S3	BD≥1 cm, DBH 1-3 cm

S1 saplings are subject to loss of the shoot leader because of browsing by large herbivores such as cattle and deer. S2 saplings have at least one shoot that is above the nominal browse line, but such shoots are still small enough to be damaged or destroyed by large herbivores. Saplings in the S3 size class are unlikely to have their height growth constrained by browsing animals and have a high probability of advancing to the tree size class.

We defined a pre-sapling seedling class (S0 seedlings) as plants that were at least 25 cm tall but had a basal diameter of less than 1 cm. Seedlings in this size class are generally visible throughout the year, whereas smaller seedlings are not (Swiecki and others 1990, 1993). In each plot, we rated the abundance of S0 seedlings using a count class scale: 0, 1 to 10, 11 to 20, 21 to 30, 31 to 40.

Within plots, we counted the number of live blue oak trees (DBH > 3 cm) and noted if the trees appeared to be of sprout origin. We also counted blue oak snags, downed trees, and stumps which appeared to have died in the 30 years before 1992. Bark presence and condition and degree of decay were used to determine the likely number of years since mortality, and site history records were used to verify field evaluations where possible. For plots in which blue oak mortality occurred, we noted the position of the dead tree relative to other trees in the plot and recorded whether the mortality caused a decrease in blue oak canopy cover and/or created a canopy gap. For example, if a blue oak tree overtopped by another tree species dies, blue oak canopy cover is reduced, but no canopy gap is created.

Results

Sapling Recruitment by Origin Class, Canopy Position, and Size Class

We observed seedling-origin saplings at 11 of the 15 study locations (*fig. 1*) and tallied 1,326 live and dead seedling-origin saplings in a total of 207 plots. Although Wantrup had the highest number of seedling-origin saplings, Pinnacles and Sierra had seedling-origin saplings in the greatest percentage of plots (*table 1*). Seedling-origin saplings were most likely to occur beyond overstory canopy or at the canopy edge at these three study locations (*table 2*).

We observed sprout-origin saplings at seven of the study locations (*fig. 2*) and tallied 182 live and dead sprout-origin saplings in a total of 33 plots. Nearly

Table 2—Percentages of live blue oak seedling-origin S1-S3 saplings in each position relative to the canopy for the three study locations with the most saplings

Location	Count of seedling-origin saplings	Position relative to canopy (pct of total)		
		Open	Edge of canopy	Under canopy
Wantrup	823	68	25	7
Pinnacles	162	69	24	7
Sierra	119	50	29	22

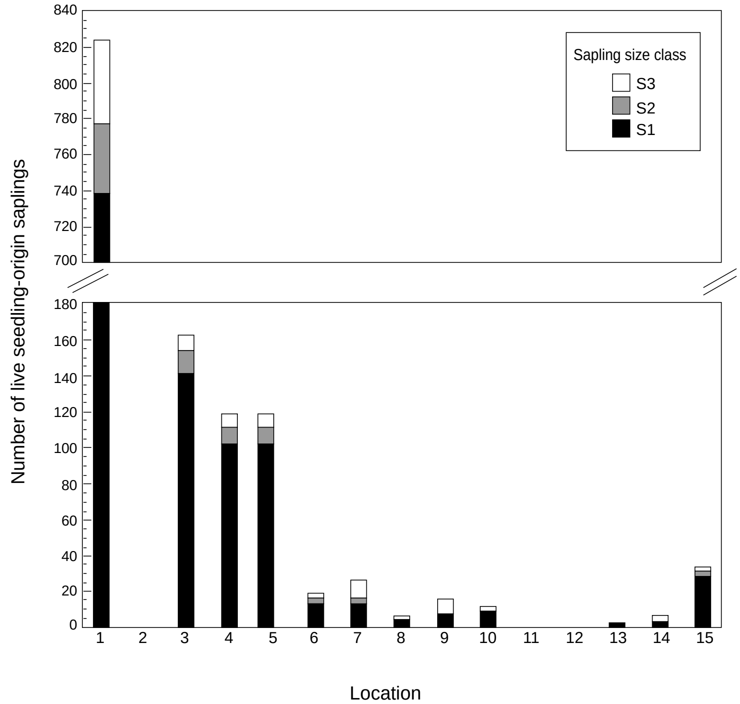

Figure 1—Total numbers of live blue oak seedling-origin saplings in plots at each location by size and origin class. Location numbers are as in table 1. S1, S2, and S3 sapling size classes are described in the Methods.

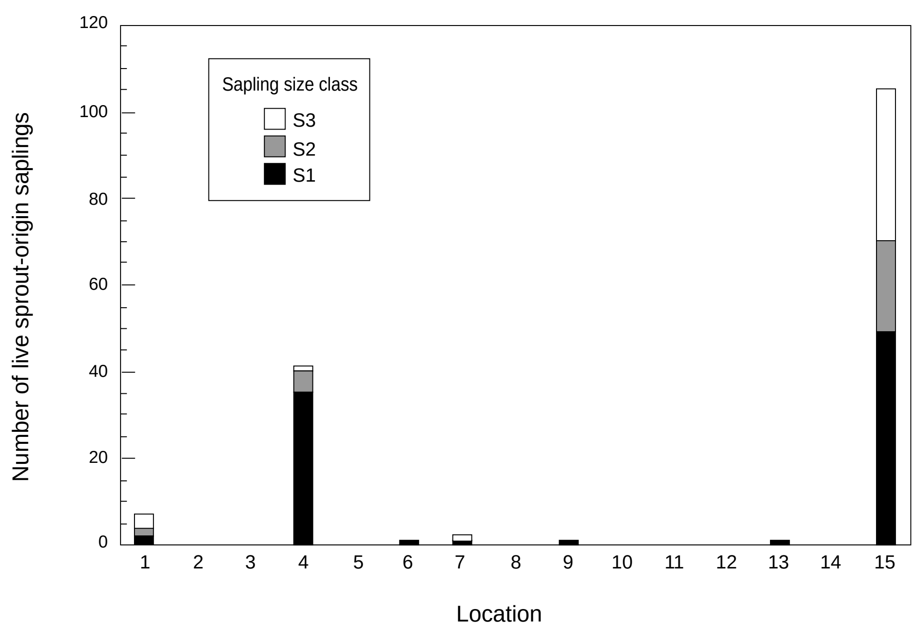

Figure 2—Total numbers of live blue oak sprout-origin saplings in plots at each location by size and origin class. Location numbers are as in table 1. S1, S2, and S3 sapling size classes are described in the Methods.

Table 3—Occurrence of sprout-origin blue oak saplings and trees by location

Location	Trees cut within the past 42 years (pct of plots)	Live sprout-origin saplings (pct of plots)	Dead sprout-origin saplings (pct of sprout saplings)	Live sprout-origin trees (pct of live trees)
Wantrup	63	3	53	1
Black Butte Lake	4	0	—	1
Pinnacles	6	0	—	3
Sierra	16	7	7	12
Hopland	3	0	—	4
Sequoia	0	1	0	2
Dye Creek	2	1	0	5
Pardee Reservoir	0	0	—	6
Pozo	5	1	0	3
Lake San Antonio	4	0	—	7
Hensley Lake	0	0	—	15
Henry Coe	5	0	—	2
Mt. Diablo	0	1	0	3
California Hot Springs	10	0	—	11
Jamestown	35	17	11	33

all of the sprout-origin saplings were located in the open, beyond tree canopy. Most locations had recent tree cutting in at least some plots, but sprout-origin saplings were generally scarce (*table 3, fig. 2)*. Only Sierra and Jamestown had sizable numbers of sprout-origin saplings, and only at Jamestown did sprout-origin saplings outnumber seedling-origin saplings (*figs. 1, 2*). Jamestown also had the largest percentage of sprout-origin trees. Some of the sprout saplings at Jamestown originated from stumps of these sprout-origin trees.

We found many stumps from both recent and older cuttings that had failed to produce sprouts. In at least one area, the lack of stump sprouting was associated with severe sapwood decay of stumps.

The majority of all saplings were in the S1 size class (*figs. 1, 2*). Most saplings in the S1 size class were much shorter than 140 cm tall. S1 saplings were usually highly branched and shrubby in habit. Most lacked a distinct leader, because of repeated browsing of the shoot tips. In contrast, virtually all S3 saplings and most S2 saplings had one or two dominant vertical shoots.

Among the 190 plots with live seedling-origin saplings, 43 percent had only a single seedling-origin sapling present, 22 percent had five or more, and 8 percent had 20 or more. The maximum number of live seedling-origin saplings per plot was 207. Among the 31 plots with live sprout-origin saplings, 42 percent had only a single sprout-origin sapling present, and 34 percent had five or more. Ten plots had both live seedling-origin and sprout-origin saplings.

We tallied at least one dead sapling at every location where live saplings were present. The percentages of dead saplings observed varied widely by location (*tables 1, 3*) and were not correlated with the total number of saplings per location. Overall, 6.9 percent of the seedling-origin saplings and 13.2 percent of the sprout-origin saplings we observed were dead. Of the plots with saplings, 6.9 percent contained only dead saplings. Many of the dead S1 saplings were in open positions and were stunted by repeated browsing. In contrast, mortality of the S2 and S3 size classes was often associated with overtopping by adjacent trees.

Seedlings in the S0 size class were found in at least one plot at 10 of the 15 study locations (*table 1*). The four locations with the highest incidence of S0 seedlings also had the greatest number of plots with seedling-origin saplings. In most cases, only a single S0 seedling was found in a given plot, but four plots at Wantrup had more than 20 S0 seedlings.

Tree Mortality and Net Regeneration

Overall, nearly 6 percent of the blue oak trees found within plots were judged to have died from causes other than cutting over the period 1962-1992 (*table 4*). Assuming that our estimated dates of mortality did not vary by more than ±10 years for the 30-year period, the overall rate of natural mortality observed for all locations was about 2 percent (1.5–3 percent) per decade, or between 1.6 and 3.2 deaths/ha/decade. Henry Coe had the highest estimated rate of mortality, between 2.7 and 5.4 percent per decade, or 3 to 6 deaths/ha/decade. The low percentage of dead trees at Hensley Lake is in part due to the prompt removal of dead trees by the landowner of the ranch portion of the location.

Table 4—Shrub frequency, blue oak density, and mortality by location

Location	Shrubs present (pct of plots)	Blue oak trees present (pct of plots)	Only blue oak trees in canopy (pct of plots)	Average blue oak density (live trees/ha)	Dead blue oak trees (pct)	Natural blue oak tree mortality (pct of plots)	All blue oak mortality[1] (pct of plots)
Wantrup	52	82	24	159	4	23	49
Black Butte Lake	2	85	85	98	4	23	25
Pinnacles	85	78	35	71	5	23	23
Sierra	83	88	6	161	2	18	24
Hopland	23	76	30	99	7	33	33
Sequoia	79	99	29	157	5	47	47
Dye Creek	16	86	80	113	6	37	38
Pardee Reservoir	12	80	58	38	10	26	26
Pozo	23	83	61	135	8	46	46
Lake San Antonio	77	86	35	101	5	28	28
Hensley Lake	3	66	65	16	3	4	4
Henry Coe	80	81	4	113	11	42	42
Mt. Diablo	44	82	35	150	6	41	41
California Hot Springs	44	94	31	128	8	50	50
Jamestown	50	67	19	59	3	7	32

[1] Includes both natural mortality and stumps originating from trees cut between 1950 and 1992.

As an estimate of net regeneration at each location, we compared blue oak sapling recruitment with total tree mortality within each plot. We made the simplifying assumptions that every live sapling represents a potential tree, and to maintain stand density, one live sapling was needed to offset each tree that had died within the past 30 years or had been cut within the past 30 to 42 years. On the basis of these assumptions, net losses in tree density due to unreplaced tree mortality occurred in more than 20 percent of the plots at each of 12 locations (*fig. 3*). Only at Pinnacles and Sierra did plots with net gains in density outnumber plots with net losses. The majority of plots at most locations show no net change in calculated blue oak stand densities.

We performed a similar calculation to compare the number of plots at each location that had gained or lost blue oak canopy cover. We assumed that saplings in the edge and open positions, but not those under canopy, represented a potential gain in canopy cover. The results of this comparison are very similar to those shown in *figure 3*. Almost all plots with increases in blue oak density also showed potential increases in blue oak canopy cover. In addition, for most locations the proportion of plots with decreased blue oak density was nearly equal to the proportion with decreased canopy cover. Only Pinnacles and Sierra had more plots with potential net gains in blue oak canopy than plots with net losses in blue oak canopy cover.

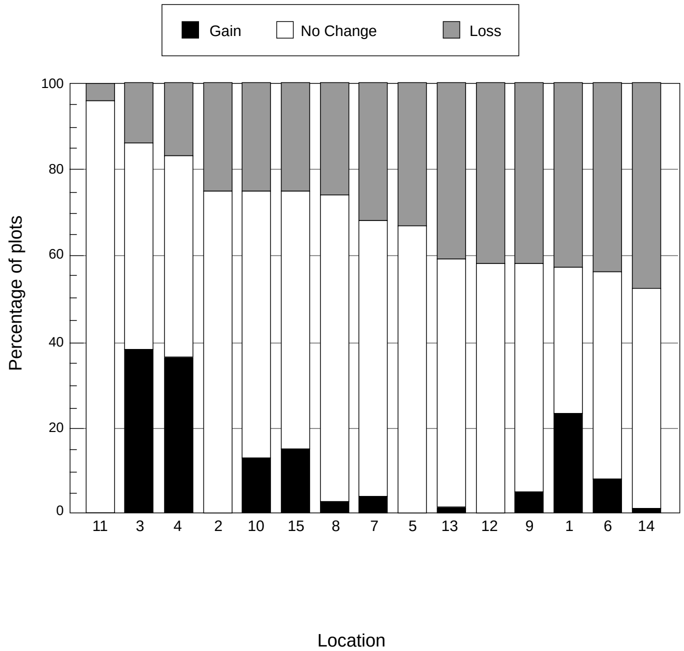

Figure 3—Calculated net changes in blue oak density by plot at each location. Location numbers are as in table 1.

Stand Vegetation Characteristics

Blue oak trees occurred in at least 66 percent of the plots at each location. Stand purity and density (*table 4*) varied widely between locations. Based on the distribution of stump sprout trees, clearings, and other vegetation characteristics, it appeared that most if not all locations had been at least partially cleared or cut within the past 150 years. Other than blue oak, the most common tree canopy species in plots were *Q. agrifolia* Née, *Q. wislizenii* A.DC., *Q. lobata* Née, *Pinus sabiniana* Douglas, and *Aesculus californica* (Spach) Nutt. We observed that regeneration by other tree species varied widely by location and generally paralleled blue oak regeneration.

The majority of all sampled plots (56 percent) lacked any shrub cover, but the frequency of plots with shrubs varied widely between locations (*table 4*). Estimated shrub cover was less than 2.5 percent in over 49 percent of the plots that contained shrubs. The most commonly occurring shrubs within plots were *Arctostaphylos* spp., *Ceanothus cuneatus* var *cuneatus* (Hook.) Nutt., *Heteromeles arbutifolia* (Lindley) Roemer, *Rhamnus ilicifolia* Kellogg, and *Toxicodendron diversilobum* (Torrey & A. Gray) E. Greene. Regeneration of shrub species occurred mainly in the same locations with regeneration by canopy species.

In most locations, the plot herbaceous layer was dominated by non-native annual grasses. The frequency of plots containing native bunchgrasses, such as *Elymus glaucus* Buckley, *Festuca californica* Vasey, or *Nassella pulchra* (A. Hitchc.) Barkworth, ranged from 1 to 89 percent. Herbaceous cover was typically high and was rated as greater than 80 percent in 64 percent of all plots. However, only 4 percent of all plots had bunchgrass cover greater than 2.5 percent.

Discussion

There were large differences in sapling recruitment between the 15 locations, both in terms of total sapling counts (*figs. 1, 2*) and the proportions of plots with saplings (*tables 1, 3*). Moderate sapling populations were found at only four locations (Wantrup, Pinnacles, Sierra, and Jamestown). An equal number of locations had absolutely no saplings within the study area (*figs. 1, 2*). The study areas at Black Butte Lake, Pardee Reservoir, Hensley Lake, and the grazed portions of Hopland were notable for their virtually complete lack of regeneration by any woody species.

Our analysis of factors associated with sapling recruitment is presented in an accompanying paper (Swiecki and others, these proceedings). However, we could readily see that blue oak saplings, saplings of other canopy species, and understory shrubs were all sparse or absent from areas subjected to heavy browsing pressure from livestock. Most of the saplings we observed were in the S1 size class (*figs. 1, 2*), and chronic browsing was clearly limiting the height growth of most of these saplings. Griffin (1971) noted that browsing is a major constraint to oak sapling growth, and several other studies have found a preponderance of blue oak saplings shorter than the browse line (Borchert and others 1993, Harvey 1989, Muick and Bartolome 1987, White 1966).

Blue oak saplings stunted by browsing may be many decades old (Harvey 1989, McClaran 1986, Mensing 1992). Saplings in this small size class are susceptible to being severely damaged or killed by rodents, fires, or other agents that would not seriously affect larger saplings or trees. Chronic heavy browsing therefore contributes indirectly, if not directly, to mortality of S1 saplings.

There were relatively high proportions of dead saplings at a few locations (*tables 1, 3*), but actual sapling mortality rates cannot be determined from these counts. Dead saplings we observed almost certainly died within the past 10 to 15 years, as it is unlikely that they would persist longer than this. However, destructive agents such as fire or livestock would greatly shorten the period that dead saplings persist, leading to differences in counts of dead saplings between locations which are unrelated to sapling mortality.

We (*table 2*) and others (Muick and Bartolome 1987) have observed that blue oak saplings are more likely to occur in the open than under tree canopy. In contrast, small blue oak seedlings are most likely to be found under blue oak canopy (Muick and Bartolome 1987, Swiecki and others 1990, White 1966). We believe that this shift in distribution results when the seedling advance regeneration beneath the canopy is released through overstory mortality or removal (Swiecki 1990; Swiecki and others 1990, these proceedings). Because adequate populations of seedling advance regeneration are a necessary prerequisite for sapling recruitment in canopy gaps, destruction of small seedlings by livestock (Bernhardt and Swiecki, these proceedings) probably also contributes to the negative effects of grazing on sapling recruitment.

McCreary and others (1991) have demonstrated that blue oak stump sprouting success can vary widely between locations cut in a single year. Our data on stumps and stump sprouts provides further evidence that the success rate for sprout sapling establishment can vary widely between locations and between different years at a given location. From a management perspective, it would be very risky to rely exclusively on blue-oak stump sprouts to restock cut stands. Judging from the distribution of stump sprout trees, clearings, and other vegetation characteristics, we concluded that most if not all of the sampled stands had been at least partially cleared or cut within the past 150 years. However, sprout-origin blue oak trees were in the minority at all study locations (*table 3*).

Our estimates of natural mortality rates for blue oak trees are similar to those reported for other oaks in California (Brown and Davis 1991, Swiecki and others 1990). Our calculated mortality rates are based on subjective evaluations of whether trees had died within the past 30 years, and such estimates may either overestimate or underestimate the number of years since tree death. However, because some trees that died after 1962 were probably removed or destroyed before our study, our calculated mortality rates probably underestimate actual mortality, in at least some locations.

By combining estimates of tree mortality and sapling recruitment, we can assess the adequacy of regeneration within each sampled stand. Our analysis indicates that sapling recruitment at 13 of 15 locations (87 percent) is inadequate to offset recent losses in blue oak density and canopy cover caused by natural mortality and tree cutting (*fig. 3*). Stand-level regeneration is probably even poorer than these figures indicate. Our analysis probably overestimates actual rates of regeneration because it includes the assumption that all live saplings will become trees. We believe that the stands we sampled represent a typical range of conditions in blue oak woodlands, and therefore our results indicate that poor regeneration rates may exist over large portions of the blue oak range. If such poor rates of regeneration persist over an extended period, the stand density and extent of blue oak woodlands are likely to decline over large portions of the existing range.

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References

Bernhardt, Elizabeth A.; Swiecki, Tedmund J. 1997. **Effects of cultural inputs on survival and growth of direct seeded and naturally occurring valley oak seedlings on hardwood rangeland**. [These proceedings]

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas. Resource Bull**. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Borchert, Mark I.; Cunha, Nancy D.; Krosse, Patricia C.; Lawrence, Marcee L. 1993. **Blue oak plant communities of southern San Luis Obispo and northern Santa Barbara counties**. Gen. Tech. Rep. PSW-GTR-139. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 49 p.

Brown, Rodney W.; Davis, Frank W. 1991. **Historical mortality of valley oak (*Quercus lobata*, Née) in the Santa Ynez Valley, Santa Barbara County, 1938-1989**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 202-207.

Griffin, Jim R. 1971. **Oak regeneration in the upper Carmel Valley, California**. Ecology 52: 862-868.

Harvey, Larry E. 1989. **Spatial and temporal dynamics of a blue oak woodland**. Santa Barbara: University of California; 170 p. Ph.D. dissertation.

McClaran, Mitchel P. 1986. **Age structure of *Quercus douglasii* in relation to livestock grazing and fire**. Berkeley: University of California; 119 p. Ph.D. dissertation.

McClaran, Mitchel P.; Bartolome, James W. 1989. **Fire-related recruitment in stagnant *Quercus douglasii* populations**. Canadian Journal of Forest Research 19: 580-585.

McCreary, Douglas D.; Tietje, William D.; Schmidt, Robert H.; Gross, Rob; Weitkamp, William H.; Willoughby, Bob L.; Bell, Fremont L. 1991. **Stump sprouting of blue oaks in California**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 64-69.

Mensing, Scott A. 1992. **The impact of European settlement on blue oak (*Quercus douglasii*) regeneration and recruitment in the Tehachapi Mountains, California**. Madroño 39(1): 36-46.

Muick, Pamela C.; Bartolome, James W. 1987. **An assessment of natural regeneration of oaks in California**. Prepared for: California Department of Forestry, Sacramento, CA. 116 p.

Swiecki, Tedmund J. 1990. **Oak diseases and insects: a delicate balance**. Fremontia 18: 58-63.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1990. **Impacts of diseases and arthropods on California's rangeland oaks**. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA. 94 p. plus appendix.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Drake, Christiana. 1993. **Factors affecting blue oak sapling recruitment and regeneration**. Prepared for: California Department of Forestry and Fire Protection, Strategic Planning Program, Sacramento, CA. 132 p.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Drake, Christiana. 1997. **Factors affecting blue oak sapling recruitment**. [These proceedings].

Vankat, John L.; Major, Jack. 1978. **Vegetation changes in Sequoia National Park, California**. Journal of Biogeography 5: 377-402.

White, Keith L. 1966. **Old-field succession on Hastings Reservation, California**. Ecology 47: 865-868.

Factors Affecting Blue Oak Sapling Recruitment[1]

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Abstract: We used logistic regression to identify environmental and management history factors associated with blue oak (Quercus douglasii*) sapling recruitment. Recent canopy gaps caused by natural mortality or clearing were positively associated with sapling recruitment. Plots with very high or low levels of tree canopy cover were less likely to have saplings than those with intermediate canopy cover levels. Across all locations, and within grazed locations, browsing intensity was negatively associated with sapling presence. Other factors significantly correlated with sapling recruitment include shrub presence, insolation, soil available water-holding capacity, fire, plot altitude, precipitation, and potential evapotranspiration.*

Different interpretations have been offered to explain the apparent flushes of blue oak recruitment that date from the 1850's through the 1890's (McClaran and Bartolome 1989, Mensing 1992, Vankat and Major 1978). Many interrelated ecosystem perturbations date to this period. Settlers and their successors introduced livestock, cut trees and cleared shrubs over large areas, altered fire frequency, hunted deer, and exterminated vertebrate predators. These and other actions also affected understory species composition, rodent populations, soil properties, and other factors. Although many of these factors have the potential to affect blue oak regeneration, the relative importance of these or other factors on current regeneration patterns cannot be determined from fragmentary historical data.

We have shown that the frequency of small blue oak (*Quercus douglasii* Hook. & Arn.) saplings (>1 cm basal diameter, ≤3 cm diameter at breast height [DBH]) varies widely between different blue oak stands (Swiecki and others, these proceedings). Although such saplings tend to be scarce within a stand, their densities within a stand are highly variable (Swiecki and others 1993). In this study, we investigated whether current differences in sapling recruitment within and between blue oak stands are related to site environmental and/or history factors. Because blue oaks typically require at least 10 to 30 years to make the transition from seedling to young tree (McClaran and Bartolome 1989), our study included only locations for which we could obtain 30 years of site history.

Methods

Plot Data

We collected data from 1500 plots, each 0.08 ha, distributed across 15 locations (*table 1*, Swiecki and others, these proceedings). We sampled 100 plots per location except at Pinnacles (99 plots) and Sierra (101 plots). We defined saplings as oaks with a basal diameter of at least 1 cm, and a dbh no greater than 3 cm. Oaks that have a basal diameter less than 1 cm but are greater than 25 cm tall are designated as S0 seedlings. We counted the number of all live and dead saplings within plots and used count classes (0, 1-10, 11-20, etc.) to estimate S0 seedling numbers.

Within each plot we identified canopy and shrub species present and visually estimated total canopy cover, blue oak canopy cover, and the proportion of the plot covered by shrubs, bare ground, herbaceous species, and native bunchgrasses. We rated the severity of current season and chronic browsing and

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Table 1—Study location management history, climate characteristics, and blue oak recruitment

Location	County	Years grazed 1962-1992[1]	Pct of plots burned 1962-1992	Average Insol12[2] (MJ/m^2)	ETdeficit[3] (cm)	Pct of plots with SoilAWC[4] ≥10 cm	Pct of plots with LocAllrecr[5] =1
Wantrup Wildlife Sanctuary	Napa	7	0	6.99	34.1	65	38
Black Butte Lake	Glenn	24, 14	0	7.51	75.3	52	0
Pinnacles National Monument	San Benito	0	78	9.40	78.1	0	52
Sierra Foothills Research & Extension Center	Yuba	30, 30, 10	0	7.77	58.5	64	52
Hopland Field Station	Mendocino	30, 0	5[6]	10.22	10.1	47	0
Sequoia National Park	Tulare	30, 10	25	10.71	57.5	8	22
Dye Creek Preserve	Tehama	30	31	7.62	72.8	9	20
Pardee Reservoir	Amador	30, 0	7	8.75	70.9	14	3
Pozo	San Luis Obispo	30	0	10.70	71.4	84	15
Lake San Antonio	Monterey	27, 3	0	9.82	83.3	83	15
Hensley Lake	Madera	30, 14	0	9.53	102.7	60	0
Henry W. Coe State Park	Santa Clara	0	34	8.60	53.2	71	1
Mt. Diablo State Park	Contra Costa	28, 23	16	7.58	73.3	51	4
California Hot Springs	Tulare	30	5	12.36	50.2	56	7
Jamestown	Tuolumne	28	11	8.52	43.3	78	41

[1]For locations with multiple grazing histories, years for each separate grazing history are listed.
[2]Average of calculated plot December average-day insolation.
[3]Difference between annual reference evapotranspiration (ETo) and average annual precipitation for 1962-1992.
[4]Estimated soil available water-holding capacity in the rootzone.
[5]Binary outcome variable indicating whether or not any live or dead S1-S3 sapling or S0 seedling is in plot.
[6]An additional 23 percent of the plots had burned in 1959.

other factors for each plot (Swiecki and others 1993). We classified plot topographic position using a scale adapted from the USDA Forest Service (Swiecki and others 1990).

We measured plot slope with a clinometer and aspect with a compass. We estimated individual plot elevations from U.S. Geological Survey topographic maps. Plot slope, aspect, altitude, and latitude data were used to calculate clear day potential solar radiation (insolation) for each plot (Rumsey 1993). We obtained information on soil types and depths from published USDA Soil Conservation Service soil surveys and unpublished soil survey data. We used plot observations on apparent soil depth, texture, and rockiness in conjunction with soil survey data to calculate estimates of total soil available water-holding capacity (AWC) for each plot (Swiecki and others 1993).

We obtained management history on grazing practices and tree cutting for the years 1962 through 1992 for each study location from current and former landowners and land managers. It was necessary to extend our tree-cutting history interval back to 1950 because of uncertainty about the date of some tree harvesting at Wantrup. We compiled fire history from 1962 or earlier from historical fire maps. For each location, we calculated reference evapotranspiration (ETo) from published data (Pruitt and others 1987) and compiled rainfall data from the nearest weather station.

Statistical Analyses

We constructed many outcome variables from plot sapling data and more than 100 potential predictor variables from plot environmental and history data (Swiecki and others 1993). We used a variety of data screening techniques to look for correlations between predictor variables before selecting a subset of variables for logistic regression analysis. We used logistic models for binary outcome variables and poisson models for outcome variables that are derived from counts. We developed within-location models, which describe the probability of recruitment at the plot level, for those locations which had sufficient levels of recruitment to allow for model fitting. We also developed all-location models that describe the likelihood of recruitment at the location level, using variables constructed from aggregate data for each location.

Results

Overall location management history details and climate characteristics of the study locations are shown in *table 1*. Stand characteristics and sapling size classes are reported in Swiecki and others (these proceedings), and detailed descriptions of each study location are reported by Swiecki and others (1993).

Within-Location Statistical Models

We constructed logistic regression models for several outcome variables, but only models for the following two variables are discussed here:

Variable Name:	*Model Type*	*Description*
Allrecr	Logistic	Any live or dead S1-S3 sapling or S0 seedling present in plot.
S123seed	Poisson	Count of live and dead seedling-origin saplings in plot.

The models are presented in *table 2*. Models for the S123seed outcome could be developed only for Wantrup, Pinnacles, Sierra, and Jamestown (*table 2*). These four locations, plus Dye Creek and Sequoia, had enough plots with recruitment to allow model building when the more inclusive outcome variable Allrecr was used (*table 2*). Comparisons between predicted and observed recruitment for this outcome are shown in *table 3*. The model for Sequoia was the least successful for predicting plots with recruitment using the P(Allrecr)≥0.5 criterion (*table 3*).

The Poisson models, based on sapling counts, generally had more significant predictor variables than the corresponding logistic models, which are based on the binary outcome variable Allrecr. The logistic and Poisson models may also be unlike because of differences between the outcome variables. For example, Pinnacles had 12 plots with only S0 saplings, which contribute to the differences between the Allrecr and S123seed models. Plots containing only sprout-origin saplings contribute to differences between the Allrecr and S123seed models at Sierra and Jamestown.

For binary predictor variables, an odds ratio (logistic models) or rate ratio (Poisson models) greater than 1 indicates that the outcome is more likely in the presence of a factor than in its absence. For example, the odds ratio of 15 for the binary variable Cut42yr in the Allrecr model for Wantrup indicates that plots cut within the past 42 years were 15 times more likely than uncut plots to have any live or dead S0-S3 recruitment. For categorical variables, model parameters indicate whether an outcome is more or less likely at the lowest level of the factor compared to each other level of the factor. For continuous variables, parameters indicate the incremental change in probability per unit increase (e.g., per meter of altitude). The odds ratio for n meters of elevational change equals the per-meter odds ratio raised to the power n.

Tree Canopy and Canopy Gaps

Total plot canopy cover was a significant predictor of sapling presence at three locations (*table 2*). Two different recodings of the canopy cover variable are used in the final models because the study areas differed markedly in their overall levels of canopy cover. Plots with very high or very low levels of canopy cover were generally less likely to have saplings than plots with intermediate levels of canopy cover (20 to 80 percent).

Some of the plots at Wantrup, Sierra, Dye Creek, and Jamestown fell in areas where trees had been cut for firewood after 1950. Variables indicating that a

Table 2—Predictor variables included in final within-location models

Predictor	Definition	Parameters[1] (95 pct confidence intervals) for outcome variables in final model for location indicated	
		Allrecr[2]	S123seed[3]
Altitude	Plot altitude (m)	Wantrup: 0.981*** (0.971-0.991)	Wantrup: 0.977*** (0.973-0.980) Sierra: 0.987*** (0.983-0.992)
ChrVertBrA	Chronic vertebrate browsing intensity in plot is rated as high	Sequoia: 0.156*** (0.052-0.468) Dye Creek: 0.165*** (0.055-0.494)	
CumGraze	Cumulative grazing score: sum of (months grazed) × (relative stocking) × (season factor) for the period 1962-1992. Relative stocking ranges from 0 (none) to 3 (high). Season factor is 1 for winter and 2 for summer or year-round.	Sierra: 0.991***(0.985-0.997)	
CurrVertBrA	Current vertebrate browsing intensity in plot is rated as high.	Wantrup: 3.22* (0.860-12.0) Jamestown: 0.234** (0.071-0767)	Pinnacles: 1.56*** (1.13-2.14) Jamestown: 0.340**(0.123-0.939)
Cut42yr	Tree cutting has occured in the plot between 1950 and 1992.	Wantrup: 15.0*** (2.98-76.5)	Wantrup: 46.7*** (17.4-175)
GaporCut42	Tree cutting has occurred in the plot between 1950 and 1992, or a canopy gap due to other factors has developed in the plot between 1962 and 1992 (estimated).	Sierra: 6.13*** (1.99-18.9) Jamestown: 3.06* (1.02-9.19)	Pinnacles: 1.17***(1.24-2.36) Jamestown: 1.67 (0.762-3.67)
Insol12	Calculated total daily insolation (MJ/m^2) for plot on the average day in December (December 10).	Sierra: 1.27* (0.972-1.66)	Pinnacles: 0.953** (0.912-0.997)
OthCanSpp	Number of tree canopy species other than blue oak in plot.	Sierra: 2.85*** (1.34-6.09)	Wantrup: 0.455*** (0.398-0.521) Sierra: 1.16 (0925-1.45)
Rebum30	Plot has burned at least two times between 1962 and 1992.	Pinnacles: 0.436 (0.157-1.21)	Pinnacles: 0.337*** (0.208-0.586)
ShrubCoverA	Plot shrub cover estimated is >2.5 pct.		Jamestown: 3.73***(1.46-9.52)
ShrubPresent	Shrubs are present within the plot.	Jamestown: 6.45***(1.91-21.8)	Wantrup: 3.23***(2.79-3.75) Pinnacles: 1.49*(.957-2.32) Sierra: 1.85*(0.904-3.79)
SmallTrees	Small-diameter trees (3 to 13 cm DBH)	Sierra: 9.45***(2.48-36.1)	Sierra: 2.19***(1.40-3.43)
SoilAWC	Estimated total available water-holding capacity within the rootzone (cm)	Pinnacles: 1.37**(1.03-1.83) Dye Creek: 1.24**(1.02-1.51)	Wantrup: 0.976***(0.960-0.993) Pinnacles: 1.45***(1.07-1.23)
StandEdgeA	One or more adjacent plots on the sampling grid falls outside of the blue oak stand.	Pinnacles: 0.284**(0.094-0.852)	
TopoPosA	Plot topographic position recoded to 3 classes: (a) hilltop, (b) upper 1/3 hillside, (c) lower 2/3 hillside and low flats		Wantrup: a-b 0.370***(0.183-0.748) a-c 0.965 (0.674-1.38) Pinnacles: a-b 3.27*** (1.83-5.85) a-c 1.35 (0.759-2.41)
TotCanopyA	Tree canopy cover recoded to three classes: (a) ≤2.5 pct, (b) >2.5 pct to 20 pct, (c) >20 pct.	Pinnacles: a-b 4.23*** (1.16-15.5) a-c 5.76*** (1.52-21.8)	
TotCanopyB	Tree canopy cover recoded to three classes: (a) ≤20 pct, (b) >20 pct to 80 pct, (c) >80 pct.	Sierra: a-b 0.349 (0.074-2.10)	Jamestown: a-b 5.50***(1.85-16.3)

[1]Model parameters are odds ratios for Allrecr and rate ratios for S123seed. Parameter values greater than 1 indicate a positive association between the predictor variable and the outcome; values less than 1 signify a negative association. Significance level is denoted by asterisks: * $P \geq 0.10$, ** $P \geq 0.05$, ***$P \geq 0.01$.

[2]Any live or dead sapling or S0 seedling in plot

[3]Count of live + dead seedling-origin saplings in plot.

Table 3–Comparison of the observed Allrecr outcome with the Allrecr outcome predicted by final logistic regression models[1]

Location	Percent of plots correctly classified by model		
	Plots with recruitment	Plots without recruitment	All plots
Wantrup	87	82	84
Pinnacles National Monument	73	64	69
Sierra Foothills Research & Extension Center	75	71	73
Sequoia National Park	0[2]	100	78
Dye Creek	20	92	82
Jamestown	83	80	81

[1]We considered that a positive Allrecr outcome was predicted if the calculated probability of Allrecr ≥ 0.5.

[2]The maximum probability of the Allrecr outcome calculated from the model for this location was 0.39.

canopy gap had developed in the plot within the past 42 years (Cut42yr, GaporCut42) were fairly strong predictors of recruitment at five of the six locations. Prediction of sapling presence by the single variable model for GaporCut42 at Dye Creek (data not shown) was nearly equivalent to that of the final multivariate model (*table 2*).

Grazing and Browsing

Past and current grazing patterns varied between and sometimes within locations (*table 1*). Most locations had been continuously or intermittently grazed from around 1900 or earlier. Pinnacles was unique in that it has not been grazed for at least 62 years. Ten locations had some plots in areas that had been out of grazing for periods ranging from 3 to 35 years. Most locations had been grazed primarily by beef cattle. Hopland has been grazed exclusively by sheep since the 1930's or earlier. Black Butte Lake was grazed primarily by sheep until the 1950's and subsequently by cattle. The study area at Sequoia has been grazed only by horses and mules since the 1940's.

Despite the diversity of grazing histories represented within the study locations, only Sierra had both moderate levels of recruitment and clear differential grazing regimes. At this location, recruitment was more likely to occur in plots with lower cumulative grazing scores (CumGraze predictor variable) (*table 2*). The logistic model shows that saplings were eight to nine times more likely to occur in plots in the nongrazed portion of the study area than in plots in the currently grazed areas.

For other locations, we used ratings of vertebrate browsing damage instead of CumGraze to examine the effects of livestock and deer browsing on the recruitment outcomes. Browsing severity variables were highly collinear with Cumgraze and therefore could not be included in the models for Sierra. Livestock were present at Sequoia, Dye Creek, and Jamestown, and at these locations, plots with high levels of vertebrate browsing damage were less likely to have sapling recruitment (*table 2*). At Wantrup and Pinnacles, which have not been grazed for a number of years, browsing variables were either nonsignificant or showed a positive association with sapling recruitment.

Fire

No fires have occurred in the past 30 years at Wantrup or Sierra, and too few plots have burned at Jamestown to allow consideration of fire in the regression models. Occurrence of a single fire within the past 30 years was not significantly related to the Allrecr outcome for Sequoia or Dye Creek.

At Pinnacles, the occurrence of multiple fires in the past 30 years (Reburn30) was negatively associated with both outcome variables (*table 2*), although the significance level of this variable dropped to P=0.111 in the Allrecr final model. Plots that had burned once between 1962 and 1992 were the most likely to have saplings and had the greatest sapling densities:

	Live S1-S3 saplings	
Number of fires 1962-1992[1]:	*Percent of plots*	*Average number per plot*
0	24	0.76
1	55	2.84
2	27	0.62
3	38	0.69

[1] All fires in this interval occurred between 1977 and 1982.

At Pinnacles, the 60 plots that either burned once or did not burn between 1962 and 1992 had 13 saplings in the S2 and S3 size classes. In contrast, the 39 plots that burned two or more times had only one sapling (an S3) larger than the S1 size class.

Vegetation

Final models for four locations showed positive associations between shrub presence or cover and recruitment (*table 2*). The significance levels of variables related to shrub cover were generally much lower in multivariate models than in single variable models, presumably because of correlations between shrub variables and other predictor variables in the models. Although blue oak saplings tended to occur in plots with shrubs, they were seldom found growing through or under shrubs.

At Sierra, the odds of having sapling recruitment within a plot increased with increasing numbers of canopy species (*table 2*). The two most common canopy species other than blue oak at this location were *Q. wislizenii* and *P. sabiniana*, and few plots had more than two canopy species other than blue oak. At Wantrup, sapling counts per plot decreased as the number of canopy species increased (*table 2*). Thirty percent of the plots at Wantrup had between three and six canopy species in addition to blue oak, with the highest numbers of tree species occurring in densely canopied plots along streams and at higher elevations.

The final models for Sierra showed a positive association between small diameter trees (3 to 13 cm DBH) and sapling recruitment. At Pinnacles, plots close to the edge of the stand were less likely to have saplings than those at the interior of the stand. The most common vegetation types beyond the blue oak stand at this location were chaparral and grasslands. No predictor variables related to herbaceous vegetation, including variables related to bunchgrass cover, were significant in the logistic regression models.

Soil and Microclimate

Estimated soil available water capacity (SoilAWC) was positively correlated with recruitment at Pinnacles and Dye Creek, both of which have very droughty soils (*table 1*). Among locations with relatively high soil water holding capacity, SoilAWC was negatively associated with recruitment at Wantrup (*table 2*), and nonsignificant at Sierra and Jamestown.

Topographic position was a significant predictor of the number of saplings per plot in the Poisson models for Wantrup and Pinnacles, but the relationship between recruitment and topographic position differed between these two locations (*table 2*).

At Dye Creek, the single variable model for TopoPosA (not shown) predicted that plots in drainages were almost six times more likely to have recruitment (*P* = 0.005) than plots in the hilltop position. Two locations showed a negative relationship between altitude and recruitment outcomes (*table 2*).

Plot insolation was included as a predictor variable in two of the final logistic regression models. At Pinnacles, a relatively xeric location, plots with more xeric exposures (high Insol12) had fewer saplings than plots with more mesic exposures (*table 2*). However, Insol12 was negatively correlated with TotCanopyA at this location, and whenever both were included in a multivariate model, Insol12 was no longer significant. Models in which TotCanopyA and Insol12 variables were substituted for each other were nearly equivalent. At Sierra, a more mesic site, there was a weak positive association between Insol12 and the Allrecr outcome (table 2). Because there were very few plots with both southerly aspects and steep slopes at Sierra, plot insolation values were generally lower there than at Pinnacles (*table 1*).

All-location Statistical Model

We developed several outcome variables that describe sapling recruitment at the location level. *Table 4* lists the parameters for the final Poisson model for the LocAllrecr outcome. This outcome is the number of plots at a location containing live or dead saplings or S0 seedlings. The LocAllrecr model differs only slightly from a model fitted to counts of plots with live seedling-origin saplings only (Swiecki and others 1993). Only a limited number of factors could be fitted in the all-location model because only 15 data points, one for each location, are used to construct the model. The final model had more variability than expected for a Poisson model.

Table 4–Predictor variables and model parameters for the all-location Poisson regression model for the LocAllrecr[1] outcome

Predictor variables	Description	LocAllrecr Rate ratio (95 pct confidence interval)[2]
AvgInsol12	Average of December average-day insolation (INSOL12) for the location (MJ/m^2).	0.778*** (0.678 - 0.893)
LocCurrVertBr	Number of plots in which current vertebrate browsing intensity is rated as high	0.978*** (0.970 - 0.986)
ETdeficit	Difference between annual reference evapotranspiration (ETo) and 1962-1992 average annual precipitation (cm).	<u>1.13</u>*** (1.07 - 1.19)
LocGaporCut	Number of plots in which either (1) tree cutting has occurred in the plot between 1950 and 1992 or (2) a canopy gap has developed in the plot between 1962 and 1992 (estimated) (GaporCut42=1)	1.11*** (1.08 - 1.15)
MaxCanopySpp	The maximum number of canopy species found in any plot at the location.	<u>0.570</u>*** (0.437 - 0.743)
MinPpt2	Lowest 2-year rainfall total (cm) for the location for the period 1962-1992.	1.23*** (1.12 - 1.35)
OneFire30	Number of plots that have burned only one time between 1962 and 1992.	1.06*** (1.04 - 1.09)
SoilAWC≥10cm	Number of plots in which the estimated soil available water-holding capacity is greater than 10 cm.	<u>1.03</u>*** (1.02 - 1.04)

[1]Count of plots containing any live or dead sapling or S0 seedling.

[2]Rate ratios greater than 1 indicate a positive association between the predictor variable and the outcome; ratios less than 1 signify a negative association. Underlined rate ratios show an apparent reversal in the direction of the association between single variable models and the final multivariate model because of collinearity in the multivariate model. Significance level is denoted by asterisks: * $P \geq 0.10$, ** $P \geq 0.05$, *** $P \geq 0.01$.

As indicated in *table 4*, the direction of the effect of some predictor variables is reversed in the final multivariate model relative to the direction they showed in single variable models. This reversal results from including correlated predictor variables in the same model. The net effects of all variables are as shown in the final model, but the effect of an individual predictor variable cannot be inferred from its coefficient in the final model if reversal has occurred.

Three climate-related variables, AvgInsol12, ETdeficit, and MinPpt2 were significant in the final model. Each of these variables was negatively associated with recruitment in its single-variable model, indicating that more xeric locations were less likely to have saplings. Conversely, SoilAWC≥10cm was negatively associated with recruitment in single variable models, indicating that locations with droughtier soils overall had higher levels of recruitment. The net effects of these interrelated variables are as shown in *table 4*.

Predictor variables related to browsing intensity and canopy gaps were significant in the final model (*table 4*) and had effects consistent with those seen in the within-location models (*table 2*). There was also a positive association between LocAllrecr and the number of plots at a location that had burned one time in the past 30 years (OneFire30, *table 4*). Other fire-related variables were nonsignificant. Because of the nonlinear relationship between plot canopy cover and recruitment, and the effects of recent gaps on canopy cover (*table 2*), we did not use average canopy cover as a predictor variable for the LocAllrecr model. Other canopy variables we constructed were not significant in the final model.

In a single variable model, the count of plots at a location containing shrubs was positively correlated with the LocAllrecr outcome (rate ratio 1.023, $P < 0.001$). This predictor variable was not significant in the final multivariate model, even though shrub-related variables were positively associated with sapling recruitment in four within-location models (*table 2*).

Discussion

All final model outcome variables include both live and dead saplings. We considered dead saplings as recruitment because dead individuals had been recruited to the sapling stage before they died. The total number of dead saplings and the number of plots containing only dead saplings were small enough that excluding dead saplings from the outcomes would not have yielded substantially different results. There were also too few dead saplings to construct separate models for sapling mortality.

Plots with nearly closed or closed canopies appear to be generally unfavorable for sapling recruitment, which is consistent with our finding that few saplings were found under tree canopy (Swiecki and others 1993, these proceedings). Muick and Bartolome (1987) reported that only 16 percent of the blue oak saplings (1 to 10 cm DBH) in their survey were located under canopy. Mature blue oaks have long been considered intolerant of shade (Sudworth 1908).

The strong positive association between canopy gaps and sapling recruitment (*tables 2, 4*) is typical of species that regenerate from persistent seedlings ("advance regeneration") located in the understory (Oliver and Larson 1990). For blue oak, we believe that small persistent seedlings in the understory, typically less than 15 to 20 cm tall, constitute advance regeneration. These small seedlings can survive in the understory for periods of at least 3 to 15 years despite repeated loss of their above-ground shoots due to desiccation or herbivory (Allen-Diaz and others 1990, Griffin 1971, Phillips and others 1996, Swiecki and others 1990). These seedlings exhibit tolerance of understory conditions, which is typical of advance regeneration, whereas blue oak saplings do not (Swiecki and others 1993).

In the absence of any recent gap, plots with little or no tree canopy were unlikely to have saplings (*tables 2, 4*). We seldom observed blue oak saplings in old (>42 years) cleared fields or other old clearings within our study areas. White (1966) reports similar observations. Several studies have shown that most blue oak seedlings become established under or very close to tree canopy (Muick and Bartolome 1987, Swiecki and others 1990, White 1966), presumably because of the combination of a favorable microclimate under tree canopy and relatively low rates of long-range acorn dispersal. Although it is difficult for first-year seedlings to establish in open sites (Gordon and others 1989; Muick, these proceedings), established advance regeneration is able to compete successfully in new canopy gaps.

Grazing and browsing variables were negatively associated with recruitment in within-location models for all currently grazed locations (*table 2*) and in the all-location model (*table 4*). From these results and our field observations of browsing damage (Swiecki and others, these proceedings), we conclude that browsing by livestock is a major constraint to both blue oak sapling recruitment and the regeneration of other woody species at many locations. Other studies (Bernhardt and Swiecki, these proceedings; Borchert and others 1989; Hall and others 1992) have also documented strong adverse effects of cattle on the growth and survival of oak seedlings and saplings in California. Livestock may inhibit blue oak sapling recruitment by both depleting the understory stock of seedling advance regeneration and adversely affecting sapling survival.

In the two nongrazed locations, there was a positive association between browsing and saplings (*table 2*). In these areas, browsing damage was caused by deer, which may have been attracted to areas with saplings because of the accessible browse they provided. On the basis of our field observations, we believe that deer browsing damage usually has little impact on blue oak sapling survival, but may tend to prolong the sapling stage by slowing height growth.

McClaran and Bartolome (1989) have suggested that fire favors sapling recruitment, but studies involving direct observation of burned areas have not shown any positive effect of fire on blue oak seedling or sapling establishment or survival (Allen-Diaz and others 1990, Haggerty 1991). Fire is clearly not requisite for sapling recruitment, because two locations with significant amounts of recruitment had no recent fires (*table 1*). Topkilled saplings normally revert to a smaller size class upon resprouting, so fire is likely to prolong the sapling stage of development. This could account for the positive association between OneFire30 and sapling presence in the all-location model (*table 4*). Fires may also open new canopy gaps by killing decadent blue oaks or other competing tree species in the overstory, thereby favoring sapling recruitment.

The associations between environmental and soil variables and recruitment in the models indicate that xeric site conditions generally do not favor blue oak sapling recruitment. Blue oak is a dominant tree in many xeric habitats and should have a competitive advantage in xeric locations because of its ability to withstand severe drought. However, saplings in xeric locations are likely to grow slowly, and the negative effects of factors such as livestock grazing or repeated fires may be of greater significance at such locations. Among the most xeric locations in this study, moderate recruitment was observed only at Pinnacles, which has not been grazed for more than 60 years (*table 1*).

Microsite conditions that seem to favor blue oak sapling recruitment in xeric locations are those that support faster growth because of greater soil moisture availability and/or reduced evaporative demand. Northerly aspects, patches of deeper soil, and topographic positions that receive runoff are more likely to have blue oak saplings in xeric locations. However, in more mesic locations, these factors are often associated with dense tree canopy cover which reduces blue oak sapling recruitment.

We observed no evidence of a direct interaction between shrubs and blue oak saplings, even though shrubs and blue oak saplings were often present in the same plots. Many of the factors related to blue oak sapling recruitment could have similar positive or negative effects on other woody species, including shrubs. At every location where we observed moderate numbers of blue oak saplings, regeneration of other woody species was also present. Conversely, with the exception of Henry W. Coe State Park, locations with little or no blue oak recruitment also had little or no regeneration of other woody species in the understory (Swiecki and others 1993, these proceedings). The failure of blue oak to regenerate is not a unique phenomenon, but appears to be part of the overall suppression of woody plants in the understory of many oak woodlands.

Blue oak sapling recruitment is a multistep process that may require many years or decades to complete. Because sapling recruitment is affected by a number of factors interacting over time, the elimination or modification of a single constraining factor will not necessarily increase the rate of recruitment. For example, eliminating livestock browsing may have little or no effect on sapling recruitment if canopy cover levels are unfavorably high or low. If seedling advance regeneration has been depleted or eliminated, factors that favor the recruitment of saplings from advance regeneration, such as gap formation, will not result in sapling recruitment.

Because colonization of old, open rangeland clearings by blue oak is uncommon under prevailing conditions, the conversion of blue oak woodland to grassland is not likely to be an easily reversible process. If blue oak is to be managed as a sustainable resource, efforts must be made to favor natural regeneration. Recruitment may be favored by altering grazing practices to reduce browsing impacts on seedlings and saplings of blue oak and other woody species. Greater attention should also be paid to the status of advance regeneration before, during, and after wood harvesting or other canopy or understory manipulations.

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References

Allen-Diaz, Barbara; Bartolome,James; McClaran, Mitchel. 1990. **Effects of fire and grazing on blue oak regeneration**. Prepared for: California Department of Forestry and Fire Frotection, Strategic Planning Program, Sacramento, CA.

Bernhardt, Elizabeth A.; Swiecki, Tedmund J. 1997. **Effects of cultural inputs on survival and growth of direct seeded and naturally occurring valley oak seedlings on hardwood rangeland**. [these proceedings].

Borchert, Mark I.; Davis, Frank W.; Michaelsen, Joel; Oyler, Lynn D. 1989. **Interactions of factors affecting seedling recruitment of blue oak in California**. Ecology 70: 389-404.

Gordon, D.R.; Welker, J.M.; Menke, J.W.; Rice, K.J. 1989. **Competition for soil water between annual plants and blue oak (*Quercus douglasii*) seedlings**. Oecologia 79: 533-541.

Griffin, James R. 1971. **Oak regeneration in the upper Carmel Valley, California**. Ecology 52: 862-868.

Haggerty, Patricia K. 1991. Fi**re effects in blue oak (*Quercus douglasii*) woodland in the southern Sierra Nevada, California**. Davis: University of California; M.S. thesis.

Hall, Lillian M.; George, Melvin R.; McCreary, Douglas D.; Adams, Theodore E. 1992. **Effects of cattle grazing on blue oak seedling damage and survival**. Journal of Range Management 45: 503-506.

McClaran, Mitchel P.; Bartolome, James W. 1989. **Fire-related recruitment in stagnant *Quercus douglasii* populations**. Canadian Journal of Forest Research 19: 580-585.

Mensing, S.A. 1992. **The impact of European settlement on blue oak (*Quercus douglasii*) regeneration and recruitment in the Tehachapi Mountains, California**. Madroño 39(1): 36-46.

Muick, Pamela C. 1997. **Effects of shade and clipping on coast live and blue oak seedling mortality and growth in California annual grasslands**. [these proceedings].

Muick, Pamela C.; Bartolome, James W. 1987. **An assessment of natural regeneration of oaks in California**. Prepared for: California Department of Forestry, Sacramento, CA. 116 p.

Oliver, C.D.; Larson, B.L. 1990. **Forest stand dynamics**. New York: McGraw-Hill, Inc.; 467 p.

Phillips, Ralph; McDougald, Neil K.; Standiford, Richard B.; McCreary, Douglas D.; Frost, William E. 1996. **Blue oak regeneration in southern Sierra Nevada foothills**. [these proceedings].

Pruitt, W.O.; Fereres, E.; Kaita, K.; Snyder, R.L. 1987. **Reference evapotranspiration (ETo) for California**. Bulletin 1922. Oakland: University of California, Division of Agriculture and Natural Resources; 14 p. plus 12 maps.

Rumsey, Tom. **Physol** [computer program]. 1993. Davis: Department of Biological and Agricultural Engineering, University of California; Fortran for Apple Macintosh.

Sudworth, George B. 1908. **Forest trees of the Pacific slope**. Washington, DC: U.S. Department of Agriculture; 441 p.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1990. **Impacts of diseases and arthropods on California's rangeland oaks**. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA. 94 p. plus appendix.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Drake, Christiana. 1993. **Factors affecting blue oak sapling recruitment and regeneration**. Prepared for: California Department of Forestry and Fire Protection, Strategic Planning Program, Sacramento, CA. 132 p.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Drake, Christiana. 1997. **Stand-level status of blue oak sapling recruitment and regeneration**. [these proceedings].

Vankat, John L.; Major, Jack. 1978. **Vegetation changes in Sequoia National Park, California**. Journal of Biogeography 5: 377-402.

White, Keith L. 1966. **Old-field succession on Hastings Reservation, California**. Ecology 47: 865-868.

Growth of Blue Oak on California's Hardwood Rangelands[1]

Richard B. Standiford[2]

***Abstract**. An individual tree basal area increment model was developed for blue oak (*Quercus douglasii *Hook. & Arn.) in California, an important woodland tree for wildlife habitat. Box-Cox regression based on 895 increment cores that showed current basal area and the relative size of the tree crown were significant variables. Models to link basal area changes over time with tree height and crown cover were developed to provide initial estimates of stand structure dynamics. Relative tree crown characteristics, site index, and diameter at breast height (DBH) were significant variables in predicting tree height. Individual tree basal area, basal area competition in trees larger than the subject tree, and tree height were significant in predicting crown cover. Use of these models for assessing projected changes in stand structure under different levels of management is demonstrated.*

Blue oak (*Quercus douglasii* Hook. & Arn.) is a widely distributed tree species on California rangelands, occurring in more or less pure woodland or savanna stands on 1.2 million ha of California's 3.0 million ha of hardwood rangelands, and in mixed stands on another 360,000 hectares (Bolsinger 1988). Blue oak woodlands have an understory of annual grasses and occasional native perennial grasses, and are found in association with foothill pine (*Pinus sabiniana* Dougl.), coast live oak (*Quercus agrifolia* Nee), and interior live oak (*Quercus wislizenii* A. DC.). Good ecological descriptions of these areas are found in Bartolome (1987), Griffin (1977), and Holmes (1990). Livestock grazing is the predominant land use on these areas, 75 percent of which are privately owned (Bolsinger 1988).

Historically, little attention was given to tree growth on blue oak woodlands because they are classed as "noncommercial" by USDA Forest Service standards (average annual growth less than 1.4 cubic m per ha per year), they have little commercial use other than for firewood, and they inhibit forage production for livestock on some areas. In recent years, however, it has been recognized that blue oak rangelands are a rich source of biological diversity. The valley-foothill hardwood and valley-foothill hardwood conifer habitat types, of which blue oak woodlands are a principal component (Mayer and Laudenslayer 1988), have 278 vertebrate species of wildlife, which rely on these lands for at least part of their habitat needs (Airola 1988). Watershed protection and esthetics are other important public values supplied by blue oak woodlands. Concern about long-term sustainability of blue oak woodlands has been expressed by policy makers, resource mangers, and the general public because regeneration failure has been documented in some areas (Bolsinger 1988, Muick and Bartolome 1987, Standiford and others 1991).

To evaluate blue oak woodland environmental values, managers need to be able to assess changes in tree cover and stand structure over time. Blue oak stand structure is closely correlated with the quality of wildlife habitat (Block and Morrison 1991, Wilson and others 1991). To date, the only information on growth and yield available for assessing blue oak stand dynamics is a whole stand model of volume, basal area, and crown cover developed for use in economic optimization of multiple resource management on blue oak woodlands (Standiford and Howitt 1993). However, this is not adequate for assessing stand structure changes over time and their effects on habitat values. The objective of this study is to develop preliminary individual blue oak tree models to allow managers to assess stand structure changes over time.

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Individual Tree Growth Models

Individual tree growth models have become increasingly important for natural resource management decision making (Holdaway 1984, Wensel and others 1987, Wycoff and others 1982). Individual tree growth is affected by tree size (height, diameter), crown characteristics (live crown ratio, crown diameter), site factors (site index, soils, habitat type), and competition with adjacent trees.

Tree competition has been modelled in a variety of ways. Crown competition factor (Krajicek and others 1961), individual tree crown radius (Curtis 1970) and the relative proportion of total crown closure at 66 percent of a tree's total height (Wensel and others 1987) are examples of crown factors used to model competition in different growth studies. A percentile distribution of basal area (Stage 1973) and the summation of basal area per hectare in larger trees, known as BAL (Wycoff 1990), are examples of basal area factors used to model competitive effects of adjacent trees.

Many blue oak stands are fairly open with varying crown diameters. The size of individual crowns or basal area in relationship to other trees in the stand are expected to closely follow the competitive impacts interacting with the tree. Open grown or widely spaced trees and trees with large crowns would be expected to have higher diameter and volume growth than closely spaced trees or trees with narrow crowns.

Methods

Seven representative study locations were selected covering a wide geographic range throughout the extent of the hardwood range area of the state. One location was at the northern end of the Sacramento Valley, two locations were in the Sierra Nevada foothills, three locations were in the Coastal Range, and one location was at the extreme southern end of the San Joaquin Valley. At each study location, 3 to 22 0.04-ha plots were randomly chosen in stands of pure blue oak, mixed blue oak and interior live oak, and mixed blue oak and coast live oak. These study locations covered a broad range of stand density, species composition, and site quality. Study sites were confined to areas that had at least 50 percent blue oak basal area. Sixty-six of the 81 study plots were pure blue oak stands.

Individual tree data collected at each plot included diameter at breast height (1.4 meters), total tree height, tree crown diameter, and 5- and 10-year radial growth. Blue oaks represented 895 of the 972 individual trees measured in this study. The sample size for non-blue oak trees was too small to be included in the analysis.

The following was calculated for each of the 81 sample plots from the individual tree data: stand volume in m^3/ha using merchantable firewood volume equations (Pillsbury and Kirkley 1984, stand basal area in m^2/ha, stand crown cover percent, site index (Standiford and Howitt 1988), and periodic annual volume and basal area growth over the previous 5- and 10-year periods.

Competition was evaluated by comparing two different indices. The basal area per ha in larger trees, BAL (Wycoff 1990), was used. It was hypothesized that as BAL increases, representing more competition from other trees in the stand, growth rate would decrease.

Another competition factor evaluated was a modification of CC_{66} (Wensel and others 1987). Instead of calculating relative crown area at 66 percent of a tree's height, relative crown area was calculated at the base of each tree by dividing projected crown area of a tree by total crown area per hectare of all trees. The formula used to calculate this crown index, RELCROWN, is shown in equation (1).

$$\text{RELCROWN}_j = \frac{CA_j}{\sum_{i=1}^{n} CA_i}$$

where: RELCROWN_j = relative crown index for tree j
CA_i = Projected crown area for tree i
CA_j = Projected crown area for tree j
n = total number of trees/ha

The size of an individual tree crown in relationship to other trees in the stand would closely follow the competitive impacts on the tree. As RELCROWN increases, a tree has more dominance in a stand, and would be expected to grow more rapidly than a tree with a smaller RELCROWN.

Since this is the first widespread growth study of individual oak tree growth on hardwood rangelands, data on height and crown growth from costly stem analysis or long-term permanent growth plots were not available. The main growth parameter which could be evaluated in this study was periodic basal area increment, determined for each tree by subtracting tree basal area 10 years ago determined from increment cores, from the current tree basal area.

The functional form of basal area increment was not known. Studies of production functions often evaluate several forms, ranging from a Cobb-Douglas logarithmic form to a linear form. Rather than imposing one of these two forms, it was decided instead to let the data itself determine the form of the basal area increment production function by using the Box-Cox transformation (Zarembka 1974). The form of the Box-Cox transformation, (λ), is shown in equations (2) through (4) below.

$$y^{(\lambda)} = \frac{y^{\lambda} - 1}{\lambda} \qquad \text{for: } \lambda \neq 0 \tag{2}$$

$$= \ln(y) \qquad \text{for: } \lambda = 0$$

$$y^{(\lambda)} = a_0 + a_1 x^{(\lambda)} + a_2 x_2^{(\lambda)} + \ldots + a_n x_n^{(\lambda)} + \varepsilon \tag{3}$$

$$\frac{y^{\lambda} - 1}{\lambda} = a_0 + a_1 \frac{x_1^{\lambda} - 1}{\lambda} + a_2 \frac{x_2^{\lambda} - 1}{\lambda} + \ldots + a_n \frac{x_n^{\lambda} - 1}{\lambda} + \varepsilon \tag{4}$$

Both the dependent variable, y, and the independent variables, x_i, are transformed with the lambda relationship shown in equation (4). The Box-Cox process solves for the coefficients, a_i, as well as for λ using a maximum likelihood process. Noncollinearity of the independent variables, additivity of the error term with a zero mean and constant variance, and symmetry of the residuals are required for unbiased estimates of the coefficients (Zarembka 1974). If λ equals zero, the relationship is a Cobb-Douglas production model. If λ equals one, the relationship is linear.

Results

The Box-Cox transformation was used to evaluate the effect of tree size, competition, and site on basal area increment. Tree size was represented by tree basal area at the beginning of the growth period. Both BAL and RELCROWN competition indices were evaluated; however, only RELCROWN was significant at the 0.10 level in the Box-Cox analysis. Site index was not a significant variable at the 0.10 level when tree size and competition factors were included. The low correlation of site with individual tree growth (R = 0.011) was surprising, given the high correlation of site index with whole stand growth (Standiford and Howitt 1988).

The basal area increment model for blue oak is shown in equation (5). Basal area increment is for growth inside bark. All variables are significant at the 0.01 level.

$$BAINC_i^{(\lambda)} = a_0 + a_1 BA_i^{(\lambda)} + a_2 RELCROWN_i^{(\lambda)} \qquad R^2 = 0.64 \tag{5}$$

where:

$BAINC_i$ = 10-year basal area periodic increment for tree i (square meters)

BA_i = Current basal area of tree i in m^2

$RELCROWN_i$ = Relative crown cover of tree i expressed as decimal

λ = 0.11

a_0 = -2.9011

a_1 = 0.3963

a_2 = 0.0413

$^{(\lambda)}$ = Box-Cox transformation (see equation (2) above)

Homoskedasticity was demonstrated across the range of independent variables using the Glejser (1969) test. Multi-collinearity was evaluated by inspection of the correlation matrix of independent variables. Since the correlation coefficient between BA and RELCROWN was less than 0.6, multi-collinearity was rejected. The mean of error term was equal to zero, and skewness of the residuals was not significantly different than zero, showing the required symmetry for unbiased estimates.

Equation (5) can be converted to (6) to directly calculate 10-year blue oak basal area increment.

$$BAINC = [\lambda(a_0 + a_1 \frac{BA^{\lambda} - 1}{\lambda} + a_2 \frac{RELCROWN^{\lambda} - 1}{\lambda}) + 1]^{1/\lambda} \tag{6}$$

Height growth was not evaluated directly in this initial study of dynamics. Height growth will be estimated by using the correlation between tree height and diameter for dominant trees from the site index relationship (Standiford and Howitt 1988). As diameter increases as determined by equation (6), height changes can also be estimated as a first approximation until permanent height growth data can be collected and analyzed.

Equation (7) shows the form of the height-diameter site index equations for dominant trees developed for hardwood rangelands (Standiford and Howitt 1988).

$$\ln(SITE) = [\ln(HT_{dom}) - .3103] + 7.882 \times \frac{1}{DBH_{dom}} \tag{7}$$

where:

HT_{dom} = total tree height in meters for dominant trees in stand

SITE = site index

DBH_{dom} = diameter at breast height (1.4 m) in centimeters for dominant trees

If site index and DBH are known, the height for dominant trees in a stand can be determined by rearranging the equation to give equation (8).

$$HT_{dom} = e^{(\ln(SITE) - 7.882 * (1/DBH_{dom}) + .3103)} \tag{8}$$

It is assumed that the height-dbh relationship for trees in lower crown classes is modified by competition level. The competition index used in (6), RELCROWN, together with (8) was used in a Box-Cox transformation to predict height for any tree in the stand, however skewness of the residuals showed that the assumption for unbiased coefficients was violated. Nonlinear regression was used to develop a height prediction relationship by assuming a logistic crown competition relationship multiplied by the transformed site index equation (8) to give:

$$HT = \frac{1}{1+e^{(a_1 RELCROWN)}}[e^{(\ln(SITE)-7.882*(1/DBH)+.3103)}] \quad (9)$$

The initial nonlinear regression was run to solve for a_1. Given this starting value and the values of the site index relationship, the entire height-diameter equation was solved for a_1, a_2, and a_3 using nonlinear regression for equation (10). All regression coefficients were significant at the 0.01 level.

$$HT = \frac{1}{1+e^{(a_1 RELCROWN)}}[e^{(\ln(SITE)+a_2*(1/DBH)+a_3)}] \quad (10)$$

where:

a_1 = -0.8177

a_2 = -10.396

a_3 = 0.7566

Changes in canopy cover over time are also of interest to hardwood rangeland managers. Just as with height growth above, this initial study of blue oak dynamics did not have permanent growth plot or stem analysis data on changes in individual crown cover available. Changes in crown characteristics were assumed to be correlated with basal area increment. Individual tree crown cover in square meters was evaluated as a function of tree size, site and competition. The results of the Box-Cox regression are shown in equation (11). Both tree height and basal area were significant at the 0.01 level. The competition index, BAL, was also significant at the 0.01 level. There was no evidence of collinearity, since the correlation coefficient between the three independent variables was less than 0.45. Conditions of symmetry were met, as skewness was not significantly different than zero. The Glejser (1969) test revealed uniform variability across the range of independent variables in the study.

$$CROWNCOV_i^{(\lambda)} = a_0 + a_1 BA_i^{(\lambda)} + a_2 BAL_i^{(\lambda)} + a_3 HT_i^{(\lambda)} \quad R^2 = 0.60 \quad (11)$$

where:

$CROWNCOV_i$ = Crown cover of tree i (m^2)

BA_i = Current basal area of tree i in m^2

BAL_i = Square meters of basal area per ha in trees larger than tree i

HT_i = Current total height of tree i in m

λ = 0.20

a_0 = 10.096

a_1 = 2.7036

a_2 = -0.0733

a_3 = 0.1581

Discussion

Given initial values for dbh, height, and crown cover for individual blue oak trees in a stand and the relationships for basal area increment (6), tree height-diameter correlation (10), and crown cover (11), projections of stand structure changes can be made. As 10-year basal area increment is estimated, height, crown, and dbh for each individual tree is updated using these relationships.

As an example of the use of this system of equations in modelling stand structure dynamics, a blue oak woodland in California's central coast with 988 stems per ha, site 12, and a 53 percent crown cover was evaluated over a 30-year period. Actual individual tree data collected from 0.04-ha plots in this stand were evaluated. Projections of stand changes over time are shown in *table 1*, assuming no mortality or regeneration. Crown cover is expected to increase from 53 to 81 percent over the 30-year simulation period, and basal area is expected to increase from 9.3 to 15.5 m^2/ha.

Table 1—Projected changes in stand characteristics for a blue oak woodland, site 12

Time	Average DBH	Basal area per ha	Volume per ha	Crown cover
yr from present	*cm*	*sq m*	*cubic m*	*pct*
0	10.9	9.3	30.6	53
10	11.9	11.2	37.1	62
20	13.0	13.3	45.1	71
30	14.2	15.5	54.5	81

A key advantage of an individual tree model is to evaluate how diameter distribution by size class changes over time. *Figure 1* shows the diameter distribution of the 988 trees per hectare over a 30-year simulation period. These changes in diameter distribution can be related to habitat suitability over time.

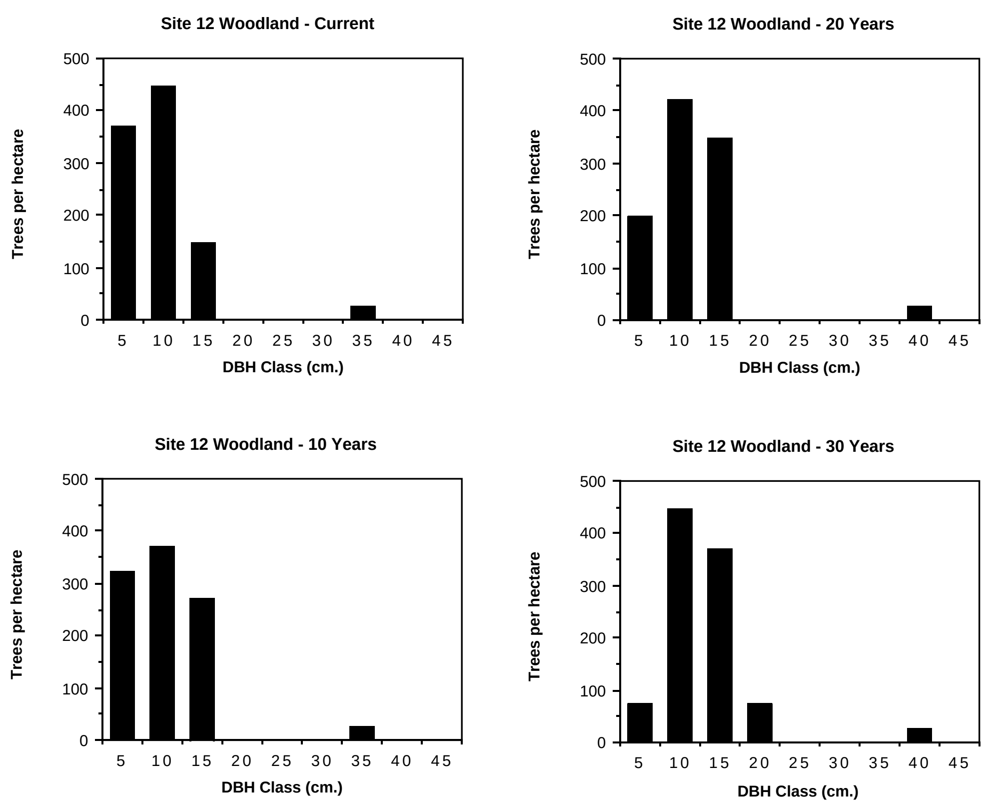

Figure 1—Example of 30-year changes in diameter distribution for a pure blue oak woodland with 988 stems per ha, site index 12, and 53 percent crown cover.

Another important structural feature that can be evaluated is oak tree cover. For a blue oak woodland in the central Sierra Nevada on site 9, with 200 stems per ha and a basal area of 7.8 m^2/ha, current oak canopy cover is 36 percent. *Figure 2* shows how the canopy of eight trees in a 0.04-ha sample plot increases over a 30-year simulation period to 45 percent cover.

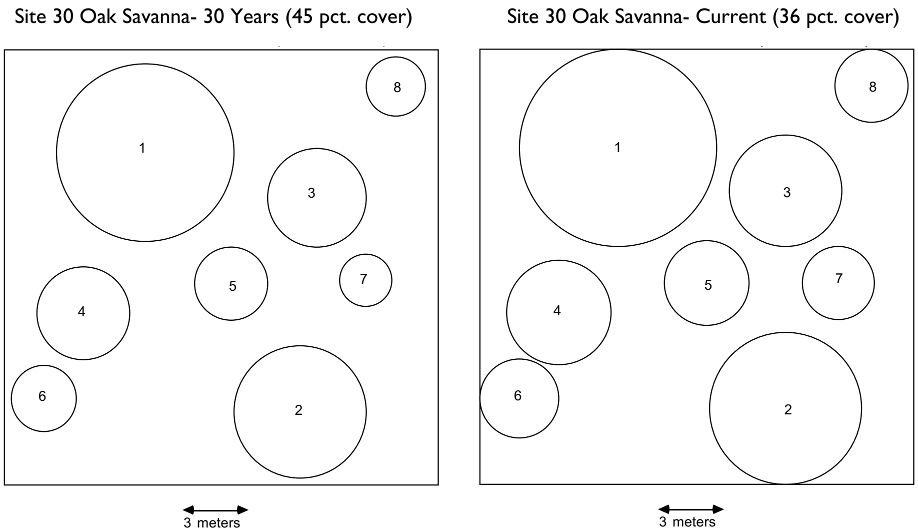

Figure 2—Example of 30-year changes in crown cover in a pure blue oak woodland with 200 stems per hectare, site index 9, and 36 percent crown cover.

Conclusion

This study provided the first individual tree model for blue oaks on hardwood rangelands in California. This modelling effort is based upon basal area increment and its correlations with crown and height over time. Future work will be needed to establish permanent plots to collect data needed to develop specific height and crown growth functions.

It was somewhat surprising that the site index relationship used for whole stand models was poorly correlated with individual tree growth. Future work will be needed to determine which site factors influence individual tree growth to refine the relationships developed in this preliminary study.

A long-term sustainability evaluation of blue oak stands requires good estimates of mortality and regeneration, in addition to site-specific growth relationships. Mortality functions can be derived from permanent growth plots. Preliminary relationships for natural oak regeneration probability have been developed (Standiford and others 1991).

This study concentrated on growth relationships for blue oak, one of the most important hardwood rangeland species in the state. Future work will be needed to develop more complete information on associated species.

References

Airola, D.A. 1988. **Guide to the California wildlife habitat relationships system**. Sacramento: California Department of Fish and Game; 74 p.

Bartolome, J.W. 1987. **California annual grassland and oak savannah**. Rangelands 9(3): 122-125.

Block, William M.; Morrison, Michael L. 1991. **Influence of scale on the management of wildlife in California oak woodlands**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 96-104.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas**. Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Curtis, R.O. 1970. **Stand density measures: an interpretation**. Forest Science 16(4): 403-414.

Glejser. H. 1969. **A new test for heteroskedasticity**. Journal of the American Statistical Association 64: 314-323.

Griffin, J.R. 1977. **Oak woodland**. In: Barbour, Michael G.; Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley and Son; 383-416.

Holdaway, Margaret R. 1984. **Modeling the effect of competition on tree diameter growth as applied in STEMS**. Gen. Tech. Rep. NC-94. St. Paul, MN: North Central Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 9 p.

Holmes, T.H. 1990. **Botanical trends in northern California oak woodland**. Rangelands 12(1): 3-7.

Krajicek, J.; Brinkman, K.; Gingrich, S. 1961. **Crown competition—a measure of density**. Forest Science 7(1): 35-42.

Mayer, K.E.; Laudenslayer, W.F. 1988. **A guide to wildlife habitats of California**. Sacramento: California Department of Fish and Game; 166 p.

Muick P.C.; Bartolome, J.W. 1987. **Factors associated with oak regeneration in California**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources. Gen. Tech. Rep. PSW- GTR-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 86-91.

Pillsbury, Norman H.; Kirkley, Michael L. 1984. **Equations for total, wood, and saw-log volume for thirteen California hardwoods**. Res. Note PNW-414. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 52 p.

Stage, A.R. 1973. **Prognosis model for stand development**. Res. Paper INT-137. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture, 32 p.

Standiford, R.B.; Howitt, R.E. 1988. **Oak stand growth on California's hardwood rangelands**. California Agriculture 42(4): 23-24.

Standiford, R.B.; Howitt, R.E. 1993. **Multiple use management of California's hardwood rangelands**. Journal of Range Management 46: 176-181.

Standiford, R.B.; McDougald, N.K.; Phillips, R.; Nelson, A. 1991. **South Sierra oak regeneration survey**. California Agriculture 45(2): 12-14.

Wensel, L.C.; Meerschaert, W.J.; Biging, G.S. 1987. **Tree height and diameter growth models for northern California conifers**. Hilgardia 55(8): 1-20.

Wilson, Randolph A.; Manley, Patricia; Noon, Barry R. 1991. **Covariance patterns among birds and vegetation in a California oak woodland**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management, October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 126-135.

Wycoff, William R.; Crookston, Nicholas L.; Stage, Albert R. 1982. **User's guide to the stand prognosis model**. Gen. Tech. Rep. INT-133. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 112 p.

Wycoff, W.R. 1990. **A basal area increment model for individual conifers in the northern Rocky Mountains**. Forest Science 36(4): 1077-1104.

Zarembka, P. 1974. **Frontiers of econometrics**. New York: Academic Press.

Blue Oak Regeneration in Southern Sierra Nevada Foothills[1]

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***Abstract**: A survey of blue oak stands in four southern Sierra areas indicated there was a substantial number of seedlings and mature trees, but there were considerably fewer trees in the sapling and pole size class. These differences prompted a long-term survival study. After 6 years, 68.5 percent of the trees were still present and had grown 0.02 inches. A study of aging seedlings showed that the percentage of seedlings less than 10 years old ranged from 52.7 percent to 98.4 percent for the three sites. More than 10 percent of the seedlings in one site were more than 25 years old. A 2-year study evaluating acorn quality showed that acorns from Madera County had a faster and higher emergence rate than acorns from Kern County.*

The Southern Sierra Hardwood Range region, consisting of Madera, Fresno, Tulare, and Kern Counties contains almost 1.5 million acres of hardwood rangeland. Eighty percent of this land is privately owned, and blue oak (*Quercus douglassii*) is the most abundant oak species. Obtaining adequate natural regeneration to maintain current stands of blue oak is of concern for some landowners, government agencies, and conservationists. Studies were conducted to evaluate regeneration factors such as blue oak size classes, acorn quality, and natural seedling survival. These studies have been carried out over the past 9 years to better understand the biology of blue oaks growing under natural conditions. Data were analyzed using an analysis of variance and differences between means were determined using Duncan Multiple range. Significance is expressed as $P \leq 0.05$.

A Survey of Blue Oak Height Classes in Madera, Fresno, Tulare, and Kern Counties

In 1987, a preliminary survey was conducted in Kern County to inventory the population and height classes of blue oaks. The following year the survey was expanded to include Tulare, Fresno, and Madera Counties. Regeneration transects were established in each of the four counties, beginning at low-elevation and open blue oak savannas. The oak-covered hardwood rangeland began at an elevation of about 600 feet in the northernmost transects of Madera County, and about 1,600 feet in the southernmost transects of Kern County. Annual rainfall at these low elevations averaged 10-15 inches (*table 1*). The elevational transects passed through the hardwood range sites heading uphill, generally west to east, until they reached the transition between hardwood range and mixed conifer forest at elevations of 3,000 feet in Madera County to 4,800 feet in Kern County.

Fourteen to twenty regeneration survey plots were located at random in patterns radiating out from each of the four elevational transects. Random plot locations were checked to ensure that they occurred in the blue oak woodland vegetation type. If a plot did not match the blue oak hardwood type, another location was randomly selected. Plots were located exactly 200 feet to the north or south of the main elevational transect. Altogether, 68 plots were sampled for this study. Each sample location was a strip transect 100 feet long and 12 feet wide (0.028 acres). Trees were classed as seedlings (trees less than a foot tall),

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Table 1—Rainfall zones for the four South Sierra Nevada counties of Madera, Fresno, Tulare, and Kern.

Rainfall zone		Elevation of rainfall zones within each county			
	Rainfall	Madera	Fresno	Tulare	Kern
	inches	*feet*			
Low	10-15	500-1,000	500-1,000	1,100-1,600	1,500-2,000
Medium-low	15-17	1,000-2,000	1,000-2,000	1,600-2,600	2,000-3,000
Medium	17-22	2,000-3,000	2,000-3,000	2,600-3,600	3,000-4,000
High	22-26	3,000-4,000	3,000-4,000	3,600-4,600	4,000-5,000

Table 2—Number of blue oak trees per acre, by height class for four different rainfall zones in Madera, Fresno, Tulare and Kern Counties

Rainfall zone	Number of blue oak by height class per acre			
	<1 ft	1 to 5 ft	5 to 10 ft	>10 ft
Low	61.43	2.79	8.38	47.47
Low-Medium	254.10	7.64	7.64	42.03
Medium	237.97	18.15	6.05	68.57
High	116.97	86.72	30.25	86.72

saplings (trees 1 to 5 feet tall), poles (trees 5 to 10 feet tall), and mature (trees over 10 feet tall). A total of 68 sample transects were taken across four rainfall zones (Standiford and others 1991) in the four counties.

The average number of blue oak trees per acre by rainfall zone for the four counties is shown in *table 2*. A general pattern emerged that showed significantly more seedlings per acre than mature trees in all but the low zone. In the lowest zone, there were about the same number of seedlings and mature trees. There were fewer sapling- and pole-size trees per acre in all rainfall zones than seedling and mature size classes. This was more pronounced in the three lower rainfall zones. These data suggested that few of the seedlings were growing into the sapling or pole size class.

Studies to Evaluate Survival and Aging of Native Blue Oak Seedlings

The survey clearly indicated that blue oak seedlings were not developing into pole or mature trees. So in 1989, a study was started to monitor the survival of naturally occurring blue oak seedlings (Phillips and others, in press). The study was conducted in Kern County on three sites with four to five replications. Each replication was 0.01 acre. Each tree was permanently marked with an identification number. The number of trees per replication ranged from 25 to 128 for a total of 605 trees. The height of each tree was measured. Yearly survival data were collected in early summer, and each surviving tree was remeasured to evaluate seedling height growth in 1994.

The percent survival of blue oak seedlings, by site, from 1990 through 1995 is as shown in *figure 1*. After 6 years, 68.5 percent of the original trees were still alive. These results were higher than those of Allen-Diaz and Bartolome (1992) who reported a 50 percent seedling survival over several years. There was no significant difference in blue oak survival among the three sites.

Seedling change in height over the 5 years of the study was significantly different on each site. Trees at Site 2 increased in height by 0.65 inches, while trees at Site 1 decreased in height by 0.17 inches and trees at Site 3 decreased by 1.21 inches. The overall change in average height for the three sites was 0.02 inches.

The initial (1989) and final (1993) tree height measurements were taken during an extended drought (1986 through 1993). During the study, the seedlings would have green shoots in the spring, but by late August many of the shoots had dried up and appeared to be dead. The average percentage of seedlings at each site that had green leaves in the spring but had lost them by fall were: Site 1, 10.59 percent; Site 2, 4.94 percent; and Site 3, 16.70 percent. The following spring, the dry shoot did not green up; instead a new shoot developed from the root.

These new shoots were shorter, possibly because of the extended drought. All three sites were grazed by cattle, but at different times of the year. There was no evidence of large ungulate grazing on the oak seedlings during the yearly evaluation of each seedling. There appeared to be a relationship between the percent of seedlings that dried up during the summer and the change in the height of the seedlings; the greater percentage of seedlings that dried up, the shorter the subsequent seedling growth. Swiecki and others (1991) observe similar results of seedlings sending up shoot from the root each spring.

Numerous years of observation of blue oak seedlings in the field indicated that most of the seedlings were older than their height would suggest. On the basis of this observation, Phillips and others (in press) developed a procedure to estimate the age of seedlings. Regression equations were developed using root crown diameter and seedling age as determined by counting the growth rings above the root crown. This work indicated that the equations were site specific; thus an equation was developed for each of three sites.

Counting growth rings of blue oak seedlings could be off by 1 or 2 years because of false growth rings caused by animal browsing or mid-summer regrowth. Since no animal browsing was observed over the 5 years of the study, and summer rains did not occur in the study area, these two factors had minimal effect on the ring counts.

All of the surviving trees were aged in 1992 using the corresponding regression equation for each site. Trees at Site 1 were significantly older (averaging 14.5 years) than trees at Site 2 (averaging 5.2 years) and Site 3 (averaging 7.2 years). *Table 3* shows the percent of trees on each site in each of the age groups. Significantly more of the seedlings in Site 2 (98.39) and Site 3 (88.78) than Site 1 (52.72) were in the 1- to 10-year group. Surprisingly, 17.95 percent of the seedlings in Site 1 were more than 20 years old, and 10.56 percent were more

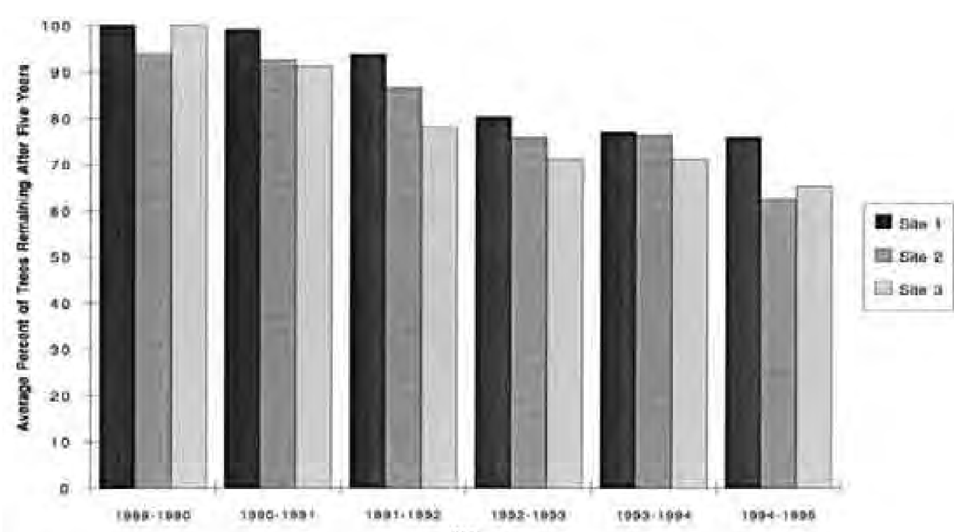


Figure 1—Average percent of blue oak seedlings that survived from 1990 through 1995 for the three sites in Kern County.

Table 3—The percent of blue oak seedlings in five age groups at three sites in Kern County

Location	Age groups (yr)				
	1-10	11-15	16-20	21-25	26 and older
			pct		
Site 1	[a]52.72	[a]19.90	[a]9.36	[a]7.39	[a]10.56
Site 2	[b]98.39	[b]1.00	[a]0.61	[a]0.00	[a]0.00
Site 3	[b]88.78	[ab]6.88	[a]1.11	[a]1.67	[a]1.56

[ab]Values within columns with different letters were different at $P \leq 0.05$

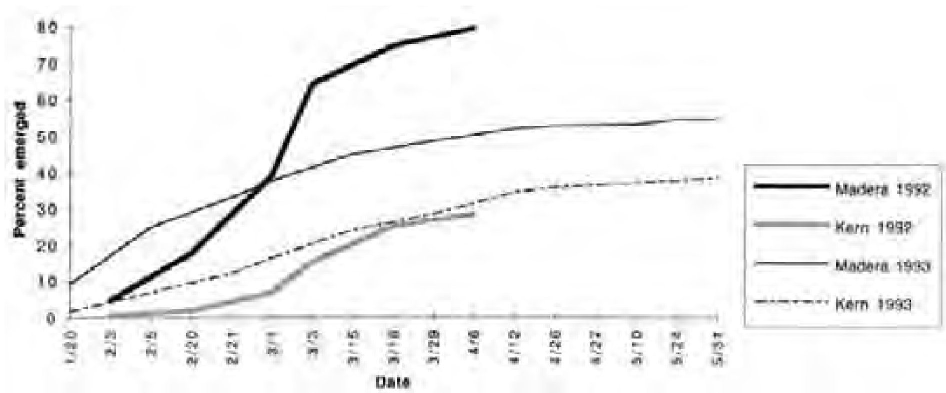
than 26 years old when compared to Site 2 (0.0 and 0.0, respectively) and Site 3 (3.23 and 1.56, respectively). It appears that the seedlings that do survive grow very slowly and live for a long time in the seedling size class.

Acorn Viability from Kern and Madera Counties

Early work by Phillips (1992) indicated there was a difference in acorn germination rate between locations and elevations in Kern and southern Tulare Counties. Based on these findings, two studies were conducted in 1992 and 1993 to evaluate viability of acorns from Madera and Kern Counties (northern and southern extremes of the survey study). Forty acorns were collected from five trees in the four rainfall zones in each county (Phillips and others 1995). The acorns were planted in outside germination frames containing sand. The first-year emergence and germination data were collected from November 3, 1991, through May 15, 1992. The second year the same data were collected from October 16, 1992, through June 8, 1993. At the end of emergence phase of the studies, each acorn was evaluated for emergence, sprouting, and not sprouting. If the radicle had erupted from the acorn, it was classified as sprouted, and the shoot must have broken the soil surface before the acorn was classified as emerged.

Both years of emergence data (*fig. 2*) showed that the acorns from Madera County emerged earlier and at a significantly faster rate than acorns from Kern County. *Figure 3* shows data for emergence and sprouting over 2 years. The percent of acorns that did not sprout was inconsistent. Kern County had the largest percentage in 1992 (30.0 percent vs 8.5 percent), but Madera County had the largest percentage in 1993 (21.4 percent vs 7.75 percent). During both years, a significantly larger percent of the acorns from Kern sprouted but did not emerge (41.3 percent vs 12.3 percent, 1992; 56.5 percent vs 25.3 percent, 1993). Also, during both years there was a significantly higher percent of emergence for Madera County than

Figure 2—Average percent emergence of seedlings by date, for Madera and Kern Counties for years 1992 and 1993.



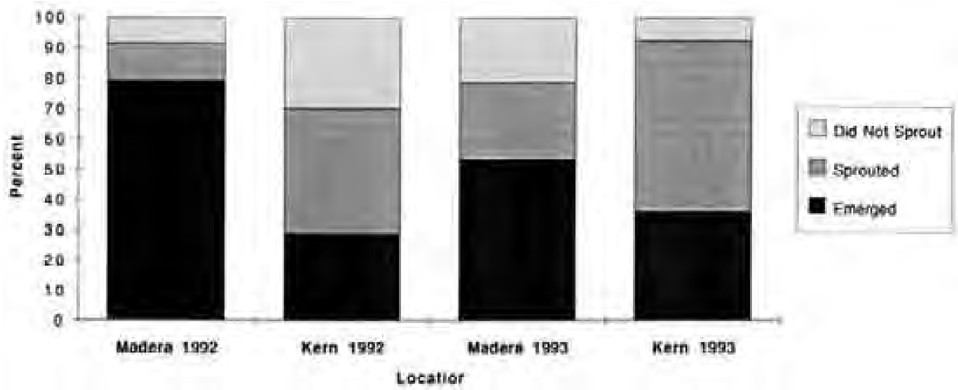


Figure 3—Average percentage of acorns that sprouted, emerged, or did not sprout, for Madera and Kern Counties for years 1992 and 1993.

Kern County (79.3 percent vs 28.7 percent, 1992 and 53.4 percent vs 36.3 percent, 1993). In 1993, "the sprouted but did not emerge" categories were divided into live sprouts/dead sprouts. Acorns from Kern County had more dead sprouts (41.6 percent) than those from Madera (21.1 percent).

This trial showed that something was preventing a large percentage of the acorns from Kern County from emerging after they sprouted. Acorn weight could account for part of the difference in emergence because acorns from Madera County were consistently heavier (1.4 grams the first year and 1.9 grams the second year) than the acorns from Kern County. However, these weight differences were not significant for both years. The possibility of genetic difference between the two oak populations could be an explanation and needs further study.

Conclusions

The survey study indicated there was a good population of the seedling and mature size classes of blue oaks. However, the population of trees in the sapling and pole size classes was limited and could raise concern regarding maintaining blue oak stands in this region. The survival rate of seedlings appeared to be adequate during the short time frame of this study, but the seedlings did not grow in height during the 4-year drought period. The age data indicated that many of these trees have been around for many years even though they were not growing in height. There appear to be geographic factors affecting the emergence of blue oak seedlings.

References

Allen-Diaz, B.; Bartolome, J.W.; 1992. **Survival of *Quercus douglasii* (Fugaceae) seedling under the influence of fire and grazing.** Madroño 39: 47-53.

Phillips, Ralph L. 1992. **Environmental factors contribute to acorn quality**. California Agriculture 46: 30-32.

Phillips, Ralph L.; McDougald, Neil K.; McCreary, Douglas. 1995. **Blue oak acorns more viable in Madera County than Kern County**. California Agriculture 49: 18-21.

Phillips, Ralph L.; McDougald, Neil K.; Standiford, Richard B.; Frost, William E. [In press]. **Oak seedling survival in Kern County**. California Agriculture.

Standiford, Richard B.; McDougald, Neil K.; Phillips, Ralph L.; Nelson, Aaron. 1991. **South Sierra oak regeneration weak in sapling stage**. California Agriculture 45: 12-14.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1991. **Insect and disease impacts on blue oak acorns and seedlings.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 149-155.

Understory-Canopy Relationships in Oak Woodlands and Savannas[1]

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***Abstract**: We summarize available information about the relationships between oak overstory and understory plants for major California rangeland types. Understory biomass, productivity, and plant species composition vary considerably because of geographic location, overstory species composition, and overstory density and distribution. Deciduous oak canopies in areas with less than 50 cm annual precipitation generally have either no effect or enhance understory productivity compared to adjacent grassland. Dense canopies in areas with more than 50 cm annual precipitation generally suppress understory productivity. Forage management implications are summarized for different woodland types around the State.*

The five major hardwood rangeland habitat types used in the California Wildlife Habitat Relationships System, occupying nearly 4 million ha, have been defined and mapped in California (Standiford and Tinnin 1996). The types, with dominant species in parentheses, are: blue oak woodland (*Quercus douglasii*); blue oak-foothill pine woodland (*Q. douglasii* and *Pinus sabiniana*), valley oak woodland (*Q. lobata*), coastal oak woodlands (*Q. agrifolia*, with *Q. engelmannii* in the south), and montane hardwood (*Quercus chrysolepis, Q. wislizenii, Q. garryana,* and *Q. kelloggii*).

Cover of the understory of oak woodlands and savannas is predominately annual grasses native to the Old World. Species composition under the canopy differs from that in the adjacent open grassland. Productivity and chemical composition also show striking differences that are important considerations for management. We summarize published information about understory composition and productivity applicable to forage management in oak-dominated vegetation.

Species Composition

Studies in the North Coast Ranges and the Sacramento Valley foothills showed consistent differences in understory composition between blue oak canopy and open grassland. Murphy (1980) reported more forbs, fewer legumes, and more perennials under sheep-grazed blue oak canopy compared to adjacent grasslands. Jackson and others (1990) reported that species composition differed significantly, with ungrazed open grassland supporting *Bromus mollis, Hordeum hystrix, Avena barbata, Bromus madritensis, Lolium multiflorum, Cynosurus echinatus, Anagalis arvensis, Daucus pusillus, Geranium molle, Madia* spp., and *Trifolium* spp. The understory was primarily *Brachypodium distachyon, Bromus diandrus, Lolium multiflorum, Bromus mollis, Hordeum leporinum, Daucus pusillus, Geranium molle, Silene* sp., and *Silybum marianum*.

Jansen (1987) reported understory composition in cattle-grazed areas similar to that reported in the other northern studies. Open grassland was composed of *Bromus mollis, Erodium botrys, Trifolium hirtum, Taeniatherum asperum, Vulpia megalura* (sic), and *Lolium multiflorum*, while the denser woodlands were *Cynosurus echinatus, Lolium multiflorm, Bromus mollis, Geranium molle, Trifolium hirtum, Bromus madritensis,* and *Stipa pulchra.*

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Mangement, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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In ungrazed woodlands and savannas in the central coast, Callaway and others (1991) found that some blue oaks facilitated understory productivity and some suppressed it. Composition in open grassland was mostly *Avena fatua* with some *Bromus mollis, Stipa pulchra,* and *Erodium botrys*. The understory was mainly *Bromus diandrus, Bromus mollis, Avena fatua,* and *Hordeum leporinum*. Savanna trees that facilitated understory productivity had relatively more *Hordeum leporinum* cover while the suppressive trees had relatively more *Stipa pulchra* understory cover. Holland (1980) described ungrazed open grassland and understory of blue oak canopies in the San Joaquin Valley and Central Coast. *Erodium botrys, Bromus mollis, Avena fatua,* and *Bromus diandrus* characterized open grassland. Species under trees dead for more than 25 years were *Bromus diandrus, Avena fatua, Erodium botrys*, and *Hordeum leporinum* while the live tree understory was primarily *Bromus diandrus, Avena fatua*, and *Bromus mollis*.

In their survey of the grazed understory of blue oaks at about 50 percent canopy along a rainfall gradient from 40 to 90 cm/yr, McClaran and Bartolome (1989) found that differences in composition of the understory and adjacent open grassland were consistent over wide areas. *Bromus mollis, Erodium cicutarium, Avena barbata,* and *Lupinus bicolor* dominated the grassland while *Festuca megalura* and *Bromus diandrus* were the most common understory species.

Live oaks appear to have comparable effects on understory composition in north and south coastal areas. Maranon and Bartolome (1993) report that light-requiring species *Lolium multiflorum, Bromus mollis,* and *Hypochoeris glabra* occurred primarily in open grassland, while shade-tolerant species in an adjacent coast live oak understory were *Montia perfolioata* and *Stellaria media*. *Bromus diandrus* did well in both habitats. *Avena fatua* dominated full-sun unclipped plots while *Bromus diandrus, Bromus mollis*, and *Lolium multiflorum* did better with clipping. In Southern California, Parker and Muller (1982) described an ungrazed grassland dominated by *Avena fatua*, and a live oak understory dominated by *Pholistoma auritum* and *Bromus diandrus*.

According to the work cited above, three widespread grass species, *Bromus mollis, B. diandrus,* and *Lolium multiflorum,* are generally common in both open and canopy. *Avena barbata* was reported common only in open, while *A. fatua* was reported common in southern grasslands and canopy. *Erodium botrys* and *Taeniatherum asperum* were common only in grassland. Striking and consistent differences in understory composition between open grassland and tree canopy understory are found throughout the State's oak woodlands and savannas.

Herbage Productivity

Tree canopy effects on understory composition and productivity depend upon rainfall, tree cover, and persistence of oak leaves on the tree. The basic pattern of biomass accumulation in California grasslands may be described as rapid fall growth following germination, slow winter growth, rapid spring growth, and summer seed set (Jackson and others 1990) (*fig. 1*). The basic pattern is altered by presence of an oak overstory.

In higher rainfall areas, the canopy suppresses understory biomass throughout the growing season. The degree of suppression depends on canopy density and is greater with evergreen species than deciduous species on similar sites (Pitt and Heady 1978). Sites comparing areas with trees to areas with trees cut and removed furnish most of the information about canopy effects in the northern part of the state.

Jansen (1987) studied canopy effects for 7 years on sites with 25, 50, and 75 percent tree cover and examined the effects of subsequent clear-cutting on seasonal production and composition at the Sierra Foothill Range Field Station

(SFRFS) near Marysville in the eastern Sacramento Valley. He found that clear-cut areas always produced more total herbage than treed areas or even grassland, although there was considerable yearly variation. Grassland produced more than the treed areas but differences were not apparent until spring.

Results from another site at Sierra Foothill Range Field Station produced long-term data on understory productivity. Kay and Leonard (1980) reported more grass under killed blue oaks than in a dense woodland. Forage productivity averaged 66 percent more if the tree roots were killed, 45 percent if only the tops were killed. In a later report (Kay 1987), productivity measurements during 21 years after tree removal showed mostly increased herbage productivity for the first 15 years (3 of 15 years were lower). Natural grasslands produced 26 percent more forage than treed areas. Increased production disappeared after the 15th year on the cleared sites. They removed accumulated mulch each year, at first by grazing, then later by mowing. On yet another SFRFS site, Jackson and others (1990) did not find differences in herbage productivity between canopy and open. Similar amounts of herbaceous biomass were present in two areas; soil moisture potential also differed little between canopy and open in their study.

Murphy (1980) reported 20 years of data from the Hopland Field Station in Mendocino County. Forage yield averaged 2,200 kg/ha in open grassland, 1,300 kg/ha under a mostly blue oak canopy. Similar reports from Hopland were reported by Bartolome and McClaran (1992) who found few within-year effects of seasonal grazing, but many between-year effects. They found less seasonal and total productivity in oak understory and more variation among years in fall-winter productivity compared to open grassland. Understory productivity averaged 50 percent of open grassland in fall/winter and 33 percent of open in spring.

Kay (1987) discussed the effect of canopy cover on year-to-year variability in forage yield. He found the improved forage yield on cleared sites was greatest in dry years, and he observed a greater yearly variation under the canopy than in open grassland. Jansen (1987) did not find a significant canopy effect on year-to-year variability.

Farther south, in regions with less precipitation such as the San Joaquin Valley, the canopy effect becomes neutral or enhances understory productivity. In contrast to the information from northern California, which is derived from experimental removal of canopy, most of the information about the south is derived from comparisons of intact canopy and adjacent open grassland. The effect appears to be highly variable by season and year for a given site.

Several important studies were conducted at the San Joaquin Experimental Range in the San Joaquin Valley north of Fresno. In a 2-year study, Frost and

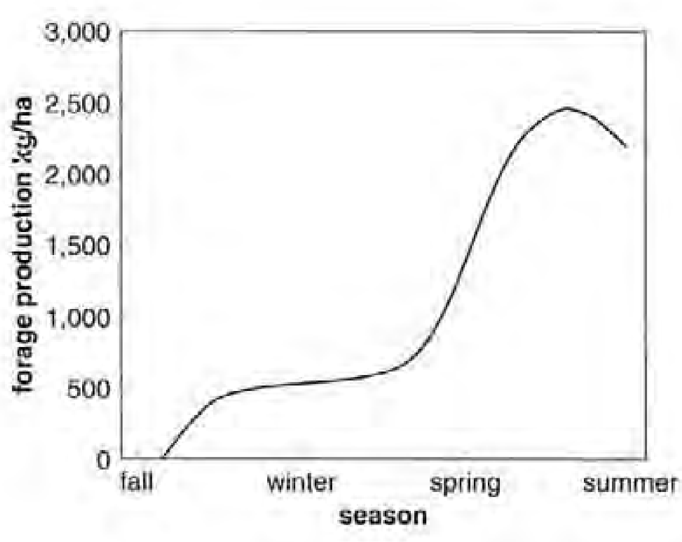

Figure 1—Typical pattern of seasonal forage growth on California's hardwood rangelands.

McDougald (1989) reported that early-season production increased in some years under the canopy. Compared to open grassland, the peak herbage under blue oak canopy was about 1,000 kg/ha greater and peak herbage under interior live oak was 700 and 1,000 kg/ha greater in the 2 years. Under foothill pine, forage was 500 kg/ha greater the first year, then not different in the second. Both years of this study had below-average precipitation. Frost and others (1991) also reported more productivity under blue oaks in late winter and at the spring peak. Frost and Edinger (1991) found more herbage production under scattered blue oak (6 percent tree canopy cover), less under foothill pine and interior live oak (12 percent tree canopy cover).

Bartolome and others (1994) removed blue oaks in San Luis Obispo County and produced a moderate increase in herb cover from 24.3 percent to 32.6 percent but no increase in herbage production. This result differs from other studies based on comparison of canopy and open, suggesting that tree-occupied sites may not have the same productive potential as nearby open grassland. McClaran and Bartolome (1989) reported that understory peak forage productivity was not enhanced in comparison to open grassland by 50 percent local canopy cover of blue oak in areas with less than 50 cm annual precipitation.

In the driest savannas with sparse canopy cover, individual trees may enhance productivity in comparison to adjacent grassland (Callaway and others 1991). Holland (1980) documented forage under blue oaks to be double that of open grassland in an ungrazed area. Once trees die, the level of productivity gradually declines to grassland levels. Duncan and Clawson (1980) note that Duncan has found more forage under blue oak in winter and spring.

Denser stands of trees, especially evergreen, consistently suppress understory forage productivity in the northern part of California. When trees are removed, productivity increases, often dramatically for a few years. In sparser stands and in the central part of the State, the tree canopy has a neutral or positive effect on forage productivity.

Forage Quality

Understory forage consistently is significantly higher in important nutrients than adjacent open grassland. Frost and others (1991) reported more protein and lower acid-detergent fiber and lignin in canopy compared to open. Blue oaks generally improve both the amount and quality of forage in the area of the San Joaquin Experimental Range. Holland and Norton (1980) found that herbs under blue oak had significantly more nitrogen, protein, phosphorus, potassium, and biomass than adjacent grassland. Kay (1987) observed significantly more nitrogen in tree understory forage and also more phosphorus, phosphate, and sulfate than in open grassland.

Kay and Leonard (1980) found that understory botanical composition shifted to more desirable forage species after tree killing, mainly because of an increase in *Bromus mollis*. This claim was repeated by Menke (1989). In contrast, Bartolome and McClaran (1992), Murphy and Crampton (1964), and Pitt and Heady (1978) observed negligible differences in forage quality due to species composition and suggested that overall quality of understory and open grassland is similar. Jansen (1987) claims that there are more undesirable plants in open than understory.

Reports of differences in composition of forage species in relation to forage quality are inconsistent: the differences in chemical composition are not. However, forage quality varies so much seasonally within sites that small differences in composition and quality between understory and open are usually unimportant as management considerations. An exception could be early-season enhancement of forage growth under canopy in the San Joaquin Valley. Frost and others (1990) suggested that moving cattle to areas with scattered blue oaks helps deal with drought because of better early-season forage under trees.

Grazing in the Understory

Very few studies have investigated grazing effects on oak understories. This contrasts dramatically with the many studies of grazing in open grassland.

Hatch and others (1992) found that recovery of native species from grazing has been highly erratic over a 25-year period in exclosures at the Hopland Field Station. In an ungrazed grassland, perennials increased from 1.8 plants/m^2 in 1958 to 2.6/m^2 in 1991 after a decline to 1.1/m^2 in 1979. In adjacent ungrazed woodland, perennials increased dramatically from 0.3/m^2 in 1958 to 2/m^2 in 1991. Change in the understory was mainly a steady increase in *Elymus glaucus*. The successional pathways differed strikingly in woodland and grassland.

Most observers have commented subjectively on the differences in grazing pressure in open grassland and the oak understory. For example, Duncan and Clawson (1980) reported that cattle prefer forage under blue oak canopy. But on the basis of utilization data, Bartolome and McClaran (1992) found no important seasonal or overall differences in utilization between canopy and open at Hopland. They also found few within-year effects of seasonal grazing by sheep on composition or productivity, but many between-year effects, which were apparently closely tied to weather patterns and the level of residual dry matter.

Management of Understory Forage

Table 1 summarizes the effects of oak canopies on understory forage productivity. The amount and quality of forage differs according to oak species and canopy cover. Given equal canopy density, live oaks suppress understory forage more than deciduous oaks. *Figure 2* generalizes the effect of 50 percent blue oak canopy on understory productivity, illustrating differences due to rainfall and/or geographic location. In the drier zone of the blue oak woodland with less than 50 cm annual precipitation, understory productivity is similar to or greater than open grassland.

Clearing of oaks was frequently recommended for range improvement and where stands are dense, especially with live oaks dominant, understory forage production can be considerably enhanced. In drier areas, especially those with deciduous canopies, less than 50 cm annual precipitation, and canopy cover less than 50 percent, the understory will not reliably respond to tree removal with increased productivity. There is considerable evidence that scattered trees consistently enhance forage productivity (*table 1*).

Forage quality under oak canopies is related to chemical composition of herbage and species composition. The oak understory is consistently higher in nitrogen and other minerals than adjacent grassland which should lead to better nutrient quality. However, when species composition is included, unpalatable species may be present. Although seasonal preference for understory forage has been frequently noted, it appears likely that species composition includes desirable and undesirable species in both open grassland and oak understory. Understory forage quality should not be a major consideration in forage management.

The effects of grazing on understory forage are very little studied, as are the successional relationships among understory species. This lack of information contrasts strikingly with the abundant information about open grasslands. Management of the understory forage has been assumed to fit the model for a scheme based on residual dry matter successfully applied to grasslands, but

Table 1—Effect of oak canopy on hardwood rangeland forage production summarized from the literature

Species group	Canopy cover	Winter forage	Spring forage production
Live oaks	Scattered (cover <10 pct)	-/+	-/+
	Sparse (cover 10-25 pct)	-/+	-/+
	Moderate (cover 25-60 pct)	-	-
	Dense (cover >60 pct)	-	-
Deciduous oaks	Scattered (cover <10 pct)	+	+
	Sparse (cover 10-25 pct)	+	+
	Moderate (cover 25-60 pct)	-/+	-/+
	Dense (cover > 60 pct)	-	-

[1]A "+" indicates that forage production is enhanced by oak canopy and a "-" indicates that forage production is inhibited by oak canopy.

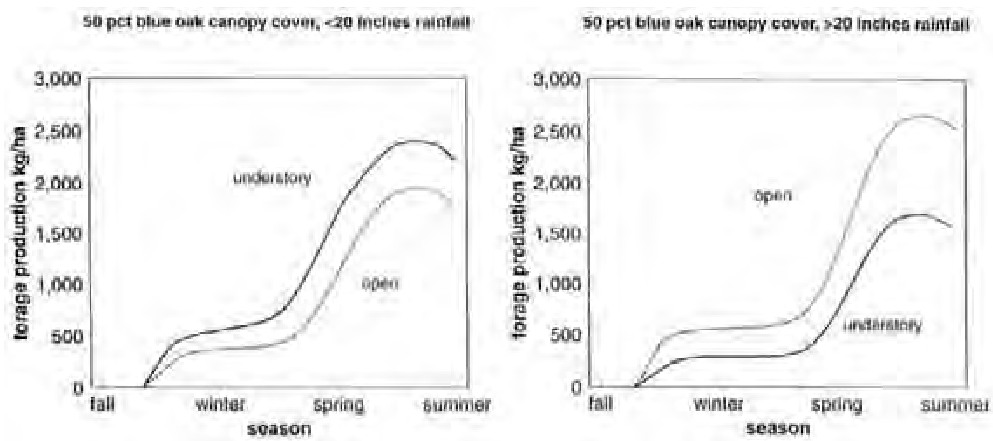

Figure 2—Effect of 50 percent blue oak canopy cover on seasonal forage production compared with open annual grassland in two rainfall zones (adapted from data of McClaran and Bartolome 1989).

there is little good research to back up this assumption. Because of the highly variable nature of the canopy effect, many more site-specific studies are needed to fully examine management options.

The mechanisms for canopy influence on the understory have been frequently investigated but rarely successfully. The expression of canopy dominance has been variously ascribed to shade (Maranon and Bartolome 1994), allelopathy (Parker and Muller 1982), water relations (Callaway and others 1991), and nutrient dynamics (Jackson and others 1990) in different combinations of sites, species, and circumstances. It appears that the generalizations about overstory-understory patterns do not have a simple suite of causal explanations. Likewise, management recommendations need to be developed conservatively, with overstory removal for forage enhancement limited to dense stands exceeding 50 percent canopy and with more than 20 inches of mean annual precipitation.

References

Bartolome, J.W.; Allen-Diaz, B.H.; Tietje, W.J. 1994. **The effect of *Quercus douglasii* removal on understory yield and composition.** Journal of Range Management 47: 151-154.

Bartolome, J.W.; McClaran, M.P. 1992. **Composition and productivity of California oak savanna seasonally grazed by sheep.** Journal of Range Management 45: 103-107.

Callaway, R.M.; Nadkarni, N.M.; Mahall, B.E. 1991. **Facilitation and interference on *Quercus douglasii* on understory productivity in northern California.** Ecology 72: 1484-1489.

Duncan, D.A.; Clawson, W.J. 1980. **Livestock utilization of California's oak woodlands.** In: Plumb, T.R., technical coordinator. Proceedings of the symposium on ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 306-312.

Frost, W.E.; Edinger, S.B. 1991. **Effects of tree canopies on soil characteristics of annual rangeland.** Journal of Range Management 44: 286-288.

Frost, W.E.; McDougald, N.K. 1989. **Tree canopy effects on herbaceous production of annual rangeland during drought.** Journal of Range Management 42: 281-283.

Frost, W.E.; McDougald, N.K.; Demment, M.W. 1991. **Blue oak canopy effect on seasonal forage production and quality.** In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 307-311.

Frost, W.E.; McDougald, N.K.; Nelson, A.O. 1990. **Coping with drought: range and livestock management recommendations.** San Joaquin Experimental Range Research Bulletin. January 1990. 4p.

Hatch, D.A.; Bartolome, J.W.; Heady, H.F.; McClaran, M.P. 1992. **Long-term changes in perennial grass populations in oak savanna.** Bulletin of the Ecological Society of America (supplement) 73(2): 202.

Holland, V.L. 1980. **Effect of blue oak on rangeland forage production in Central California.** In: Plumb, T.R., technical coordinator. Proceedings of the symposium on ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 314-318.

Holland, V.L.; Norton, J. 1980. **Effect of blue oak on nutritional quality of rangeland forage in central California.** In: Plumb, T.R., technical coordinator. Proceedings of the symposium on ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 319-322.

Jackson, L.E.; Strauss, R.B.; Firestone, M.K.; Bartolome, J.W. 1990. **Influence of tree canopies on grassland productivity and nitrogen dynamics in a deciduous oak savanna.** Agriculture, Ecosystems, and Environment 32: 89-105.

Jansen, H.C. 1987. **The effect of blue oak removal on herbaceous production on a foothill site in the Northern Sierra Nevada.** In: Plumb, T.R.; Pillsbury, N.H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 343-350.

Kay, B.L. 1987. **Long-term effects of blue oak removal on forage production, forage quality, soil, and oak regeneration.** In: Plumb, T.R.; Pillsbury, N.H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 351-357.

Kay, B.L.; Leonard, O.A. 1980. **Effect of blue oak removal on herbaceous forage production in the North Sierra foothills.** In: Plumb, T.R., technical coordinator. Proceedings of the symposium on ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 323-328.

Maranon, T.; Bartolome, J.W. 1993. **Reciprocal transplants of herbaceous communities between *Quercus agrifolia* woodland and adjacent grassland.** Journal of Ecology 81: 673-682.

Maranon, T.; Bartolome, J.W. 1994. **Coast live oak (*Quercus agrifolia*) effects on grassland biomass and diversity.** Madroño 41: 39-52.

McClaran, M.P.; Bartolome, J.W. 1989. **Effect of *Quercus douglasii* (Fagaceae) on herbaceous understory along a rainfall gradient.** Madroño 36: 141-153.

Menke, J.W. 1989. **Management controls on productivity.** In: Huenneke, L.F.; Mooney, H.A., eds. Grassland structure and function: California annual grassland. Dordrecht: Kluwer Academic Publishers: 173-199.

Murphy, A.H. 1980. **Oaks and livestock—Management options.** In: Plumb, T.R., technical coordinator. Proceedings of the symposium on ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 329-322.

Murphy, A.H.; Crampton, B. 1964. **Quality and yield of forage as affected by chemical removal of blue oak (*Quercus douglasii*).** Journal of Range Management 17: 142-144.

Parker, V.T.; Muller, C.H. 1982. **Vegetational and environmental changes beneath isolated live oak trees (*Quercus agrifolia*) in a California annual grassland.** American Midland Naturalist 107: 69-81.

Pitt, M.D.; Heady, H.F. 1978. **Responses of annual vegetation to temperature and rainfall patterns in Northern California.** Ecology 59: 336-350.

Standiford, R.B.; Tinnin, P. 1996. **Guidelines for managing California's hardwood rangelands**. Oakland, CA; University of California, Division of Agriculture and Natural Resources Publication 3368: 173 p.

Fire History of a Mixed Oak-Pine Forest in the Foothills of the Sierra Nevada, El Dorado County, California[1]

Scott L. Stephens [2,3]

Abstract: *Fire history and stand composition (species, density, basal area) of a mixed oak-pine forest was investigated in three plots with varied aspects (south, east) and slopes (5 , 30, and 50 percent) in Diamond Springs, El Dorado County, California. Elevation varied from 530 to 600 m in the fire history plots. Oaks dominate the area, contributing 75 percent of the basal area. Fire history information from 1850 to 1952 was obtained from 31 ponderosa pine stumps that were logged in 1952. Mean fire intervals in the three plots were 7.8, 7.8, and 7.7 years and the period between fires varied from 2 to 18 years. The last fire in this area occurred in 1947. Although the sources of these fires are uncertain, the use of fire by early range managers is a plausible explanation given the past land uses of this area.*

Vegetation types common in the Sierra Nevada foothills include foothill woodlands, chaparral, mixed evergreen woodlands, and California black oak (*Quercus kelloggii*) forests (Baker and others 1981). Very little fire history information exists for these vegetation types (Parsons 1981). The lack of fire history information is in part due to a lack of trees that are appropriate (old, fire-scarred trees resistant to decay) for fire-scar sampling because of early logging, range improvement, and firewood cutting operations.

One fire history study has been carried out in foothills of the Sierra Nevada at the University of California Sierra Foothill Range Field Station, 30 km east of Marysville, California (McClaran and Bartolome 1989). In this study, fire-scarred trees were sampled in a blue oak (*Quercus douglasii*) woodland. Mean fire intervals (MFI) (Stokes 1980) at two sites within the field station were 7.4 years. Fire intervals varied from 2 to 17 years and there was no significant difference ($p > 0.2$) in MFI between the sites from 1890 to 1948. MFI was significantly reduced between Anglo-American settlement in 1848 and fire suppression in the 1940's because of historic range management practices (McClaran and Bartolome 1989).

Fire scars can be assigned a calendar year when cross-dating techniques are used (Swetnam and others 1985). With this technique, a composite fire history can be produced, and differences in MFI over the sampling period can be examined. When cross dating techniques are not possible because of false and missing rings, intervals between fires have been reported (Finney and Martin 1992).

Significant Anglo-American settlement in foothill woodlands started shortly after the discovery of gold in 1848, and large numbers of livestock and alien annual plants became landscape dominants by 1900 (Burcham 1957). Early investigators reported that burning was a common practice in the foothills of the Sierra Nevada from 1900 to 1940 (Leiberg 1902; Sampson 1944). Ranchers commonly burned oak forests/woodlands to maintain forage production, and the intervals between fires were commonly between 8 and 15 years (Sampson 1944).

Native Americans also influenced the fire regime in the foothills of the Sierra Nevada. Native Americans possibly shortened the intervals between fires for specific land management objectives (Anderson 1993). More than 75 percent of the plant material used by most tribes of the Sierra Nevada came from epicormic branches or adventitious shoots from a diverse group of native plants (Anderson 1993). New shoots were long, flexible and straight, had few bark blemishes, and were not forked,

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making them excellent material for basket making. Shoots with these characteristics are produced only after fire or pruning. Native Americans also specifically burned areas with California black oak to reduce the loss of acorns to insects such as filbert worms (*Melissopus latiferreanus*) and filbert weevils (*Curculio* spp.) (Anderson 1993). Many of the Native American-ignited fires probably spread extensively through the mixed oak-pine forests in the foothills of the Sierra Nevada.

Fires that occurred prehistorically in the Sierra Nevada burned in a variety of sizes, severities, intervals, and, to a lesser extent, seasons (Swetnam and others 1992). Fire suppression has changed the prehistoric fire regimes of the Sierra Nevada by suppressing most low- and moderate-intensity events. This fundamental change has reduced pyrodiversity (the variety in intervals between fires, seasonality, and fire characteristics, producing biological diversity at the micro, stand and landscape scales [Martin and Sapsis 1991]) in mixed oak-pine forests of the Sierra Nevada. The resulting diverse ecosystem structures, in turn, produced the conditions necessary for future diverse fires. Today, most low- and medium-intensity fires are suppressed by wildfire agencies. The most extreme fires burn, because suppressing these fires is almost impossible given high fuel loads coupled with extreme fire weather (Stephens 1995).

The objective of this paper is to develop a fire history for a mixed oak-pine forest in the foothills of the Sierra Nevada. Information from this study can be used to determine the historic fire regime that occurred in this ecosystem in the late 19th and mid-20th centuries.

Methods

Study Area

Fire history was investigated in a mixed oak-pine forest in the foothills of the Sierra Nevada approximately 8 km southwest of the town of Diamond Springs, California (*fig. 1*). The plots are located in T9N R11E NE 1/4 of section 17, latitude 38° 38′, longitude 120° 46′ 45″, between 530 and 600 m above sea level, approximately 1.5 km northwest of the North Fork of the Cosumnes River.

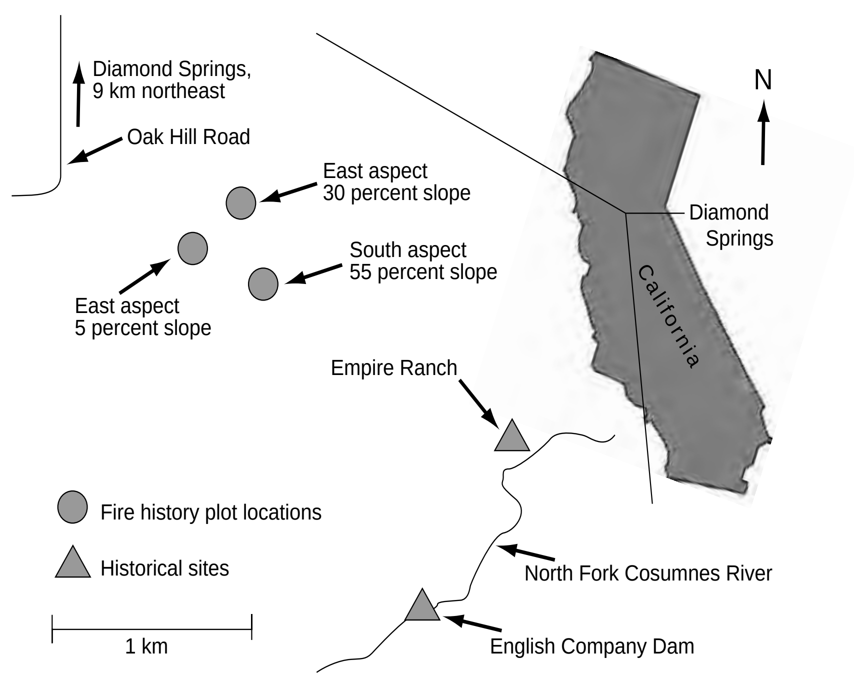

Figure 1—Location of fire history plots in a mixed oak-pine forest in the foothills of the Sierra Nevada, El Dorado County, California.

Forest Composition

Twelve 0.04-ha circular plots were randomly placed within the 10-ha study area to determine forest composition. All trees greater than 1.37 m in height were measured at diameter at breast height (DBH). The following stand parameters were calculated for each species: basal area (m^2/ha), tree density (trees/ha), average quadratic mean diameter (DBH), percent basal area by species, and percent tree density by species. The diameter of all ponderosa pine (*Pinus ponderosa*) stumps within the 12 plots were also measured, and stump density and basal area were calculated. Stump diameter was measured at approximately 40 cm above the soil surface.

Fire History

Thirty-one fire-scarred ponderosa pine stumps were sampled in three fire history plots. Combinations of aspect and slope (east aspect, 5 percent slope; east aspect, 30 percent slope; south aspect, 55 percent slope) were used to determine whether these factors affected MFI. The Smirnov test (Lehmann 1975) was performed to evaluate whether significant differences ($P < 0.05$) in MFI existed between sample locations (McClaran and Bartolome 1989). The sampled area was logged in 1952, and all ponderosa pines larger than 30 cm DBH were harvested. An extensive survey of the area produced only two live ponderosa pines with fire scars, and they were sampled to determine the last year that a fire had occurred in the study area. Fire-scarred interior live oak (*Quercus wislizenii*) trees were found in the study area, but determination of MFI was impossible because of extensive rot in the scarred area.

Ponderosa pine stumps were sectioned with a chainsaw in order to locate the best series of fire scars (Finney and Martin 1992); up to four wedges or full cross sections for each stump were removed and taken to the laboratory for analysis. All fire scar samples were sanded to a smoothness of 400 grit. Fire scars were identified by the characteristic disruption and healing patterns of radial tree-ring growth (McBride 1983, Finney and Martin 1992).

Intervals between fire scars were obtained by counting annual rings. Annual rings were counted along radii with the widest increment; often this involved tracing individual rings from zones of narrow growth to those of wider increment (Finney and Martin 1992). Scar intervals were assembled for each stump, and plot MFI was calculated by averaging all fire intervals within each of the fire history plots.

Results

This mixed oak-pine forest is composed of interior live oak, canyon live oak (*Quercus chrysolepis*), foothill pine (*Pinus sabiniana*), black oak, gray leaf manzanita (*Arctostaphylos viscida*), ponderosa pine, toyon (*Heteromeles arbutifolia*), valley oak (*Quercus lobata*), California buckeye (*Aesculus californica*), and blue oak in order of decreasing basal area (*table 1*). Average tree density was 1,635 trees/ha, and average basal area was 30.27 m^2/ha. Oaks dominate the area, comprising 75 percent of the average basal area, whereas ponderosa and foothill pines contributed 16 percent of the basal area. Ponderosa pine stump density was 16.67 stumps/ha (standard error = 4.7), and average stump basal area was 7.95 m^2/ha (standard error = 2.38). Stump diameter varied from 56 to 110 cm in all plots.

Average MFI for the east aspect 5 percent slope, east aspect 30 percent slope, and south aspect 55 percent slope were 7.8, 7.8, and 7.7 years, respectively (*table 2*). No significant differences ($P > 0.05$) in MFI were detected between the three fire history plots. Fire intervals varied from 2 to 18 years within the three plots (*figs. 2–4*).

Table 1—Summary of average mixed oak-pine forest inventory calculations in the foothills of the Sierra Nevada, El Dorado County, California[1]

Species	Basal area	Density	DBH	Pct basal area	Pct density
	m^2 /ha	*trees/ha*	*cm*	*pct*	*pct*
Interior live oak	14.50 (1.57)	692.53 (80.5)	16.54 (0.93)	47.91	42.35
Canyon live oak	5.62 (2.55)	200.09 (83.99)	17.73 (2.56)	18.57	12.24
California black oak	2.19 (0.66)	25.25 (8.70)	31.56 (3.03)	7.23	1.53
Gray leaf manzanita	2.17 (0.67)	260.74 (63.10)	10.45 (1.63)	7.18	15.94
Toyon	0.40 (0.13)	348.12 (84.19)	3.64 (0.20)	1.31	21.30
Foothill pine	3.54 (1.24)	33.42 (10.36)	38.24 (5.62)	11.69	2.04
Ponderosa pine	1.42 (1.14)	69.20 (24.45)	10.45 (2.43)	4.68	4.21
Valley oak	0.21 (0.02)	2.08 (0.03)	36.00 (3.01)	0.70	0.13
Blue oak	0.10 (0.01)	2.08 (0.03)	25.00 (2.08)	0.34	0.13
California buckeye	0.12 (0.01)	2.08 (0.03)	27.00 (2.25)	0.39	0.13

[1] Numbers in parentheses are standard errors.

Discussion

The length of the fire history record of the east aspect, 30 percent slope plot was 102 years (*table 2*), corresponding to 1850-1952 AD. This is the period when significant Anglo-American settlement occurred in the foothill woodlands, and during this period surface fires were common. The three plots had approximately equal MFI of 7.8 years which is similar to the MFI of 7.4 years found by McClaran and Bartolome (1989) in blue oak woodlands approximately 80 km northwest of this location.

The three fire history plots were approximately 1.5 km northwest (uphill) of the Empire ranch that began operations in 1868 (possibly earlier) adjacent to the North Fork of the Cosumnes River, T9N, R11E, S16 (Peabody 1988). This area was used as winter range for cattle (Peabody 1988). Mining was also common in this area, and the English Company Dam was constructed on the North Fork of the Cosumnes River (Peabody 1988) approximately 1.75 km southeast (downhill) of the fire history plots. The dam may have been a hydraulic mining debris basin and was the origin of a ditch weir diverting water for sluicing at Dead Man Hollow and Martinez Creek (Peabody 1988). The Alta California Telegraph line was located 2 km east of the fire history plots, and it was installed in 1856 (Peabody 1988). Mining, cattle grazing, and early development were therefore extensive in this area, beginning shortly after the discovery of gold in 1848.

A Miwok Native American community was located 4 km north of the study site in Squaw Hollow (Peabody 1988). This was an extensively used area and a ceremonial roundhouse was built at this site. Several bedrock mortars and

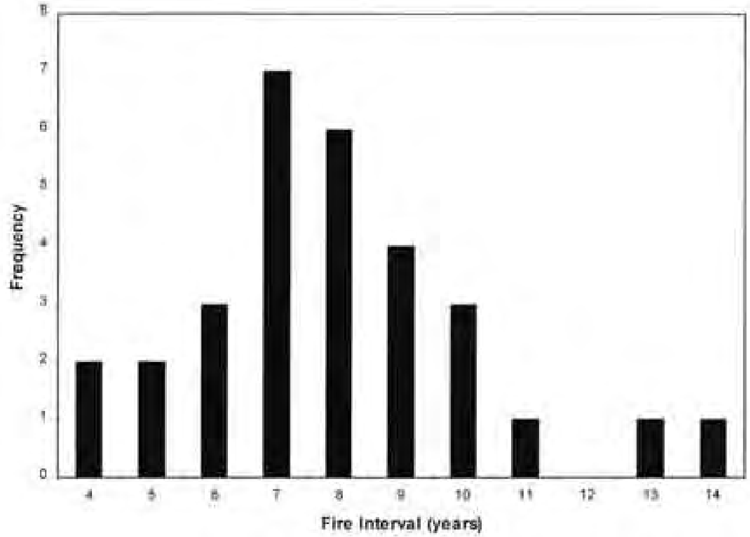

Figure 2—Distribution of fire intervals from the east aspect, 5 percent slope, fire history plot.

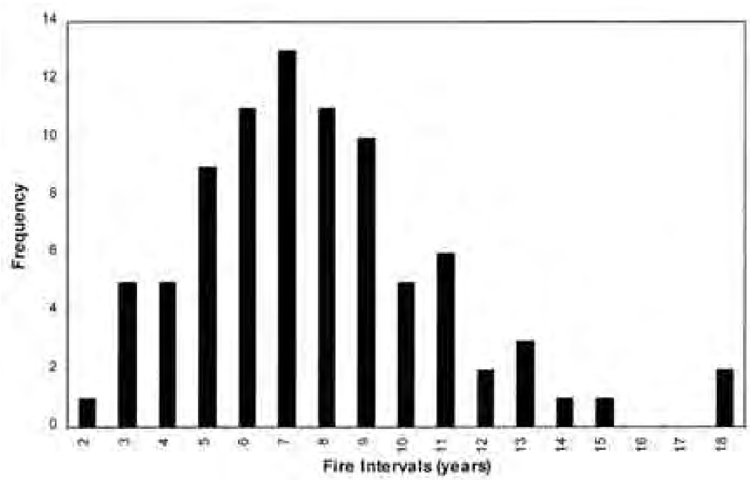

Figure 3—Distribution of fire intervals from the east aspect, 30 percent slope, fire history plot.

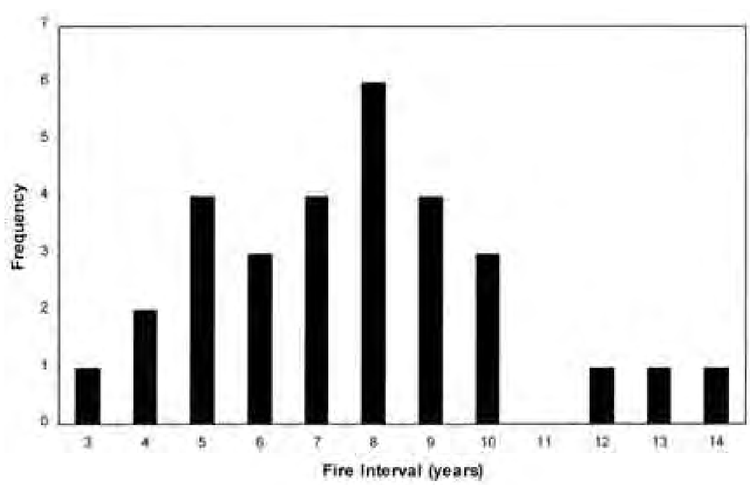

Figure 4—Distribution of fire intervals from the south aspect, 55 percent slope, fire history plot.

Table 2—Summary of fire history information in the foothills of the Sierra Nevada, El Dorado County, California

Plot location	East aspect 5 pct slope	East aspect 30 pct slope	South aspect 55 pct slope
Number of stumps sampled	7	17	7
Number of fire scars	30	85	30
Mean fire interval (yr)	7.8	7.8	7.7
Fire interval range (yr)	4 to 14	2 to 18	3 to 14
Median fire interval (yr)	7	7	8
Fire record length (yr)	87	102	82
Plot elevation (m)	600	560	530
Plot area (ha)	1.0	1.5	0.75
Last fire	1947	1947	1945

cremation grounds are located within 1.5 km of the fire history plots, indicating there was once a significant Native American presence in the region.

The fire history information analyzed in this study cannot be attributed to Native American burning because the record begins in the Anglo-American settlement period of 1850. The MFI found in this study agrees with the recorded burning practices of early ranchers (Sampson 1944).

Lightning fires are relatively rare in oak woodlands throughout California (Griffen 1988). During the 1970's, an average of 23 lightning ignitions were recorded annually for each 1,000,000 ha protected by the California Department of Forestry in the Amador-El Dorado ranger units (Keeley 1981). This study area is within the boundaries of the Amador-El Dorado ranger unit. In contrast, the number of lightning ignitions over the same period in the Eldorado National Forest was 148 for each 1,000,000 ha protected (Keeley 1981). Lightning ignitions are more common at higher elevations.

The exact origin of the fires recorded in this study cannot be determined. No comprehensive historical information exists on the number of lightning fires in this area from 1850 to 1952. Although the sources of these fires are uncertain, the use of fire by early range managers is a plausible explanation given the past land uses of this area. Other areas in the Sierra Nevada such as the mixed conifer forest had fire suppression programs beginning in the 1900's, but fires ignited for range management purposes continued at this location until the late 1940's.

Fire history studies can give accurate and precise information about the temporal distribution of the past fire regime, but MFI determined from all techniques will be conservative. This occurs because all fires may not scar a tree and scars may be destroyed by later fires, rot, and insects (Finney and Martin 1992).

Use of fire history information to reconstruct past forest structure is difficult. Evaluation of the effects and behavior of past fires is limited when the fuel complexes they operated within were fundamentally different than the present. Surface fuel complexes present during the Anglo-American settlement period in the foothills of the Sierra Nevada were dominated by annual grasses (Burcham 1957) because of the frequent burning and livestock grazing. These fires were probably of relatively low intensity (Byram 1959), but they spread extensively through the foothill communities because of high horizontal fuel continuity from the grasses.

No significant differences in MFI were detected between the three fire history plots in this study. High surface fuel continuity allowed most fires to spread throughout the study area and, therefore, similar MFI were recorded in each fire history plot. Fires that were ignited near the North Fork of the Cosumnes River could have easily spread uphill and were recorded in the fire history plots.

The study site had some relatively large ponderosa pines before being logged in 1952. The largest stump measured had a diameter of 110 cm that is much larger than the current maximum of 47 cm DBH. This forest was likely relatively open before fire suppression began in the late 1940's. Fire scars recorded in this study could have been produced from the consumption of leaf litter, dead and down fuel, and annual grasses. Current tree density of 1,635 trees/ha has produced a forest structure that is more susceptible to large, high-intensity wildfires. Frequent burning in this ecosystem reduced fire hazard because of the reduction in fuel load and fuel continuity.

A large prescribed burning program could be implemented again in this area, but restrictions from home building and development would complicate the process. Many homes have been built on 2- to 8-ha parcels in this region of El Dorado County since 1970. This development has produced a fragmented urban-wildland intermix area, and prescribed burning programs would be difficult to implement.

Conclusion

Average MFI in this mixed oak-pine forest were approximately 7.8 years from 1850 to 1952. Fire intervals varied from 2 to 18 years in this ecosystem during the early settlement period. Although the sources of these fires are uncertain, the use of fire by early range managers is a plausible explanation given the past land uses of this area.

Acknowledgment

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References

Anderson, M.K. 1993. **Experimental approach to assessment of the potential ecological effects of horticultural practices by indigenous people on California wildlands**. Berkeley: University of California. Ph.D. dissertation.

Baker, G.A.; Rundel, P.W.; Parsons, D.J. 1981. **Ecological relationships of *Quercus douglasii* in the foothill zone of Sequoia National Park, California.** Madroño 28: 1-12.

Burcham, L.T. 1957. **California rangelands: an historic-ecological study of the range resources of California.** Sacramento: California Division of Forestry.

Byram, G.M. 1959. **Combustion of forest fuels.** In: Davis, K.P., editor. Forest fire: control and use. New York: McGraw-Hill; 61-89.

Finney, M.A.; Martin, R.E. 1992. **Short fire intervals recorded by redwoods at Annadale State Park, California.** Madroño 39: 251-262.

Griffen, J.R. 1988. **Oak woodlands**. In: Barbour, M.G.; Major, J., eds. Terrestrial vegetation of California. Special publication number 9. California native plant society; 383-416.

Keeley, J.E. 1981. **Distribution of lightning and man caused wildfires in California.** In: Conrad, C.E.; Oechel, W.C., eds. Proceeding of the symposium on dynamics and management of Mediterranean-type ecosystems. Gen. Tech. Rep. GTR-PSW-58. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 431-437.

Lehmann, E. 1975. **Non-parametrics: statistical methods based on ranks**. San Francisco: Holden-Day, Inc.

Leiberg, J.B. 1902. **Forest conditions in the northern Sierra Nevada**. Professional Paper No. 8, Series H. Forestry 5. Washington, DC: USDI Geological Survey.

Martin, R.E.; Sapsis, D.B. 1991. **Fires as agents of biodiversity: pyrodiversity promotes biodiversity.** In: Proceedings of the symposium on biodiversity of northwestern California; 1991 October 28-30; Santa Rosa, CA. Berkeley: University of California Wildland Research Center; 150-157.

McBride, J.R. 1983. **Analysis of tree rings and fire scars to establish fire history**. Tree-Ring Bulletin 43: 51-67.

McClaran, M.P.; Bartolome, J.W. 1989. **Fire-related recruitment in stagnant *Quercus douglasii* populations.** Canadian Journal of Forest Research 19: 580-585.

Parsons, D.J. 1981. **The historical role of fir in the foothill communities of Sequoia National Park**. Madroño 28: 111-120.

Peabody, G.W. 1988. **The historical perspective supplement for the Pleasant Valley-Oak Hill-Sly Park area plan and environmental impact report**. Placerville, CA: El Dorado County Community Development Department, Parks and Recreation Division; 646 p.

Sampson, A.W. 1944. **Plant succession on burned chaparral lands in northern California**. Bulletin no. 685. Berkeley: University of California, College of Agriculture, Agricultural Experiment Station; 144 p.

Stephens, S.L. 1995. **Effects of prescribed and simulated fire and forest history of giant sequoia (*Sequoiadendron giganteum* [Lindley] Buchholz.)- mixed conifer ecosystems of the Sierra Nevada, California**. Berkeley: University of California; Ph.D. dissertation. 108 p.

Stokes, M.A. 1980. **The dendrology of fire history.** In: Stokes, Marvin A.; Dieterich, John H., technical coordinators. Proceedings of the fire history workshop; 1980 October 20-24; Tucson, AZ. Gen. Tech. Rep. RM-81. Fort Collins, CO: Rocky Mountain Forest and Experiment Station, Forest Service, U.S. Department of Agriculture; 1-3.

Swetnam, T.W.; Thompson, M.A.; Sutherland, E.K. 1985. **Spruce budworm handbook, using dendrochronology to measure radial growth of defoliated trees.** Agriculture handbook number 639. Cooperative State Research Service, Forest Service, U.S. Department of Agriculture.

Swetnam, T.W.; Baisan, C.H.; Caprio, A.C.; Touchan, R.; Brown, P.M. 1992. **Tree ring reconstruction of giant sequoia fire regimes**. Final report to Sequoia-Kings Canyon and Yosemite National Parks. Tucson, AZ: Laboratory of Tree Ring Research, University of Arizona; 90 p.

Efficacy of Herbicide Application Methods Used to Control Tanoak (*Lithocarpus densiflorus*) in an Uneven-Aged Coast Redwood Management Context[1]

Douglas D. Piirto[2] Brenda Smith[3] Eric K. Huff[4] Scott T. Robinson[5]

Abstract: *Three methods of tanoak (*Lithocarpus densiflorus *[Hook. & Arn.] Rehd.) control involving the application of the amine or ester form of triclopyr were evaluated in this coast redwood uneven-aged forest management study of herbicides. A cut-stump application with the amine form of triclopyr (Garlon 3A), frill cut with the amine form of triclopyr, basal-bark (outer surface) with the ester form of triclopyr (Garlon 4), and an untreated control were replicated three times. The tanoak control results in Douglas-fir (*Pseudotsuga menziesii *[Mirb.] Franco) and/or coast redwood (*Sequoia sempervirens *[D. Don] Endl.) predominated stands obtained in earlier studies in northern California and Oregon appear to be similar to the results of this study obtained in Santa Cruz County coast redwood stands. The need for tanoak control in an uneven-aged forest management context is discussed.*

Tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.)[6] is a prolific sprouter and aggressive competitor with coast redwood (*Sequoia sempervirens* [D. Don] Endl.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in mixed coniferous forests (Barrett 1995, Burns 1983, Burns and Honkala 1990a, 1990b, Little 1979, Tappeiner and others 1990). The coniferous species are commercially more valuable than tanoak (although tanoak is presently useful for fuelwood in the Santa Cruz area). Finding an effective means to control the competing populations of tanoak is often desirable. Whereas significant research information is available on controlling tanoak competition under management of even-aged forests, little information is available about controlling tanoak under management of uneven-aged coast redwood.

Although tanoak has many ecosystem values, as a source of food and cover for various species of wildlife, in cut areas following timber harvest operations, tanoak sprouting can often interfere with the natural regeneration and growth of coast redwood and Douglas-fir. In such instances, the selective use of herbicides accompanied with planting of coast redwood and Douglas-fir could help maintain the site for commercial purposes and ensure that tanoak will not be an undesirable competitor.

The goal of this research was to find an effective means to reduce a wide range of tanoak diameter classes (*fig. 1*). The specific objectives of this research project were to:

- Evaluate the efficacy of herbicide application techniques for control of tanoak, and
- Identify tanoak research priorities in the context of uneven-aged management of coast redwood and Douglas fir stands.

Literature Review

Early work to control tanoak using picloram, 2,4-D, and 2,4,5-T in a cut-frill treatment was conducted in Mendocino County, California, by Radosevich and others (1976). Ten years after treatment, tanoak mortality with 2,4-D, 2,4,5-T, and

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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[6]Scientific names are from Little (1979).

Figure 1—Dense population of varied tanoak trees sizes within the study site at Swanton Pacific Ranch.

picloram was 87, 79, and 94 percent, respectively. Only 2,4-D is still available for use in California.

A basal application of the ester form of tricloplyr (Garlon 4)[7,] yielded satisfactory results (Warren 1980a). Warren sprayed small-diameter stems of tanoak and madrone during March, June, and September, 1975. After 2 years, "good" control of tanoak was obtained when a mix of 3 gallons of Garlon 4 to 100 gallons of diesel was used. In addition, "good" control was achieved from treatments made in June and September when a mix of 1 to 2 gallons of Garlon 4 to 100 gallons of diesel was used. The best results were obtained with stems less than 3 inches in diameter.

Tappeiner and others (1987) conducted a study on tanoak control in southwestern Oregon using cut-stump, cut-frill, and basal-spray treatments at different times of the year. The herbicides tested in that study were triclopyr, 2,4-D, and picloram + 2,4-D. With the cut-stump treatments, 2,4-D, triclopyr, and picloram + 2,4-D applied during November and February caused the greater mortality and reduced total sprout length and clump area more than applications in May and August. Results of the cut-frill treatments indicated that herbicides applied during November caused the greatest dieback. Triclopyr generally produced better control with less variability. Basal treatments exhibited less control compared to the cut-frill application. Basal treatments using triclopyr gave better control in August. Although good control has been shown with picloram + 2,4-D, this herbicide is not certified for use in California.

Helgerson (1990) studied the response of underplanted Douglas-fir seedlings to herbicide control of a sclerophyll hardwood overstory. Frills around the base of the trees were each injected with 2 ml of triclopyr mixed with water (1:1, v/v). The primary species treated were tanoak, Pacific madrone (Arbutus *menziesii* Pursh.), and chinkapin (*Castanopsis chrysophylla* [Dougl.] A. DC.). Two years after treatment, 50 one-year-old (i.e. 1-0) container-grown Douglas-fir plugs and 50 two-year-old (i.e., 2-0) Douglas-fir bareroot seedlings were planted in the treated area. Helgerson concluded that stem injection of hardwoods was a viable

[7]Garlon 3A and Garlon 4 are Trademark names of products of the DowElanco Company.

approach of converting hardwood stands back to Douglas-fir; both plugs and bareroots were acceptable planting stock.

Cafferata and Yee (1991) used both the amine and ester forms of triclopyr (Garlon 3A and 4) for control of tanoak at Jackson Demonstration State Forest, Fort Bragg, California. Cut-stump, frill, and basal applications were compared. Trees evaluated 1.5 years after cut-stump treatment with Garlon 3A gave 80-84 percent control of resprouts. Garlon 3A gave 41 percent control of all frill- treated trees; 99 percent of trees treated were tanoak. Basal treatments of undiluted Garlon 4 gave 55 percent mortality of stems less than 1 inch in diameter and 12 percent mortality of stems from 1 to 3 inches in diameter, 87 percent of the treated trees being tanoak.

Additional and more detailed information on herbicide control of tanoak can be found in Cafferata and Yee (1991), Helgerson (1990), Tappeiner, and others (1987), Warren (1980a,b), and Wurm (1976). Information on the ecology and silvical characteristics of tanoak and coast redwood can be found in Barrett (1995), Burns (1983), Burns and Honkala (1990a,b), Olson and others (1990), Tappeiner and McDonald (1984), and Tappeiner and others (1990). Research work on the economic potential of tanoak has been and is currently under way at several locations in northern California (Area Independent Development Corporation 1987, California Department of Forestry 1994).

Materials and Methods

Herbicide Characteristics

After reviewing the chemicals available to control tanoak, it was decided that the best candidates were triclopyr in the form of an amine (Garlon 3A) and a triclopyr formulation containing 4 pounds of triclopyr ester per gallon (Garlon 4).

Triclopyr was chosen for two reasons. It has been shown to be an effective control agent of tanoak in other experiments (Cafferata and Yee 1991, Tappeiner and others 1987, Warren, 1980a, b) and triclopyr is considered environmentally safe because of its degradation characteristics. Based on field studies, triclopyr is reported to degrade fairly rapidly when used according to label directions. Thus the potential for triclopyr reaching groundwater is greatly reduced (DowElanco 1990). Triclopyr is readily converted to its parent molecule and easily degraded by the sun, resulting in minimal to no adverse effects to aquatic organisms when applied around streams and other bodies of water (DowElanco 1990).

The amine form of triclopyr used in the frill and cut-stump treatments in this experiment is a water-soluble triethylamine salt formulation which contains 3 pounds of the triclopyr acid per gallon. The ester form was used in basal applications and is an oil-soluble, water emulsifiable butoxyethyl ester formulation which contains 4 pounds of triclopyr acid per gallon.

The triclopyr contained in both formulations acts much like the normal growth hormones in a plant. However, as the chemical is absorbed and moves to the growth centers of the plant's internal structure, it disturbs the natural balance of plant growth hormones. This imbalance inhibits normal cell division and related chemical processes, thus producing twisted and thicker tissues which result in the shutdown of plant processes and eventual death.

Site Characteristics

Uneven-aged forest management is being implemented at Swanton Pacific Ranch, Cal Poly's (California Polytechnic State University, San Luis Obispo) demonstration school forest and ranch (Big Creek Lumber Company 1991). The ranch, located 12 miles north of Santa Cruz, has numerous stands of coast redwood and Douglas-fir in competition with tanoak and was thus chosen as the site for this tanoak control experiment.

The study plots are located in the Little Creek watershed area at Swanton Pacific Ranch. This area had been clearcut and burned between 1907 and 1923 (Big Creek Lumber Company 1991). An intense fire occurred in the area in 1948. The vegetation resulting from these major disturbances is a varied tree-size stand of mixed tanoak, coast redwood, and Douglas-fir with scattered understory brush and herbaceous vegetation. A recent timber harvest (1990/91) implementing uneven-age forest management has been completed in the stand (i.e., Stand B) adjacent to the study plots.

The average site index (base age 100 years) for the Little Creek drainage area is 133 feet with a range of 94 to 200 feet (Lindquist and Palley 1963). The predominant soil types are Ben Lomond-Catelli-Sur complex and Maymen stony loam (Bowman and Estrada 1980). The topography for the immediate area of the study plots is best characterized as a very steep (i.e., greater than 35 percent), northeast aspect. The mean annual precipitation for this area is 60 inches. Fog is also an important regulator of climate and vegetation for this area.

Experimental Design

Twelve square plots (50 ft by 50 ft) were established in a randomized block design on 0.7 acres. Three replications of the three application methods plus an untreated control were randomly assigned to the 12 plots. The three methods of application include cut-stump, frill, and basal treatment. The treated tanoak trees ranged in diameter from 0.25 inches to 18 inches, with an average diameter at breast (DBH) of 4.25 inches and a height of 21 feet.

An unpaired *t*-test was used to analyze the statistical significance of the data obtained. This statistical test was chosen because treatments were compared only to the results obtained for the one control plot of that treatment category.

Cut-Stump Method

Trees were felled in four of the plots, and the freshly cut stumps in three of these plots were sprayed to wet the cambial layer with undiluted triclopyr amine (Garlon 3A) plus a blue dye. The fourth plot was considered the control and received no herbicide treatment. A rubber-tired skidder was used to endline larger diameter logs. These logs were eventually bucked-up, split, and sold as firewood. Smaller slash was lopped and scattered (and kept below the 30-inch level) throughout the cut-stump plots.

Frill Method

A series of adjacent, overlapping hatchet cuts, 1-2 inches in length, and 2-4 feet above the ground were made on the trunks of all live trees within each frill plot. Undiluted triclopyr amine (Garlon 3A) (2 ml) was applied (i.e., squirted) into the exposed cambium area in the frill cut immediately after the cut was made. Three of the plots were treated with the herbicide, while a fourth plot served as the control and was chopped as above, but received no herbicide.

Basal Method

A mixture of 25 percent Garlon 4 (triclopyr ester) and 75 percent diesel (similar to Pathfinder[9] sold by DowElanco) was applied to the outer bark of each tree with a backpack sprayer. The application was made to the lower 24 inches of each tree and care was taken to treat the entire circumference. The fourth plot served as the control and received no treatment of any kind. A machete was used on a few larger diameter trees to make cuts in the cambium at approximately 4 feet above the ground to increase herbicide uptake. It should be noted, in the case of larger trees where cuts were made, that the basal method is not the same as the frill method. Only a small percentage of trees in the basal method were cut. The cuts were not uniform in size or shape, nor did they girdle the tree.

[9]Pathfinder is a Trademark name of a product of DowElanco Company.

Efficacy Rating System

The plots were monitored every 3 months for one year. Quantitative evaluations were done at 6-month intervals for 1 year (i.e., June 1991 and December 1991).

The methods of rating the plots varied with the treatment type. Every tanoak tree in each 50-foot × 50-foot plot was subject to an efficacy rating. To evaluate the effectiveness of the cut-stump method, the number of live resprouts per cut stump was counted. Additionally, sprout height was measured for each sprouting stump to determine whether a significant difference existed between the average sprout heights of the treated and untreated stumps. In a few of the test plots, some of the stump resprouts had been browsed by deer within 6 months after treatment. There was even more browsing in the test plots 12 months after treatment. Where browsing occurred, the sprouts were counted but not used to determine sprout height.

To determine the amount of control obtained with the frill and basal methods, a visual estimate of the percentage of crown dieback was made after treatment. The idea was to estimate the level of mortality resulting from the herbicide treatment on each tree. The final estimate for each tree was reached by consensus decision of two evaluators. It is difficult to differentiate between dieback because of the applied herbicide and mortality resulting from the existing natural stand conditions.

Results and Discussion

Cut-Stump Method

Six months after the triclopyr amine (Garlon 3A) application, good control was evident. Only 12 percent of the 198 treated cut stumps showed evidence of live resprouts (*table 1*). Sprouts averaged 5.3 inches in height (*table 1*). A total of only 138 sprouts was identified on the 12 percent of the treated cut stumps that sprouted (*table 1)*. By comparison, 85 percent of the control stumps had a total of 617 visible sprouts 6 months after cutting (*table 1*). The average height of the sprouts for the control stumps was 4.8 inches. Approximately 90 percent of the sprouts on the treated and untreated stumps appeared healthy and vigorous. The remaining 10 percent of the sprouts were brownish-green and appeared to be dying.

Table 1—Tanoak control obtained at Swanton Pacific with a cut-stump application of Garlon 3A

Replication number	Month recorded	Number of stumps in plot	Number of stumps that sprouted	Percent stumps that sprouted	Total number live sprouts	Average sprout height per sprouted stump
						inches
1	6	54	10	19	80	5.3
2	6	62	2	3	11	4.2
3	6	82	11	13	47	6.5
	Totals:	**198**	**23**		**138**	
	Averages:			**12**		**5.3**
1	12	53	5	9	83	5.4
2	12	61	3	5	11	4.3
3	12	80	12	15	59	6.5
	Totals:	**194**	**20**		**153**	
	Averages:			**10**		**5.4**
Untreated	6	54	46	85	617	4.8
Untreated	12	52	50	96	915	5.2

Plots were reevaluated 12 months after treatment. Stumps sprayed with triclopyr amine (Garlon 3A) continued to show limited resprouting. Only 10 percent of the 194 treated stumps had sprouts (*table 1*). Four stumps of the original 198 treated cut stumps could not be found. The average sprout height for the cut-stump treatment was 5.4 inches. The untreated control stumps had a total of 915 sprouts. Only two of the control stumps had no resprouts, and the average sprout height was 5.2 inches. Two nontreated cut stumps from the original 54 treated stumps could not be located.

An unpaired t-test was used to compare sprouting of treated versus control stumps 12 months after treatment. The results yielded a *t*-value of –12.998 at a significance level of $P = 0.0005$. The number of sprouts from cut-stumps treated with triclopyr amine (Garlon 3A) were significantly less than the number of sprouts in the control plot. There was no significant difference between the mean sprout height for treated stumps and the control stumps.

In summary, 10 percent of the triclopyr amine (Garlon 3A) treated cut stumps sprouted compared to more than 96 percent for the control cut stumps which had statistically significant sprouting. There was no statistical difference in sprout height between the two groups. There could be several reasons for sprouting from triclopyr amine (Garlon 3A) treated cut stumps. It is possible that the cambial layer of some stumps was not completely covered with a sufficient amount of the herbicide, allowing some untreated areas to resprout. Another factor promoting sprouting of treated stumps was mechanical damage that resulted from the removal of the cut tanoak trees and associated slash. The damaged, exposed areas on the triclopyr amine (Garlon 3A) treated stump group could have stimulated sprout development. When using cut-stump treatment, careful application is necessary to achieve optimum results.

Frill Method

Six months after treatment, 92 percent of the trees treated with triclopyr amine (Garlon 3A) using the frill method showed leaves browning within the upper and lower crowns (*table 2*). Treated tanoak trees had 53 percent crown browning or dieback owing to this treatment. However, 45 percent of the trees in the control plot (i.e., frill cut made with no herbicide) also showed signs of dieback. The average amount of crown dieback in the frill, nonherbicide treated plot was 26 percent (*table 2*).

Table 2—Tanoak control obtained at Swanton Pacific with a frill application of Garlon 3A

Replication number	Month recorded	Number of trees in plot	Number of trees with any noted crown dieback	Percent of trees with dieback	Average percent crown dieback per browning tree
1	6	44	40	91	34
2	6	64	59	92	58
3	6	51	47	92	66
	Totals:	**159**	**146**		
	Averages:			**92**	**53**
1	12	41	37	90	70
2	12	61	56	92	82
3	12	48	47	98	75
	Totals:	**150**	**140**		
	Averages:			**93**	**76**
Untreated	6	60	27	45	26
Untreated	12	57	22	39	40

Twelve months after treatment, 140 (93 percent) of the 150 herbicide treated trees showed signs of dieback. An average of 76 percent of the 140 crowns were browning or showing dieback symptoms. In contrast, the untreated plot had 39 percent of its trees browning in the crown while average crown dieback was 40 percent (*table 2*).

An unpaired *t*-test of the 12-month data was run comparing treated trees to the frill-untreated trees. The results yielded a *t*-value of 9.941 with a significance level of $P = 0.0005$. Frilled trees treated with triclopyr amine (Garlon 3A) showed significantly more dieback than untreated trees.

Most of the dieback seemed to be in the upper half of the crown of the tree. Dieback seemed to start from the top and work toward the base of the crown. This top-down dieback result differs from what has been reported in past herbicide research. Tanoak treated by the frill method in these earlier studies, reportedly, starts to brown at the base of the crown and follows the flow of the chemical up the bole of the tree (Tappeiner and others 1987). The difference in this experiment may have been due to the application of undiluted triclopyr amine (Garlon 3A) in December when the evergreen tanoak trees are less physiologically active. Thus, when the trees resumed growth, the triclopyr amine (Garlon 3A) had already translocated throughout the stem and taken effect in the upper crown first.

Tanoaks smaller than 8 inches in diameter had much more dieback than treated trees more than 8 inches in diameter. This reduced dieback in larger trees may be related to the difficulty of making hatchet frill cuts that effectively penetrate the cambial layer. Further research evaluating dieback differences in trees of different sizes may be needed to explain the results observed in this study.

Basal Method

Six months after treatment, 34 percent of the trees treated with the basal method had leaves browning within the crown (*table 3*). The average amount of crown dieback per tree was estimated to be approximately 26 percent. In contrast, 21 percent of the control trees (10 out of 47 trees) showed signs of crown dieback. On average, about 28 percent of each tree crown in the control group had dieback (*table 3*).

Twelve months after herbicide treatment, 45 percent of 181 trees were browning. The amount of browning for each herbicide-treated tree averaged 49

Table 3–Tanoak control obtained at Swanton Pacific with a basal method application of Garlon 4 and diesel

Replication number	Month recorded	Number of trees in plot	Number of trees with any noted crown dieback	Percent of trees with dieback	Average percent crown dieback per browning tree
1	6	73	16	22	18
2	6	42	22	52	30
3	6	79	23	29	29
	Totals:	**194**	**61**		
	Averages:			**34**	**26**
1	12	68	19	28	18
2	12	39	28	72	60
3	12	74	25	34	68
	Totals:	**181**	**72**		
	Averages:			**45**	**49**
Untreated	6	47	10	21	28
Untreated	12	44	9	20	42

percent of the live crown. Nine (20 percent) of the 44 trees in the control plot had about 42 percent crown dieback (*table 3*).

An unpaired *t*-test with the 12-month basal treatment data produced a value of 1.878 with significance values between $P = 0.025$ and 0.050. Dieback due to the basal treatment was not significantly different from the dieback identified in the control plot.

Larger-diameter tanoak trees were not as greatly affected by the basal application of triclopyr ester (Garlon 4) as the smaller-diameter trees. As with the frill treatment, the browning first took place in the upper portion of the crown and then progressed down toward the base of the tree

Research Implications

The results of this study substantiate earlier work (Cafferata and Yee 1991; Helgerson 1990; Radosevich and others 1976; Tappeiner and others 1987; Warren 1980a, 1980b; and Wurm 1976). Tanoak in Santa Cruz County coast redwood stands can be controlled with triclopyr (i.e., Garlon 3A and Garlon 4). The degree of tanoak control has been shown, in this and earlier studies, to be affected by several factors such as the chemical form of triclopyr used, month of application, timing of triclopyr application in relation to when the frill cut or stump cut is made, size of tree, and the extent of follow-up work (e.g., slash clean-up) that follows triclopyr application. Size of tree, adequate herbicide coverage, and uniformity of treatment appear to be major variables affecting the extent of dieback observed for both the frill and basal methods of application in this study.

Today there is pressure to rely more and more on uneven-aged forest management or the maintenance of a constant forest cover. These systems require scrutiny and control of a desired number of stems over a broad range of diameter classes. Having too many trees of either an undesired species or wrong size can impair the successful short- and long-term implementation of uneven-aged management. And, landowner objectives may not be met in a timely and economically feasible manner.

Thus, it is critical to control the number of undesired trees over a broad range of diameter classes. Much of the previous research on controlling unwanted brush and trees has focused on even-age forest management. More information is needed on the successful use of herbicides and other control strategies over a broad range of tree sizes as well as information about their cost effectiveness, given the expected income stream for uneven-aged managed forests. More research is needed on why, when, and where it is appropriate to undertake vegetation (i.e., tanoak) control using the uneven-aged forest management system. Some concerned citizens are advocating that natural processes (i.e., deer browsing) may be all that is necessary to control species and structural composition. Very little research exists to validate this type of plant control on a long-term basis in uneven-aged managed forests.

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References

Area Independent Development Corporation. 1987. **Economic potential of tanoak timber in the North Coast Region of California.** Prepared for the California Department of Commerce; 25 p.

Barrett, John W. 1995. **Regional silviculture of the United States.** New York: John Wiley and Sons, Inc.; 643 p.

Big Creek Lumber Company. 1991. **Forest management plan for the Swanton Pacific Ranch.** Unpublished report developed for the Natural Resources Management Department, California Polytechnic State University, San Luis Obispo, CA.

Bowman, Roy H.; Estrada, David C. 1980. **Soil survey of Santa Cruz County, California.** Washington, DC: Soil Conservation Service, U.S. Department of Agriculture [in cooperation with University of California, Agricultural Experiment Station].

Burns, Russell M., technical compiler. 1983. **Silvicultural systems for the major forest types in the United States.** Agric. Handb. 445. Washington, DC: U.S. Department of Agriculture; 191 p.

Burns, Russell M.; Honkala, Barbara H., technical coordinators. 1990a. **Silvics of North America: Volume 1. Conifers.** Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 675 p.

Burns, Russell M.; Honkala, Barbara H., technical coordinators. 1990b. **Silvics of North America: Volume 2. Hardwoods.** Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 877 p.

Cafferata, Peter H.; Yee, Fay A. 1991. **A comparison of techniques to control sprouting hardwoods on harsh sites in western Mendocino County.** California Forestry Note. 105. Sacramento, CA: California Department of Forestry and Fire Protection; 15 p.

California Department of Forestry and Fire. 1994. **Hardwood management and utilization demonstration workshop held on Jackson State Forest.** Jackson Demonstration State Forest Newsletter. No. 48, Summer issue; 10 p.

DowElanco. 1990. **The environmental properties of triclopyr.** Form No. 137-1945-490. DowElanco Company; 4 p.

Helgerson, Ole T. 1990. **Response of underplanted Douglas-fir to herbicide injection of sclerophyll hardwoods in southwest Oregon.** Western Journal of Forestry 5(3): 86-89.

Huff, E.K.; Robinson, S.T. 1993. **Herbicide control of Tanoak (Lit*hocarpus densiflorus*) at Swanton Pacific Ranch.** Unpublished Senior Project. Natural Resources Management Department, California Polytechnic State University, San Luis Obispo, CA; 49 p.

Lindquist, J.L.; Palley, M.N. 1963. **Empirical yield tables for young-growth coast redwood.** Bull. 796. Berkeley, CA: University of California College of Agriculture Experiment Station; 47 p.

Little, Elbert L., Jr. 1979. **Checklist of United States trees (native and naturalized).** Agric. Handb. 541. Washington DC: U.S. Department of Agriculture; 375 p.

Olson, David F.; Douglass, F. Roy; Walters, Gerald A. 1990. ***Sequoia sempervirens* (D. Don) Endl. Redwood.** In: Burns, Russell M.; Honkala, Barbara H., technical coordinators. Silvics of North America: Volume 1. Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 541-551.

Radosevich, S.R.; Passof, P.C.; Leonard, O.A. 1976. **Control of hardwoods improves Douglas-fir growth.** California Agriculture 30(10): 19.

Smith, Brenda; Piirto, Douglas D.; Huff, Eric K.; Robinson, Scott T. 1993. **Efficacy and environmental impacts of herbicide application methods for control of tanoak (*Lithocarpus densiflorus*) at Swanton Pacific Ranch.** Final Report submitted to Cal Poly Foundation. Natural Resources Management Department, California Polytechnic State University, San Luis Obispo, CA; 49 p.

Tappeiner, John C.; McDonald, Philip M.; Roy, Douglass F. 1990. ***Lithocarpus densiflorus* (Hook. & Arn.) Rehd., Tanoak.** In: Burns, Russell M.; Honkala, Barbara H., technical coordinators. Silvics of North America: Volume 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 417-425.

Tappeiner, John C.; McDonald, Philip M. 1984. **Development of tanoak understories in conifer stands.** Canadian Journal of Forest Research 14: 271-277.

Tappeiner, John C.; Pabst, Robert J.; Cloughesy, Michael. 1987. **Stem treatments to control tanoak sprouting.** Western Journal of Forestry 2(2): 41-45.

Warren, L.E. 1980a. **Control of sprouting hardwoods with basal applications of Garlon 4 herbicide.** Down to Earth 37(1): 22-27.

Warren, L.E. 1980b. **Control of tanoak and associated species with cut surface treatments of Garlon 3A herbicide.** Industrial Vegetation, Turf and Pest Management 12(1): 8-14.

Wurm, Ross. 1976. **Cut frill herbicide treatments control hardwood weed trees.** Industrial Vegetation Management. 8(1): 21-24.

RESTORATION

II

Restoration of Oak Woodlands[1]

Douglas D. McCreary[2]

Restoration is defined as bringing something back to a former or normal condition. Interest in the restoration of hardwood rangelands in California arose primarily because tree removal was changing the normal condition of many of these lands. Firewood harvesting, agricultural conversions, range clearing, and residential and commercial development were, and are, the main activities causing woodland loss. On some hardwood rangelands where mature trees were not being removed, there was concern that the woodland character of these lands would also eventually be altered because several species of native oaks were apparently not regenerating well. It was feared that without adequate regeneration, these wooded landscapes would convert to grasslands or brushy hillsides, and a whole suite of ecological values associated with these areas would be adversely affected.

At the time of the first Oak Symposium in 1979, research on oak regeneration and restoration was in its infancy. There were several papers in the Proceedings (Plumb 1980) that dealt peripherally with factors that may inhibit natural regeneration, and a paper on current practices for propagating oaks, but no reported studies on planting of oaks or the restoration of oak woodlands. During the second Oak Symposium in 1986, several papers specifically addressed the reasons for poor regeneration. By this time, researchers had started evaluating different approaches for planting acorns and oak seedlings. However, as reported in the Symposium Proceedings, (Plumb and Pillsbury 1987), early efforts to replant or restore degraded areas were difficult and often unsuccessful. The same factors that inhibited natural regeneration also prevented the establishment of artificially planted seedlings.

By the time of the third Oak Symposium at Davis, California, in 1990, interest and research in the natural and artificial regeneration of California oaks had expanded dramatically, and the emphasis had shifted from understanding what was causing poor natural recruitment to determining how to artificially regenerate oaks. An entire session, comprising 17 papers, was devoted exclusively to the regeneration and restoration of hardwood rangelands. These papers dealt with a wide range of subjects from how genetics and acorn size affect field performance to how to plant, maintain, and protect seedlings in the field. As reported in the Conference Proceedings, these studies indicated that artificially regenerating oaks was difficult, but seedlings could be successfully established if plantings were intensively managed. Browsing, herbivory, moisture competition, and acorn depredation were a few of the more common problems that could be overcome with sufficient site preparation, seedling protection, and seedling maintenance. These early research projects also focused almost exclusively on blue and valley oaks, the two species most commonly identified as regenerating poorly in portions of California.

The papers presented in the restoration session in this Symposium expanded on information from the Oak Symposium in 1990 and demonstrated that we have come a long way in developing successful approaches during the past decade.

[1] Presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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The two factors most critical to seedling survival—plant competition and animal damage—can be prevented through various weed removal and seedling protection practices. Although growth is often extremely slow in natural or "volunteer" seedlings, planted oaks can grow rapidly if well-adapted, vigorous plant material is used, and sufficient protection and maintenance are provided during and after planting. This provides an opportunity to get seedlings quickly to the sapling stage, where they will be less vulnerable to browsing pressures which can keep natural seedlings stunted for years.

The papers in this session also indicated that researchers are now interested in developing restoration strategies for more than just blue and valley oak and are evaluating practices for restoring California black oak, Oregon white oak, and coast live oak as well. Even though these species may be regenerating adequately over most of their range, there are situations in which specific factors are limiting their ability to replenish themselves. There is also interest in developing approaches that will work in a wide range of environments, from intensively developed urban landscapes, to isolated, wildland settings.

The challenge for the future extends beyond learning how to successfully plant a given species of oak on a given site. By and large we know how to do that now, although the approaches we have developed are still fairly costly and/or labor intensive. Because of this high cost, it is unlikely that private landowners will undertake large-scale restoration without some financial incentives or more cost-effective methods. In addition to lowering costs, what we need to understand better now is how to restore plant communities, including not only the trees, but associated understory plants as well. Beyond that, we need to know whether these communities can naturally reproduce and sustain themselves so that they will continue to provide habitat for the myriad of wildlife species dependent on them. This is no easy or short-term task. Future research, and the sharing of experimental findings through proceedings such as this, should help make this goal a reality.

Oak Seedling Establishment by Artificial Regeneration on California Rangelands[1]

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Abstract: *Blue oak (*Quercus douglasii *H. & A.) and valley oak (*Q. lobata *Née) seedling establishment on California rangelands is poor in many locations. Research on artificial regeneration is documenting that weed competition and small mammal and insect herbivory can contribute substantially to mortality where large herbivores are excluded. Success of natural oak recruitment and restocking and mitigation programs may be severely limited unless herbaceous plant control and protection against small mammals and insects are part of management activities.*

During the past decade, scientists, resource managers, and conservation groups in California have become concerned about the lack of young trees in stands of native oaks (*Quercus* spp.) growing in the state's Mediterranean-like climate. Recruitment varies geographically and within species (Bolsinger 1988, Muick and Bartolome 1987, Swiecki and others 1993). Recruitment is relatively sparse in blue oak (*Q. douglasii* H. & A.) stands, which occupy about 1.2 million ha or 40 percent of all oak woodlands, and is almost nonexistent in valley oak (*Q. lobata* Née) stands (Bolsinger 1988). Unsuccessful blue oak and valley oak recruitment results from mortality at the seedling and sapling stages, rather than from inadequate germination and seedling emergence (Griffin 1971). The failure of most oak seedlings (plants less than 30 cm high) to reach sapling size (30–150 cm tall) or larger brings into question the sustainability of California's oak resources and their ability to support a variety of natural resource needs.

In the study presented, we examined the influence of weeds and small mammal and insect herbivory on emergence, survival, and growth of blue and valley oak seedlings developing from directly planted acorns.

Study Sites

All plantings were established between latitudes 35°15´ and 39°15´ N in California (*fig. 1*). Blue oaks were planted at the Canyon Ranch (CYNRN), San Luis Obispo County; the University of California (UC) Hopland Research and Extension Center (HREC), Mendocino County; and the UC Sierra Foothill Research and Extension Center (SFREC), Yuba County. Sites for valley oaks included Briones Regional Park (BRP), Contra Costa County; and HREC.

Understories at all sites are dominated by annual grasses. Throughout the study areas, annuals continue to grow until all available soil water is exhausted. A discussion of the ecology and composition of California's annual grasslands and the demise of the pristine perennial grasslands is presented by Heady (1977).

Elevation, rainfall, and soil characteristics at the several sites (*table 1*) represent conditions typical of those occurring in natural stands of the oaks found in the Coast Ranges, interior coastal ranges of the San Joaquin Valley, and western foothills of the Sierra Nevada in the Sacramento Valley.

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[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management and Urban Interface Issues; 1996 March 19-22; San Luis Obispo, Calif.

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Figure 1—Locations of study sites.

Methods

Acorns, representing local genotypes, were fall-collected from several trees at each site and placed in cold storage (4 °C) until planting. Storage between 1 and 4 °C is recommended by Korstian (1927) and Harrington (1972) to retard germination without a reduction in emergence potential.

Blue and valley oak acorns were planted directly in field plots during November and December in 1986 and 1987. Blue oaks were planted at HREC in 1986 and at CYNRN and SFREC in 1987. Valley oak was planted at HREC in 1986 and at BRP and HREC in 1987. All sites were in open oak woodland, away from canopy influence and on terrain as flat as possible to reduce effects of slope exposure and inclination. All sites also were fenced to prevent browsing of seedlings by large herbivores, an acknowledged problem (Longhurst and others 1979, Duncan and Clawson 1980).

At each site, two levels of weed control (weed-free and the naturally occurring vegetation) were treatments in a randomized complete block. Herbicides were applied annually to eliminate weeds. The two treatments were replicated four times each. In each 100-acorn replicate, acorns were planted in four parallel rows of 25 each, with rows 30 cm apart and acorns within rows also 30 cm apart. Planting depth was 5 cm, a depth suggested for use in controlled environments (Lobel and George 1983) and considered a minimum to discourage

Table 1—Characteristics of the study sites

Location[1]	Elevation	Average annual precipitation	Soils: Surface soil texture	Soils: Depth	Soils: Estimated AWC[2]	Soils: Soil series[3]	Soils: Soil family
	m	*cm*		*cm*	*cm cm*$^{-1}$		
Blue Oak							
CYNRN	545	28	Clay loam	155	0.14-0.17	Ayar	Fine, montmorillo nitic, thermic Typic Chromoxererts
HREC	273	94	Loam	183	0.14-0.17	Hellman	Fine, mixed, thermic Mollic Palexeralfs
SFREC	182	72	Gravelly loam	53	0.11-0.16	Argonaut	Fine, mixed, thermic Mollic haploxeralfs
Valley Oak							
BRP	124	48	Clay loam	193	0.16-0.18	Botella	Fine-loamy, mixed, thermic Pachic Argixerolls
HREC	273	94	Loam	152	0.14-0.17	Yorkville	Fine, mixed, thermic Typic Argixerolls

[1]CYNRN = Canyon Ranch, HREC = UC Hopland Research and Extension Center, SFREC = UC Sierra Foothill Research and Extension Center, BRP = Briones Regional Park

[2]AWC = Available Waterholding Capacity

[3]All are upland soils except Botella which is alluvial.

disturbance by mice (Griffin 1971). This depth has been found to be a good compromise between improved protection from predation and reduced emergence that occurs from planting at a greater depth (Tietje and others 1991). After emergence, screens were placed randomly over half of the seedlings in each replicated treatment to protect them from herbivory by small mammals and insects. Screened and unscreened seedlings became subplots, creating a split-plot design.

Data evaluated by analysis of variance (ANOVA) included emergence, survival measured in spring of each growing season, and height of plants each fall. To increase the power of the ANOVA, data for each species were pooled by years in a repeated measures analysis. When there was a significant time interaction, ANOVAs for each year were used to assess treatment effects. This was done to ensure a conservative interpretation of data. For height measurements, the longest stem was used if branching occurred. Unless otherwise noted, significant differences are reported at the 95 percent level of confidence.

When necessary for the ANOVA, the arcsine transformation of percentage emergence and survival was used to maintain homogeneity of variances. The results presented are treatment averages for the original measurements.

Cages (closed cylinders 15 cm in diameter and about 40 cm high) made out of aluminum window screen material were used for protection at all but one location, CYNRN. At this site, 14-strand rigid plastic seedling protectors 5 cm in diameter, 30 cm high, and with a larger mesh were substituted. This material was used, because the threat from insects, primarily grasshoppers (*Melanoplus devastator* Scudder), was minimal.

Results

Blue Oak

For blue oak, average seedling emergence over all planting dates and sites was nearly a third greater ($P \leq 0.05$) with weed control, and average survival in this treatment was three times greater ($P \leq 0.01$) in 1995 (*fig. 2*). For seedlings growing with weed control, survival was different ($P \leq 0.01$) between protected and unprotected seedlings, but the absolute difference did not change significantly during the study. In 1995, survival for protected seedlings was about a fifth greater (*fig. 2*). Measured over the course of the study, the contrast in survival between protected and unprotected seedlings growing without weed control changed significantly ($P \leq 0.01$). Through interaction with time, survival of unprotected seedlings declined more rapidly; it was less than one-fifth that of protected seedlings ($P \leq 0.01$) in 1995 (*fig. 2*).

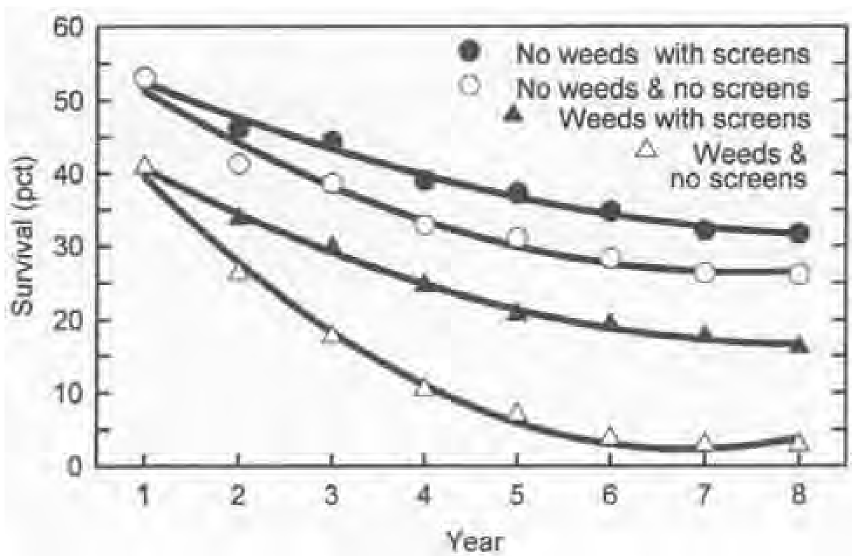

Figure 2—Average blue oak emergence and survival (percent of acorns planted) in three plantings. Values for Year 1 are percent emergence.

Where weeds were controlled, the height differential between protected and unprotected blue oak seedlings was nearly two-thirds ($P \leq 0.01$) in 1995 (*table 2*), but the difference in height was not an unqualified measure. As seedlings

Table 2—Average effects of weed control and screen protection on 1995 seedling height (centimeters) at three blue oak and at three valley oak sites

Species	Screen protection	Seedling height[1] Weeds present	Weeds absent
		cm	
Blue Oak	No	[2]	76b
	Yes	68b	124a
Valley Oak	No	[2]	68c
	Yes	80b	127a

[1]Values for each species not followed by the same letter are different ($P \leq 0.01$) by Least Significant Difference Separation.

[2]Inadequate survival for reliable estimates.

increased in size, screens were opened to prevent restriction of growth. This created access and permitted limited insect and small mammal herbivory, which affected measurements. Among seedlings with complete initial screen protection, the 1995 height of those growing with no weed control was only half that ($P \leq 0.01$) of those growing weed free (*table 2*).

Valley Oak

Average valley oak seedling emergence over all planting dates and sites was nearly two-thirds greater ($P \leq 0.01$) with weed control, and average survival in this treatment was more than double that without weed control ($P \leq 0.01$) in 1995 (*fig. 3*). In both main plot treatments, loss during the course of the study was more rapid for unprotected seedlings ($P \leq 0.01$). Through interaction with time, survival of unprotected seedlings growing with and without weed control was, respectively, 60 percent and less than 25 percent of that for protected seedlings ($P \leq 0.01$) in 1995 (*fig. 3*). Decline in survival of protected seedlings growing with weed control was due, in part, to pocket gopher (*Thomomys bottae* Eydoux & Gervais) herbivory that became serious after the second season.

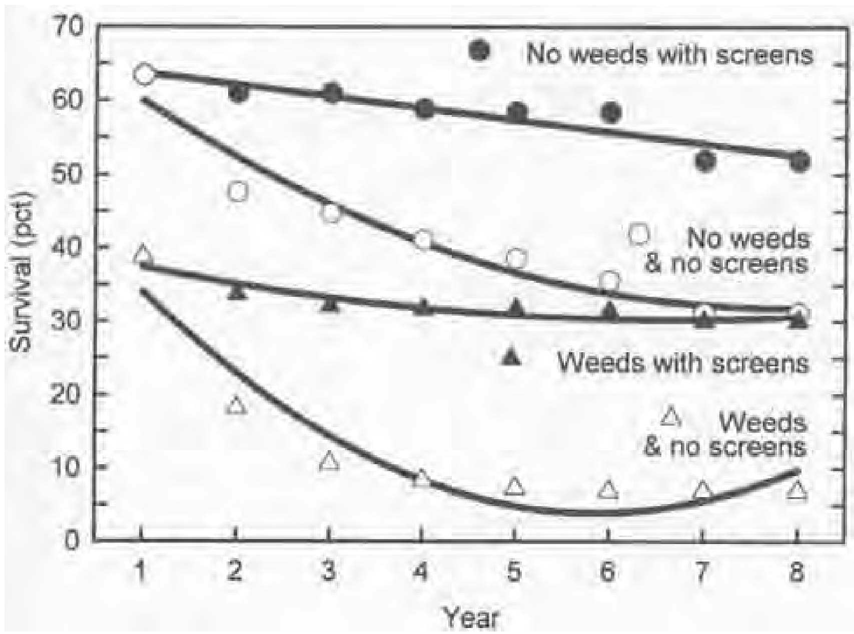

Figure 3—Average valley oak emergence and survival (percent of acorns planted) in three plantings. Values for Year 1 are percent emergence.

In 1995, protected valley oak seedlings growing weed free were more than 85 percent taller than those unprotected in the same treatment ($P \leq 0.01$) (*table 2*). Between protected seedlings growing with and without weeds, the differential was about 60 percent ($P \leq 0.01$). Contrasted with blue oak, the average height of protected valley oak seedlings growing without weed control was nearly 20 percent greater ($P \leq 0.01$) than that of seedlings growing unprotected but weed free (*table 2*).

Discussion

The difference in mortality among blue oak seedlings growing with and without initial full screen protection was greatest in the absence of weed control; after seven seasons, more than five times as many protected seedlings were alive—16 percent vs. 3 percent (*fig. 2*). The difference was much smaller with weed control, about 1.2 times as many protected seedlings were present after seven seasons—32 percent vs. 26 percent (*fig. 2*). The best treatment—weed control with screens—contained more than 10 times as many seedlings as the worst treatment—no weed control and no screens. The differential effect of screens on survival was

Table 3—Statistical significance of contrasts (treatment effects and their interaction) identified by ANOVA of values for each of the 8 years shown in figs. 2 and 3

Contrasts	Statistical significance (*P*) of contrasts[1] Year 1	Year 2	Year 3	Years 4-8
	Blue Oak			
Weeds	0.01	0.01	<0.01	<0.01
Screens	[1]n.a.	<0.01	<0.01	<0.01
Weeds × Screens	[1]n.a.	[1]n.s.	0.01	<0.01
	Valley Oak			
Weeds	<0.01	<0.01	<0.01	<0.01
Screens	[1]n.a.	<0.01	<0.01	<0.01
Weeds × Screens	[1]n.a.	[1]n.s.	<0.05	<0.01

[1]n.a. = not applicable; n.s. = not significant

due to an interaction with main plot treatments that developed with time (*table 3*).

Average survival of blue oak during the study period was influenced by geographic location. At CYNRN, it was 40 percent of the average value for HREC and SFREC, locations where average survival during the study was not different. This difference may be related to rainfall. At CYNRN, average rainfall is one-third that of the average for the other two locations. As in blue oak, the greatest difference in valley oak seedling survival was between protected and unprotected subplot treatments where weeds were not controlled; after seven seasons, four times as many protected as unprotected seedlings were alive—30 percent vs. 7 percent (*fig. 3*). With weed control, the difference was smaller; less than twice as many protected seedlings were alive after seven seasons—52 percent vs. 31 percent (*fig. 3*). After three growing seasons, there was no difference in survival between unprotected seedlings growing with weed control and protected seedlings growing without such control. As in blue oak, the best treatment after seven seasons was weed control combined with screen protection. There were more than seven times as many seedlings in this treatment compared with the worst treatment—no control with no protection. Over time, interaction developed between weed control and protection factors (*table 3*).

Of the three valley oak plantings, the most and least successful were consecutive annual plantings at HREC. During the planting seasons, rainfall at this site was 70-80 percent of average. Average annual rainfall at BRP is about half that at HREC, as it was during the planting season. Survival in the three plantings, affected by both physical parameters and pocket gopher herbivory, provided inconclusive evidence that location influenced plant performance.

The value of weed control was identified early in the study by Adams and others (1987), but it is not a unique observation. Throughout the East, Midwest, and Canada, the benefits of controlling weeds to promote survival and growth of oaks and other hardwoods propagated naturally and artificially are well documented (Bowersox and McCormick 1987, Siefert and Fischer 1985, von Althen 1987). In California, Griffin (1971) demonstrated that reduced precipitation, in addition to annual grass competition, greatly reduced blue and valley oak establishment.

As expected, the addition of screen protection in our study improved survival. Griffin (1976) observed that small mammals and insects continued to attack oak seedlings, even after exclusion of deer. In the eastern United States, rodents are the chief obstacle to reproducing oaks from seeded acorns (Johnson 1979, Krajicek 1955). Grasshoppers, a principal predator at several locations in our study, are favored by a cover of herbaceous plants that provides habitat for development and feeding (Linit and others 1986). They probably contributed more to damage among unprotected seedlings growing without weed control than to unprotected seedlings growing with weed control.

Shade produced by screens probably contributed to the differential in survival and height between protected and unprotected seedlings. Crow (1988) observed that seedlings of northern hardwoods, including those of northern red oak (*Q. rubra* L.), in the central United States generally benefit from shade because it reduces water stress by moderating temperatures and evapotranspiration. A more complete review of shade influence was presented by Adams and others (1992). In our study, we believe that screens provided an element of protection against excessive transpiration, but the shade factor and its unmeasured positive effect could not be separated from the value of screens as protection against herbivory.

Screens, interacting with the environment, also may have contributed to a lower rate of loss for protected valley oak compared with protected blue oak in both main plot treatments, weed control and no weed control. In contrast, comparisons of the loss rate between unprotected seedlings of the two species in each treatment showed no difference.

The concentration of planted acorns in this study may have contributed to rodent herbivory. Because the fossorial pocket gopher locates its food primarily by odor (Hungerford 1976), predation by this rodent may have been encouraged by closely spaced seedlings in geometric patterns, a factor that may have influenced herbivory by other small mammals as well. Seedlings growing in patterns approximating the more random, natural distribution of oak trees may be less vulnerable to both aboveground and belowground attack.

Experience suggests that pocket gophers can present a prolonged threat. Roots of oaks are vulnerable to attack from these small mammals until trees are 5 cm or more in diameter at the base. The use and value of underground screens as protection against the rodents have been reported (Adams and Weitkamp 1992, Adams and McDougald 1995).

Supporting Studies

Weed-Control Strategies

An unpublished supporting study conducted by two of the authors evaluated alternative weed–control strategies as they might affect survival and growth of 2- to 3-month-old nursery stock protected from large herbivores and initially screened against small mammals and insects (Adams and Sands 1995). At HREC and SFREC, three successive blue oak plantings were established in winter 1987–88, 1988–89, and 1989–90 using the transplants for evaluation of three weed control strategies: (1) a one-time, post-planting application of herbicides, (2) porous plastic (PP) mulch mats, and (3) impervious plastic (IP) mats. These were compared with no weed control.

For promotion of survival, no one weed control strategy was superior. In 1995, average survival of blue oak seedlings with some type of weed protection was more than three times that with no control.

At both sites, more growth occurred with the two types of plastic mats, and seedlings growing with IP mats were tallest. The greater height of seedlings observed in the IP mat strategy may have been a product of more effective weed suppression over time and the influence of IP mats on the soil environment.

Survival in the IP mat treatment was less in the 1989-90 plantings than in the 1988-89 plantings when measured in spring 1992. Mortality was attributed to depredation by rodents, particularly meadow voles (*Microtus* spp.), which caused the majority of mortality and continue to girdle seedlings. The IP mat weed control strategy appeared to aggravate the problem by providing cover for rodents. By spring 1993, the difference measured in 1992 disappeared.

A contributing factor to rodent damage in this study was absence of all weed control (with the exception of applied weed-control treatments) within the half-acre enclosures used. The accumulation of biomass (primarily dead annual grass) apparently created habitat attractive to rodents. The accumulation of biomass also provided attractive habitat for grasshoppers, and the insects defoliated many seedlings, especially at SFREC in 1990.

Herbicides for control of weeds, as used in this study, were considered the most practical strategy. This conclusion was based on cost and the potential for synthetic mulch mats to aggravate rodent depredation.

Seeded Acorns and Nursery Stock Compared

In another unpublished study, survival and growth of blue and valley oak seedlings developing from seeded acorns and 2- to 3-month-old nursery stock were compared at several locations beginning in 1988–89 (Adams and others 1995). All seedlings were protected from large herbivores and grown weed free with half of each plant material initially screened against small mammals and insects.

After 6 years, average survival of screened blue oak seedlings developing from nursery stock was 80 percent, about a third greater than for those developing from seeded acorns. Survival of unscreened plant material was not different by class, but it was much less than either group of screened seedlings; the average was about 25 percent.

For valley oak, no difference in survival between classes of plant material could be measured. At one of the two planted sites, ground squirrels (*Spermophilus beecheyi* Richardson) attacked nursery stock immediately after planting and caused severe loss. At the second site, survival of all but one group of seedlings was high, nearly 100 percent. Only survival of unscreened seedlings developing from seeded acorns was different, about 90 percent.

Protection, but not class of plant material, enhanced growth of both species. After 6 years, the average height of protected blue oak seedlings was double that of unprotected seedlings, and in the valley oak plantings, protected seedlings were a third taller.

In this study, as in the others, rodents were a major cause of mortality. Selective attack on valley oak transplants by ground squirrels may have been encouraged by the cultural practices used during propagation. The seedlings were well watered and fertilized. Frequent watering during propagation may have leached tannins from the acorns. Tannins are believed to discourage consumption of the embryo-containing apical portion by eastern gray squirrels (*Sciurus carolinensis* Gmelin), several other vertebrates, and acorn weevil larvae (*Curculio* sp.) (Steele and others 1993). There is a rich literature describing the influence of fertilizer on herbivory. For example, fertilized young conifers are more likely to be attacked by rodents than unfertilized trees (Gessel and Orians 1967, Sullivan and Sullivan 1982). Enhanced palatability of nursery stock may explain the attack. Where ground squirrel populations are high, control may be necessary to prevent major seedling losses.

The temporal occurrence of other rodents, such as meadow voles, also was noted. For several years, voles damaged many seedlings at one valley oak site and at one blue oak site. Gophers were a chronic problem at all sites, but attack usually was localized and not general. As in the other studies, grasshoppers presented a problem, but their severity may have been reduced by grazing of the surrounding area, which reduced herbaceous growth and its value as cover for the insects.

While the results from this study strongly suggested that 2- to 3-month-old blue oak nursery stock is more likely to survive than seedlings developing from seeded acorns, initial protection from herbivory clearly was needed to take advantage of this potential.

Among sites in the study, there were great differences in annual rainfall. For the first two seasons, rainfall was 50 percent of average at the most xeric sites and 70-100 percent of average at the more mesic sites. Average rainfall during the first two seasons at the more mesic sites was nearly three times greater than at the dryer sites. However, survival of blue oak did not reflect these differences; in 1995, survival was greater at the most xeric site. It is tempting to hypothesize that climatic adaptation of blue oak represents a spectrum, but the spatial and temporal influence of small mammal and insect herbivory and other biotic factors make this speculation risky.

Conclusions

Weed competition can severely limit emergence of blue and valley oak seedlings developing from planted acorns and limit survival of both these and seedlings developing from 2- to 3-month-old nursery stock. More importantly, weed competition may prevent the development of seedlings into saplings. Competition may be the most important obstacle to oak recruitment; it appears necessary to maintain new plantings weed free through at least the first growing season. However, weed competition is only one problem.

Protection of oak seedlings and saplings against mammals and insects also is important. Protection can be as critical as weed control. Herbivory may vary with time and location, but some level of aboveground protection usually will be required until young oak trees are big enough to resist attack.

Large herbivores are a recognized problem, but small mammals also can present a threat. Among the second group are black-tailed jackrabbits (*Lepus californicus* Gray), omnivores such as raccoons, and a host of rodents. Common among the latter are rabbits (*Sylvilagus* spp.), meadow voles, deer mice (*Peromyscus maniculatus* Wagner), and pocket gophers, all known threats. Grasshoppers also can be a problem. Protection, as well as control of weeds, may be necessary to ensure success of restocking and mitigation programs and natural recruitment.

With protection from small mammals and insects, seedlings developing from 2- to 3-month-old nursery stock and growing weed free may have a survival advantage over those produced from directly seeded acorns growing under the same conditions. However, costs of propagating, transporting, and planting this plant material probably will make it economically unattractive for large-scale use where resource values per unit area are low, such as on rangelands, a conclusion reached by Standiford and Appleton (1993).

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References

Adams, Theodore E.; McDougald, Neil K. 1995. **Planted blue oaks may need help to survive in Southern Sierras**. California Agriculture 49(5): 13-17.

Adams, Theodore E.; Sands, Peter B. 1995. **Effects of selected weed control strategies on blue oak nursery stock**. Unpublished manuscript.

Adams, Theodore E.; Sands, Peter B.; Stanley, Marion E. 1995. **Performance of blue and valley oak seedlings developing from seeded acorns and transplants**. Unpublished manuscript.

Adams, Theodore E., Jr.; Sands, Peter B.; Weitkamp, William H.; McDougald, Neil K. 1992. **Oak seedling establishment on California rangelands**. Journal of Range Management 45(1): 93-98.

Adams, Theodore E., Jr.; Sands, Peter B.; Weitkamp, William H.; McDougald, Neil K.; Bartolome, James. 1987. **Enemies of white oak regeneration in California**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 459-462.

Adams, Theodore E., Jr.; Weitkamp, William H. 1992. **Gophers love oak—to death**. California Agriculture 46(5): 27-29.

Bolsinger, Charles L. 1988. **The hardwoods of California timberlands, woodlands, and savannas**. Resource Bull. PNW-RB-48. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Bowersox, T.W.; McCormick, L.W. 1987. **Herbaceous communities reduce the juvenile growth of northern red oak, white ash, yellow poplar, but not white pine**. In: Hay, Ronald L.; Woods, Frank W.; DeSelm, Hal, eds. Proceedings of the central hardwood forest conference VI; 1987 February 24-26; Knoxville, TN. Knoxville, TN: Department of Forestry, Wildlife and Fisheries, University of Tennessee; 39-43.

Crow, Thomas, R. 1988. **Reproductive mode and mechanisms for self-replacement of northern red oak (*Quercus rubra*)--a review**. Forest Science 34(1): 19-40.

Duncan, D.A.; Clawson, W.J. 1980. **Livestock utilization of California's oak woodlands**. In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 306-313.

Gessel, Stanley P.; Orians, Gordon H. 1967. **Rodent damage to fertilized silver fir in western Washington**. Ecology 48(4): 694-697.

Griffin, James R. 1971. **Oak regeneration in the upper Carmel Valley, California**. Ecology 52(5): 862-868.

Griffin, James R. 1976. **Regeneration in *Quercus lobata* savannas, Santa Lucia Mountains, California**. American Midland Naturalist 95(2): 423-435.

Harrington, James F. 1972. **Seed storage and longevity**. In: Kozlowski, Theodore T., ed. Seed biology, volume 3. New York: Academic Press; 145-245.

Heady, Harold F. 1977. **Valley grassland**. In: Barbour, Michael G.; Major, Jack, eds. Terrestrial vegetation of California. New York: John Wiley & Sons, Inc.; 491-514.

Hungerford, Kenneth E. 1976. **Food preferences and food location by pocket gophers in Idaho**. In: Siebe, Charles C.; Howard, Walter E.; Marsh, Rex E., eds. Proceedings of the seventh vertebrate pest conference; 1976 March 9-11; Monterey, CA. Davis, CA: Department of Wildlife, Fish and Conservation Biology; University of California; 131-138.

Johnson, Robert L. 1979. **Adequate oak regeneration—a problem without a solution?** In: Proceedings of the seventh annual hardwood symposium of the hardwood research council: Management and utilization of oak; 1979 May 1-4; Cashiers, NC. Asheville, NC: Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 59-65.

Korstian, Clarence F. 1927. **Factors controlling germination and early survival in oaks**. Bulletin No. 19. New Haven, CT: School of Forestry, Yale University; 115 p.

Krajicek, John E. 1955. **Rodents influence red oak regeneration**. Note No. 91. St. Paul, MN: Central States Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 2 p.

Linit, M.J.; Johnson, P.S.; McKinney, R.A.; Kerby, W.H. 1986. **Insects and leaf area losses of planted northern red oak seedlings in an Ozark forest**. Forest Science 32(1): 11-20.

Lobel, Denice F.; George, Alan G. 1983. **Plant your own oak tree**. Leaflet 21334. Berkeley, CA: Division of Agricultural Sciences, University of California; 4 p.

Longhurst, William M.; Connolly, Guy E.; Browning, Bruce M.; Garton, Edward O. 1979. **Food interrelationships of deer and sheep in parts of Mendocino and Lake Counties**. Hilgardia 47(6): 191-247.

Muick, Pamela C.; Bartolome, James W. 1987. **Factors associated with oak regeneration in California**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U. S. Department of Agriculture; 86-91.

Siefert, John R.; Fischer, Burnell C. 1985. **Northern red oak and white oak planting in a commercial clearcut with chemical weed control**. In: Dawson, John O.; Majerus, Kimberly A., eds. Proceedings of the central hardwood forest conference V; 1985 April 15-17; Urbana-Champaign, IL. Society of American Foresters Publication 85-05. Urbana-Champaign, IL: Department of Forestry, University of Illinois; 35-39.

Standiford, Richard B.; Appleton, Donald L. 1993. **Preliminary study on harsh site offers hope for blue oak regeneration**. California Agriculture 47(4): 17-20.

Steele, Michael A.; Knowles, Travis; Bridle, Kenneth; Simms, Ellen L. 1993. **Tannins and partial consumption of acorns: implications for dispersal of oaks by seed predators**. American Midland Naturalist 130(20): 229-238.

Sullivan, Thomas P.; Sullivan, Druscilla S. 1982. **Influence of fertilization on feeding attacks to lodgepole pine by snowshoe hares and red squirrels**. The Forestry Chronicle 58(6): 263-266.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Drake, Christina. 1993. **Factors affecting blue oak sapling recruitment and regeneration**. Sacramento: Forest and Rangeland Resources Assessment Program (FRRAP), California Department of Forestry and Fire Protection; 132 p.

Tietje, William D.; Nives, Sherryl L.; Honig, Jennifer A.; Weitkamp, William H. 1991. **Effect of acorn planting depth on depredation, emergence, and survival of valley and blue oak**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31–November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 14-20.

von Althen, F.W. 1987. **Site preparation and weed control in hardwood afforestation in Ontario**. In: Hay, Ronald L.; Woods, Frank W.; DeSelm, Hal, eds. Proceedings of the central hardwood forest conference VI; 1987 February 24-26; Knoxville, TN. Knoxville, TN: Department of Forestry, Wildlife and Fisheries, University of Tennessee; 75-80.

Constraints on Germination and Emergence of Emory Oak[1]

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***Abstract**: We investigated the effects of post-collection processing and duration of storage, acorn size, soil source, and microclimate on viability, germination, emergence, and seedling size of Emory oak, to determine if these characteristics affect its recruitment and distribution. Removal of the acorn cup increased germination up to 5-fold. Germination did not decline between 0 and 35 days of storage. Acorn size was positively correlated with viability, germination, and seedling size. Seedling emergence was not affected by soil source or microclimate. We conclude that given adequate soil moisture, germination and emergence do not limit Emory oak distribution.*

Oak (*Quercus*) woodlands and savannas occupy several million hectares of arid and semi-arid wildlands in the southwestern United States and northern Mexico. These savannas and woodlands have been intensively and extensively used by humans since before the turn of the 20th century. Historically, oak trees were harvested from large areas because they were highly valued as timber for mines and as fuel for wood-fired smelters (Bahre and Hutchinson 1985). Today, local oak trees are valued for timber, food for people and animals, fuel, watershed protection, and aesthetic purposes (Young and Young 1992).

However, despite the areal extent and the economic, ecologic, and historic importance of these savanna and woodland systems, we know little about processes that contribute to their sustainability (McPherson 1992). For example, previous research suggests that oak seedling establishment in southern Arizona is variable and infrequent. Oak seedling recruitment within oak woodlands during 1989 (a relatively dry year) averaged 44 individuals/ha (Borelli and others 1994). Sanchini (1981) reported mean Emory oak seedling densities of 300, 0, and 309/ha in 1978, 1979, and 1980, respectively. Seedlings of Emory oak (*Quercus emoryi* Torr.), the dominant oak tree at lower treeline in southeastern Arizona, are relatively abundant under mature canopies, but are absent from grasslands below treeline (Weltzin and McPherson 1994, 1995). Mechanisms controlling such patterns have not been investigated. Successful management of this and other oak species will depend on a knowledge of mechanisms controlling its reproductive autecology and seedling recruitment, "bottlenecks" that potentially constrain oak tree distribution (Harper 1977).

Recognizing that little is known about the reproductive autecology of Emory oak (McPherson 1992), we chose to investigate potential constraints on germination and emergence of Emory oak. Specifically, we studied three potential limiting factors: (1) the effects of post-collection acorn processing and duration of storage on germination; (2) the relationship between acorn size and viability, germination, emergence, and seedling size; and (3) the effects of soil source and microclimate on emergence. Each of these factors was evaluated in separate experimental trials.

Emory oak is the only member of the black (or red) oak (Erythrobalanus) subgenus in Arizona. Unlike most black oaks, stratification does not enhance germination of Emory oak acorns, which is greatest when acorns are planted immediately after picking, and has been reported to decline with increasing time of storage to 0 percent within 60 days of storage (Nyandiga and McPherson 1992). Since such a narrow window of opportunity exists for germination to occur and because acorns are difficult to store (Nyandiga and McPherson 1992),

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it becomes important for managers and researchers to know how to most efficiently store acorns while still maximizing germinability.

Managers and researchers typically separate the acorn cup (modified involucre) from the acorn shortly after acorns are harvested (Young and Young 1992). However, this is a labor-intensive activity with unknown effects on viability and germination. For example, the acorn cup may contain secondary compounds that alter the probability or timing of germination. Our observations indicate that germination occurs at the acorn's apex; thus we hypothesized that the acorn cup does not affect germination.

Previous research indicates that seed size is often positively correlated with germination and seedling growth, presumably because larger seeds have more tissue resource available than smaller seeds (Houssard and Escarre 1991). Tecklin and McCreary (1991) found that acorn mass was directly related to emergence, survival, and height of *Q. douglasii*. However, this relationship between acorn size and seedling success has not been investigated for Emory oak. On the basis of studies with other oaks, we hypothesized that acorn size is positively correlated with Emory oak germination, emergence, and seedling size.

In the field, differences in soil texture may also affect acorn germination and emergence and thus contribute to observed patterns of Emory oak seedling recruitment. Distributions of soil particle size under tree canopies are "gravelly sandy clay loams," whereas soils in adjacent grasslands range from "gravelly sandy loams" to "sandy loams" (Weltzin unpubl. data[3]). In addition, tree canopies may ameliorate understory microclimatic conditions by altering light and precipitation distribution or attenuating temperature extremes (Haworth and McPherson 1995). On the basis of observations of Weltzin and McPherson (1994, 1995) that Emory oak seedlings are most abundant under Emory oak tree canopies and absent from adjacent grasslands, we hypothesized that emergence of Emory oak would be greater in understory soil and understory microclimatic conditions than in grassland soil and grassland microclimatic conditions.

[3]Unpublished data on file, University of Arizona, School of Renewable Natural Resources, Tucson, Arizona.

Methods

Acorns were collected when ripe in July and August 1995 from at least 20 trees. Acorns were visually examined for insects and pathological infestation and sorted by flotation. Acorns that floated or had visible insect damage were discarded (sensu Nyandiga and McPherson 1992). All germination trials were conducted in petri dishes in a growth chamber under the following conditions: 12-hour day, 30 °C daytime temperature, and 20 °C nighttime temperature (as per Bonner 1988). Acorns with radicles that exceeded 1 mm were considered germinated. All germination trials began in early July 1995 and continued for 30 days after the last acorn germinated. Percent germination was calculated on the basis of the total number of acorns used in each trial.

Data were tested for normality with the Shapiro-Wilk *W*-statistic (Shapiro and Wilk 1965). Non-normal data were transformed or ranked (Conover and Iman 1981) before analysis of variance with general linear models. Data were tested for homogeneity of variances with Hartley's test (1950). Main effects and interactions were considered significant at $P < 0.05$; means were separated with Fisher's LSD (Least Significant Difference) mean separation test (Sokal and Rohlf 1981).

Post-Collection Processing and Storage Trial

This study employed a completely randomized design in a factorial arrangement with two factors: acorn treatment (cups left on acorns throughout germination trial, cups removed upon harvest, and cups removed after storage but before germination trial) and storage time (0, 7, 14, 21, 28, and 35 days). Stored acorns were kept in moist sand at 2 °C (Young and Young 1992).

Acorn Size Trial

Acorns were separated into three distinct size classes by mass: large (>0.9 g), medium (0.6-0.8 g), and small (<0.5 g). Fifty acorns were randomly selected from each size class and were tested for viability with tetrazolium chloride, which stains respiring tissue red (*sensu* Nyandiga and McPherson 1992). An acorn was classified as viable if more than 50 percent of the tissue was stained red. An additional 100 acorns in each size class were used to study germination, emergence, and seedling size.

The time to germination was recorded for each individual acorn. Germinated acorns were transferred to pots filled with silica sand within 48 hours of germination. Acorns were buried 1 cm below the surface of the sand. Pots were retained in the growth chamber and monitored for shoot emergence; the time to emergence was recorded. For this trial, emergence is the number of acorns with shoots that emerged out of the number of acorns that germinated. Thirty-five days after germination, seedlings were destructively harvested, and above- and belowground dry-weight biomass (excluding the acorn) was determined.

Soil Type and Microclimate Trial

This study consisted of two experiments conducted simultaneously in the greenhouse and in the field. For both experiments we used field soil collected from lower Garden Canyon (31° 29' N, 110° 20' W), Fort Huachuca Military Reservation in southeastern Arizona. Haworth and McPherson (1995) provide a detailed site description. At Garden Canyon, we placed 0.5-m^2 plots under five randomly selected mature Emory oak trees, and in five randomly selected locations in semi-desert grassland below lower treeline. Plots under canopies were located on the north side of the tree bole between the bole and the canopy edge. At each plot, we filled 20 1-liter pots with soil from the top 20 cm of the soil profile (n = 200 pots). Half of the pots from each plot were retained in the field, and half were transported to a greenhouse in Tucson, Arizona. In the field, pots were redistributed under the constraint that each plot contained one pot from each of the 10 plots. Pots were buried such that the soil surface within the pot was level with the surrounding soil. Five acorns were planted 1 cm below the soil surface in each pot. Each plot was covered with 5-mm wire mesh to exclude vertebrates. Pots were weeded throughout the entire experiment. Initially, pots were not watered. However, since no emergence was observed for 3 weeks after planting, a second set of acorns was planted. Thereafter, pots were watered and monitored weekly for 3 and 10 weeks, respectively. For both experiments, percent emergence was calculated on the basis of the total number of acorns planted.

In the greenhouse, the pots with understory and grassland soil were arranged in a completely randomized design, and five acorns were planted into each pot. Pots were watered and monitored for emergence three times/week for 8 weeks. Emergence data were analyzed with Student's t-test on ranked data.

Results

Post-Collection Processing and Storage

Data were normally distributed with equal variances. A two-way interaction between acorn treatment and storage duration precluded simple consideration of main effects. Therefore, interpretation is based on interaction means.

Within storage-duration treatment, timing of acorn cup removal did not affect germination. After 7 and 35 days of storage, acorns without cups had higher germination (53 and 78 percent) than acorns with cups intact (10 and 20 percent), respectively. Presence of acorn cups did not affect germination during other storage periods (47 percent).

Within acorn cup treatment, there were no consistent patterns of germination with respect to storage period. Acorns without cups (i.e., cups removed either before or after storage) had higher germination after storing for 35 days (78 percent) compared to storing for 28 days (43 percent), and germination following other storage times was intermediate (54 percent). In contrast, acorns stored and germinated with cups intact had higher germination after 0, 21, and 28 days of storage (42 percent) than after 7 days (10 percent), and germination associated with other storage times was intermediate (22 percent).

Acorn Size

Viability and germination did not differ between acorns in the large and medium size classes (*table 1*). However, viability and germination of acorns in the small size class was less than either of the larger size classes. Emergence of germinated acorns was nearly 100 percent, and did not differ between size classes. The larger the acorn, the greater the total (e.g., shoot and root) biomass produced. Mean time to germination (12 days) and emergence (19 days) did not differ between size classes.

Table 1—Effects of **Quercus emoryi** *acorn size on mean viability, germination, emergence, and seedling size*

Attribute	Large (>0.9 g)	Medium (0.6-0.8 g)	Small (<0.5 g)
Viability *(pct)*	100 a[1]	96 a	90 b
Germination rate *(days)*	11 a	13 a	11 a
Germination *(pct)*	27 a	20 a	11 b
Emergence rate *(days)*	19 a	21 a	19 a
Emergence *(pct)*	96 a	95 a	100 a
Root and shoot mass *(g)*	48 a	35 b	21 c

[1]Within rows, means with the same letter do not differ ($P > 0.05$) according to Fisher's LSD test.

Soil Type and Microclimate

Cumulative seedling emergence in the greenhouse did not differ between understory and grassland soils (9 percent). Similarly, under field conditions, main and interactive effects of soil source and microclimatic conditions did not affect cumulative emergence (26 percent).

Discussion

Removal of acorn cups increased germination of *Quercus emoryi* as much as 5-fold, and in no case reduced germination. On this basis, we reject the hypothesis that the presence of the acorn cup does not affect germination. We therefore recommend that acorn cups be removed during acorn processing. Acorn cups not only inhibit germination, but their presence interferes with the ability to float-test acorns to assess their density: acorns that sink in water have a greater probability of being viable than those that float (Hubbard 1995).

Timing of cup removal (i.e., before or after short-term storage) did not affect germination in our trials, indicating that managers or researchers can remove acorn cups any time before planting. The high variability expressed with germination trials on this species suggest there may be a number of factors affecting an acorn's germination success (Nyandiga and McPherson 1992).

Viability, germination, and seedling size of *Q. emoryi* were positively correlated with acorn size, which is consistent with other *Quercus* species (e.g., Tecklin and McCreary 1991). These results support our hypothesis. To maximize germination and emergence, we recommend that managers and researchers select relatively large acorns for revegetation projects and experimental studies.

Results from greenhouse and field trials lead us to reject our hypotheses that emergence in understory soil and understory microclimatic conditions will exceed emergence in grassland soil and grassland microclimatic conditions. This suggests that factors other than soil or microclimate limit seedling emergence. However, supplemental watering in the field may have masked differences in emergence that otherwise may have resulted from variability in soil and microclimate. Reasons for low emergence in the greenhouse are unknown. To better assess inter-annual effects of seasonal temperature and precipitation regimes on seedling emergence, this study will be repeated in 1996.

Results from these studies suggest that germination and emergence are not critical bottlenecks to oak distribution. Therefore, other aspects of recruitment may exert primary control over observed patterns of oak seedling distribution (Weltzin and McPherson 1994, 1995). Hubbard (1995) suggested that there is sufficient dispersal of acorns into adjacent grasslands to facilitate downslope movement of lower treeline. Results from these studies and preliminary data from other field and greenhouse trials (Germaine 1997, Weltzin unpubl. data[3]) suggest that amount and timing of precipitation exert important constraints on seedling emergence. For example, emergence of *Q. emoryi* at a southern Arizona field site was 25-45 times greater in watered plots than in unwatered plots (Germaine 1997).

Many ecological processes, including oak recruitment, are episodic. Recruitment of *Q. emoryi* appears to coincide with periods of above-average summer precipitation (McClaran and McPherson 1995). Consequently, future research should involve long-term monitoring of experimental treatments in order to better assess inter-annual variation in precipitation and recruitment.

Conclusions

Our investigations of different factors affecting germination and emergence revealed that regardless of the timing of acorn cup removal (e.g. before or after storage), removing the acorn cup increased germination up to 5-fold. Germination did not decline between 0 and 35 days of storage. Viability, germination, and seedling size were positively correlated with acorn size, but emergence and time to germination and emergence did not differ between size classes. Seedling emergence was not affected by soil source or microclimate. Therefore, given adequate soil moisture, germination and emergence are not bottlenecks limiting Emory oak distribution.

References

Bahre, Conrad J.; Hutchinson, Charles J. 1985. **The impact of historical fuelwood cutting on the semidesert woodlands of southeastern Arizona.** Journal of Forest History 29: 175-186.

Bonner, F.T. 1988. **Seeds of woody plants.** In: Mathews, S., ed. Advances in research and technology of seeds. Part II. Wageningen, The Netherlands: Pudoc; 81-112.

Borelli, Simone; Ffolliott, Peter F.; Gottfried, Gerald J. 1994. **Natural regeneration in encinal woodlands of southeastern Arizona.** Southwestern Naturalist 39(2): 179-183.

Conover, W.J.; Iman, Ronald J. 1981. **Rank transformations as a bridge between parametric and non parametric statistics.** The American Statistician 35(3): 124-133.

Germaine, Heather L. 1997. **Constraints on establishment of Emory oak at lower treeline**. Tucson: University of Arizon; 79 p. M.S. thesis.

Harper, John L. 1977. **Population biology of plants.** New York: Academic Press Inc.; 892 p.

Hartley, H.O. 1950. **The maximum F-ratio as a short-cut test for heterogeneity of variance.** Biometrika 37: 308-312.

Haworth, Kathryn; McPherson, Guy R. 1995. **Effects of *Quercus emoryi* trees on precipitation distribution and microclimate in a semi-arid savanna.** Journal of Arid Environments 31: 153-170.

Houssard, C.; Escarre, J. 1991. **The effects of seed weight on growth and competitive ability of *Rumex acetosella* from two successional old-fields.** Oecologia 86: 236-242.

Hubbard, J. Andrew. 1995. **Mechanisms of lower treeline shift: seed fate of *Quercus emoryi* acorns.** Tucson: University of Arizona; 48 p. M.S. thesis.

McClaran, Mitchel P.; McPherson, Guy R. 1995. **Can soil organic carbon isotopes be used to describe grass-tree dynamics at a savanna-grassland ecotone and within the savanna?** Journal of Vegetation Science 6: 857-862.

McPherson, Guy R. 1992. **Ecology of oak woodlands in Arizona.** In: Ffolliott, Peter F.; Gottfried, Gerald J.; Bennett, Duane A.; Hernandez, C.; Victor, M.; Ortega-Rubio, Alfredo; Hamre, Robert H., technical coordinators. Ecology and management of oak and associated woodlands: perspectives in the southwestern United States and northern Mexico. 1992 April 27-30; Sierra Vista, AZ. Gen. Tech. Rep. RM-218. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 24-33.

Nyandiga, Charles O.; McPherson, Guy R. 1992. **Germination of two warm-temperate oaks, *Quercus emoryi* and *Quercus arizonica*.** Canadian Journal of Forest Resources 22:1395-1401.

Sanchini, Paula J. 1981. **Population structure and fecundity patterns in *Quercus emoryi* and *Quercus arizonica* in southeastern Arizona.** Boulder: University of Colorado; 149 p. Ph.D. dissertation.

Shapiro, S.S.; Wilk, M.B. 1965. **An analysis of variance test for normality (complete samples).** Biometrika 52: 591-611.

Sokal, R.R.; Rohlf, F.J. 1981. **Biometry.** New York: W.H. Freeman Co.; 219 p.

Tecklin, Jerry; McCreary, Douglas D. 1991. **Acorn size as a factor in early seedling growth of blue oaks.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31- November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 48-53.

Weltzin, Jake F.; McPherson, Guy R. 1994. **Distribution of Emory oak (*Quercus emoryi* Torr.) seedlings at lower treeline.** United States Section, International Association for Landscape Ecology Annual Meeting abstracts; 1994 March 23-26; Tucson, AZ. volume 9, p. 130.

Weltzin, Jake F.; McPherson, Guy R. 1995. **Potential effects of climate change on lower treelines in the southwestern United States.** In: DeBano, Leonard F.; Ffolliott, Peter F.; Ortega-Rubio, Alfredo; Gottfried, Gerald J.; Hamre, Robert H.; Edminster, Carl B., technical coordinators. Biodiversity and management of the Madrean Archipelago: the Sky Islands of Southwestern United States and Northwestern Mexico; 1994 September 19-23; Tucson, AZ. Gen. Tech. Rep. RM-264. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 180-193.

Young, James A.; Young, Cheryl G. 1992. **Seeds of woody plants in North America.** Rev. ed. Portland, OR: Dioscorides Press; 407 p.

An Evaluation of Coast Live Oak Regeneration Techniques[1]

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Abstract: *A test to evaluate four planting techniques for coast live oak (*Quercus agrifolia *Née) was established in spring 1992 on the California Polytechnic State University, San Luis Obispo, California. Treatments included tree shelters (Tubex®), oak leaf mulch, tree shelters plus mulch, and an unprotected control. Seedling survival 1 year after planting ranged from 14.3 to 37.1 percent. The greatest survival was obtained with oak mulch, and the tallest seedlings, but lowest survival, with tree shelters. Although the shelters enhanced seedling growth, the seedlings averaged only 5.9 inches in height at 1 year. Because of poor survival, empty planting spots were replanted in 1993, 1994, and 1995. By December 1995, average coast live oak stocking ranged from 60 to 74 percent, and height from 3.5 to 15.6 inches for the control and tree shelter treatments, respectively.*

This report describes a project in which several techniques were used to enhance the survival of direct seeded coast live oak (*Quercus agrifolia* Née). What was initially intended to be a 1-year planting project evolved into a 4-year planting "marathon." This is the only effort in California that we are aware of in which the same plantings spots were seeded 4 successive years to achieve as close to 100 percent stocking as possible. Surveys during the past several years indicate a general lack of adequate coast live oak regeneration throughout its range. Bolsinger (1988) reported that about 90 percent of the coast live oak type had few or no saplings or seedlings. And, attempts to artificially regenerate coast live oak in local wild environments have not been successful (Muick 1991, Plumb and Hannah 1991).

A myriad of causes have been identified to explain the poor success of both natural and artificial restocking (Davis and others 1991, Swiecki and others 1990). Swiecki and Bernhardt (1991) provide an excellent overview of the factors affecting the restoration of valley oak (*Q. lobata* Née). Most of these factors apply to coast live oak as well. Herbivory and moisture stress are two key factors negatively affecting both seedling establishment and survival. Mice (Davis and others 1991), deer (Griffin 1971), cattle (McClaran 1987), and grasshoppers (McCreary and Tecklin 1994) are some of the biota that can cause significant seedling losses. However, once established, oak seedlings can often survive stem and foliage losses because of their resprouting capacity. On the other hand, gophers can kill both seedlings and saplings, and they can destroy a root system, preventing resprouting (Adams and others 1992, Davis and others 1991, Lathrop and Yeung 1991). Where gophers are present, the root systems must be protected.

A wide variety of protective devices have been used to prevent herbivory, including window screens (Adams and others 1992, McCreary and Tecklin 1994), fencing (Davis and others 1991, Tietje and others 1991), and individual plant exclosures (Plumb and Hannah 1991, Swiecki and Bernhardt 1991). Plastic translucent tubes called tree shelters (Tubex®) have received considerable attention during the past few years (Costello and others 1991, Potter 1988). They are touted not only because they protect seedlings from herbivory, but also because they promote height growth (McCreary 1993).

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Moisture stress is a major environmental factor responsible for poor germination (Plumb and Hannah 1991) and seedling death (Barnhart and others 1991, Lathrop and Yeung 1991). Low rainfall, an obvious contributor to moisture stress, was considered the major reason for poor success of regeneration work during the latter part of the 1980's (Plumb and Hannah 1991). Other major causes of water stress are plant competition, particularly from annual grasses (Adams and others 1992, Davis and others 1991), and coarse soil textures (Plumb and Hannah 1991). Competing vegetation can be controlled with herbicides and mulching (Adams and others 1992, McCreary 1991). Irrigating young plants during the dry season has also been used in several oak regeneration studies (Costello and others 1991, Swiecki and Bernhardt 1991). The latter obtained better height growth with irrigation.

Some of the many factors that affect oak seedling germination and survival have been briefly noted. The main objective of the work reported here was to determine the effect of tree shelters, oak leaf mulch, and summer irrigation on coast live oak seedling survival. Because of low seedling survival, we decided to replant the same planting spots to determine how much additional work would be needed to achieve a high level of stocking.

Methods

Site Description

The study area is located on Radio Tower Hill (RTH), just west of the main California Polytechnic State University (Cal Poly) campus, San Luis Obispo, California. It is on a northeast aspect at about 400 feet in elevation with slopes between 10 to 40 percent. The test plots occupy about 0.5 acres in a long narrow strip between a ridge line and a stand of coast live oak along the northeast border. A preliminary analysis indicated that the soil is a loamy, mixed, thermic, ultric soil that was keyed out to be a Catelli coarse, sandy clay loam. Except for thicker "O" and "A" horizons, there is little difference between the soil in the grassy plot area and that under the adjacent oak canopy (*table 1*).

Table 1—Comparison of soil characteristics between the open grassy test area and under the canopy of the adjacent oak stand

Site	pH	Soil horizon depth					Accumulated
		O[1]	A	B	BC	C	depth to "A" to "C"
		inches					
Open grass	5.4-5.7	0.4	1.6	8.3	5.1	13.8+	15.0
Oak canopy	5.5-5.8	0.8	4.7	8.7	3.9	9.9+	16.3

[1]Soil horizons are defined as follows: O = organic zone, A = mineral zone, B = accumulation zone, and C = unconsolidated parent material.

Annual grasses are the predominant vegetation on the project area with scattered northern monkey flower (*Mimulus aurantiacus* Curtis), coyote bush (*Baccharis pilularis* DC.), and California sage brush (*Artemisia californica* Less). There is also scattered advanced coast live oak regeneration in the annual grass along the upper edge of the oak stand, including several new seedlings along the canopy drip line. The oak stand is composed of a wide range of sizes and conditions of coast live oak. Photographic evidence over the past 82 years indicates that there has been a considerable increase in the size of the stand since 1908.

Although no formal animal monitoring was done, deer (*Odocoileus hemionus columbianus*) are often seen in the plot area. There was evidence of extensive pocket gopher (*Thomomys bottae* Eydoux & Gervais) activity at the beginning of the study that seemed to greatly increase in 1995. In some areas, exit and feeding holes are only 6 to 12 inches apart. Grasshoppers (species not identified) were present throughout the summer months; but in summer 1994, as noted by McCeary and Tecklin (1994) at the Sierra Field Station, there was a population explosion. It was common to find four or five grasshoppers on a single seedling. Leaf and stem damage was similar to that described by McCreary and Tecklin (1994)—leaves partially to completely gone and bark stripped from the smaller stems.

Treatments

This project included a small statistically designed regeneration test to compare the effectiveness of tree shelters and oak leaf mulch on coast live oak seedling survival and growth. Because of poor initial seedling survival, planting spots without a live seedling were replanted for 3 additional years. A small irrigation study was also established the third year of the project.

1991-1992 Activities

The Regeneration Test involved four treatments: (1) untreated control, (2) oak litter mulch, (3) tree shelters (4 feet tall and 3.5 inches wide), and (4) tree shelters plus oak litter mulch. The test consisted of 35 randomly located clusters, each containing four planting spots randomly assigned to the treatments. The planting spots in each cluster were in a square pattern and about 4 feet apart. Planting data, site preparation, seed source, and irrigation schedule are listed in *table 2*. All planting spots were pre-dug with a 6-inch power auger to a depth of 12 to 18 inches. An 18-inch long by 6-inch diameter cylinder of 1-inch mesh chicken wire was placed in each hole for gopher protection; the holes were then refilled with

Table 2—Planting date, seed source, monthly irrigation schedule, and other treatment factors for the four planting cycles of the Coast Live Oak Regeneration Test

	Year of planting			
Cultural factors	1991-1992	1992-1993	1993-1994	1994-1995
Planting date	Late April	Late January	Late February	Early February
Site preparation	Pre-dug holes to 18 in., scalping	Litter replacement, scalping	Litter replacement, scalping	Litter replacement, no scalping
Seed source	Poly Canyon	Poly Canyon	Mixed[1]	Mixed
Acorns per planting spot	2	3	2	2
Irrigation schedule	June-Sept.	April-Oct.	June-Sept.	June-Sept.
Water per planting spot	1 gal.	0.5 gal.	0.5 gal.	1 gal.
Method of irrigation	1-gallon[2] container	Hand irrigation	Hand irrigation	4-gallon[3] container

[1]Acorns from Cal Poly Campus and from Pleasanton Ridge, Pleasanton, CA.

[2]Water for each planting spot was supplied from a 1-gallon plastic container with a small hole punched in the bottom.

[3]Water for all four treatments was supplied from a 4-gallon container fitted with four 1-gallon/hour drip emitters.

the excavated soil. A 5-ft square area containing each cluster was scalped to mineral soil in March 1992 to control grass competition.

Acorns were picked in October from a tree in Poly Canyon, about 1 mile across the campus from RTH. They were air-dried for about 10 days, then stored in plastic bags in a cold box at 38 °F. About 2 weeks before planting, the acorns were placed in plastic bags containing moist vermiculite and stored at 70-75 °F. Two pregerminated acorns with radicles approximately 1/4 inch long were sown in each planting spot during the first week of April. The control planting spots received no additional preparation. Oak leaf litter for the mulch treatment was collected from the adjacent oak stand and spread over a planting spot to a depth of about 2 inches. The litter was held in place with a 1.5- by 1.5-ft piece of chicken wire secured in place with hemp staples. Tree shelters were secured with 3/4-inch thick wooden stakes; the tops of the shelters were covered with fine plastic mesh or wire to keep out birds and other small animals.

Irrigation for the Regeneration Test was applied to each planting spot at the rate of 0.5 or 1.0 gallons per month from late spring to early fall (*table* 2). Seedling survival (*fig. 1*) and height (*fig. 2*) were measured several times from May 1992

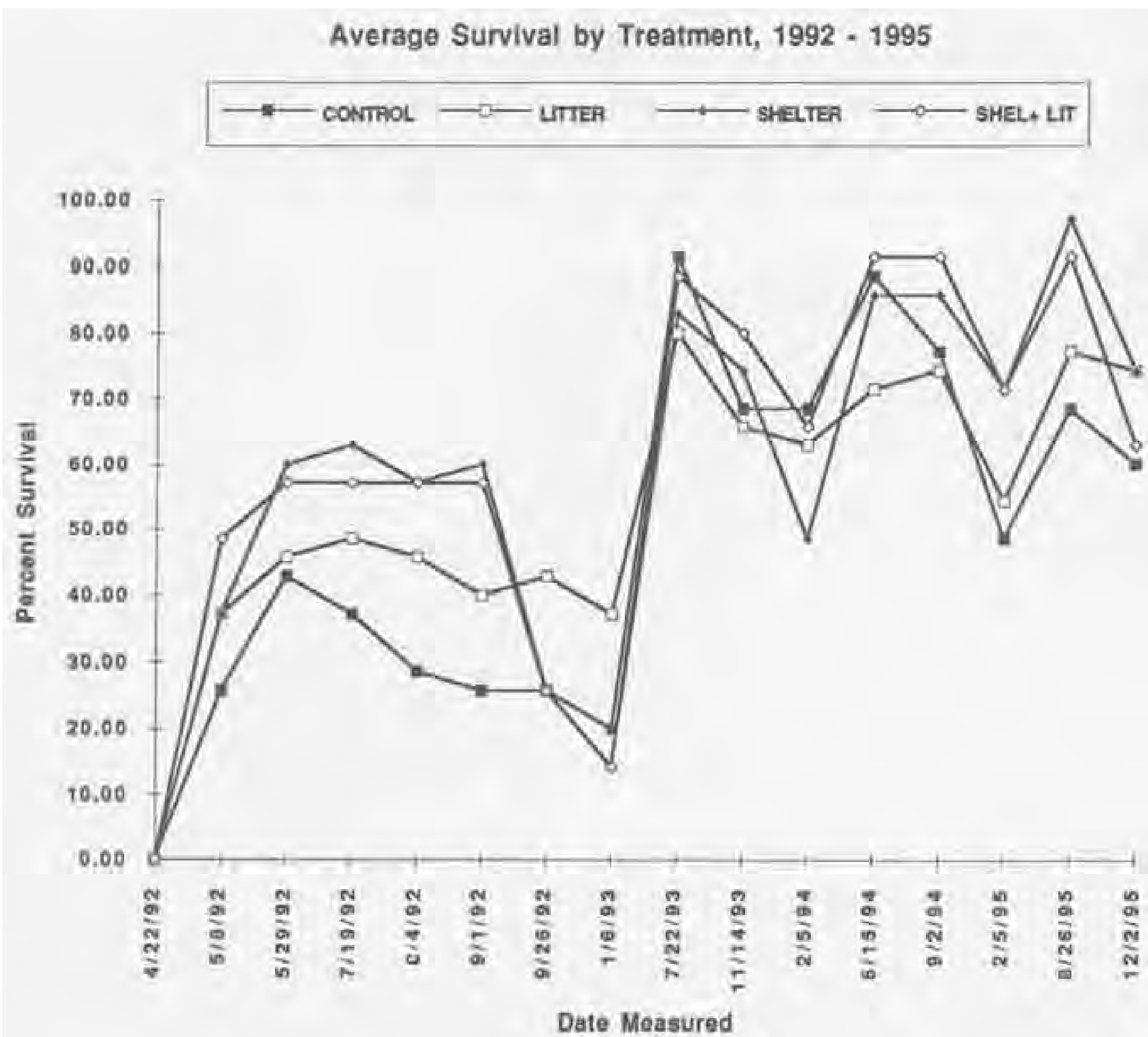

Figure 1—Percent survival of coast live oak seedlings for four planting cycles beginning in 1991. A dramatic decline in survival occurred each fall; little increase in stocking was gained after the second planting.

until January 6, 1993. All sample dates for 1992 and subsequent planting years are shown in *figures 1* and *2*.

1992-1993 Activities

Planting spots without a live seedling were replanted in late January with three germinating acorns (*table 1*). Each cluster was rescalped and the oak litter mulch replaced. Monthly irrigation of 0.5 gallons per planting spot began in late April and continued until October.

1993-1994 Regeneration Activities

All planting spots without live seedlings were replanted with two germinating acorns in late February (*table 3*). We made no effort to keep track of the acorn source for this or the following year's planting. Acorns were either from Poly Canyon or Pleasanton, California. The litter treatments were again refurbished and each 5- by 5-foot plot area rescalped.

A small irrigation study was established in March 1994 to compare two rates of irrigation (1/2 and 1 gallon per planting spot) and a nonirrigated control. Ten treatment clusters were arbitrarily dispersed throughout the Regeneration Test area with each treatment randomly assigned within a cluster. Each planting spot

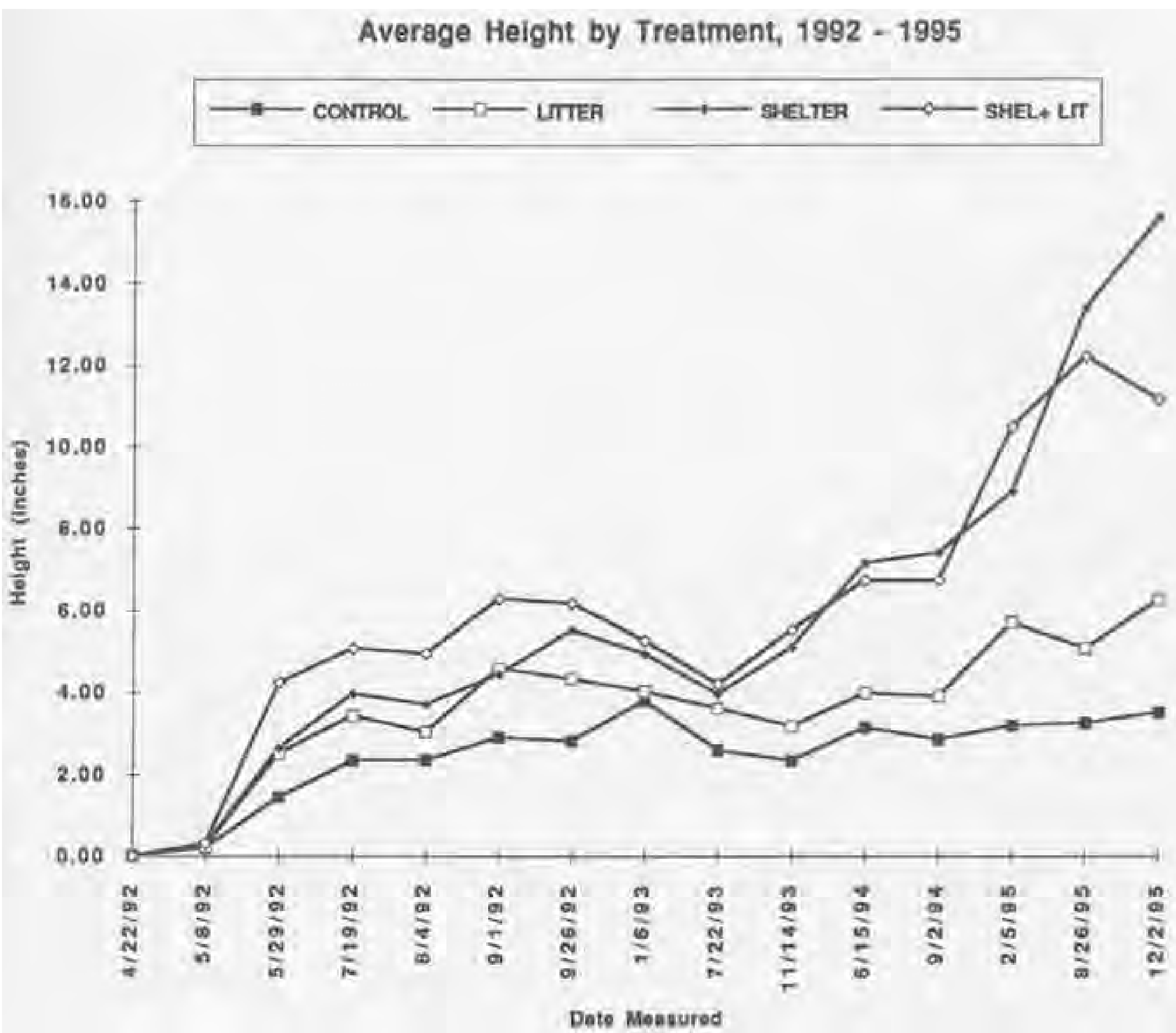

Figure 2—Average height of the coast live oak seedlings protected by tree shelters dramatically increased in 1995. However, death of several of the tallest seedlings (up to 43.3 inches tall) between August and December 1995 resulted in a drop in average seedling height for the tree-shelter-plus-litter treatment.

Table 3—Planting date, monthly irrigation schedule, and other treatment factors for the Coast Live Oak Irrigation Study

	Year of research activity	
Cultural factors	1993-1994	1994-1995
Planting date	Late February	Early February
Acorns or seedlings per planting spot	2	2
Irrigation schedule		
Water application per planting spot	June-Sept. Variable[1]	June-Sept. Variable[2]

[1]Three rates: 0, 0.5, and 1 gal. per planting spot.
[2]Nonirrigated control plots received 0.5 gal. water per planting spot on the June irrigation date.

was pre-dug with a 6-inch diameter auger, lined with chicken wire and refilled. Six-inch diameter chicken wire cylinders 12 inches tall were attached to the top of the gopher exclosures to reduce aboveground herbivory. Three germinating acorns were sown at each planting spot that were arranged in a triangular pattern, approximately 3 feet apart. The immediate plot area was scalped at planting time. Water was metered from 0.5- and 1-gallon plastic containers fitted with 1-gallon/hour drip irrigation fittings. Water was applied monthly from June to September 1994. Height and survival sampling dates are show in *figure 3*.

1994-1995 Activities

The regeneration test and irrigation study sites were replanted in early February 1995 with germinating acorns from either Poly Canyon or Pleasanton. Litter was replaced as before; however, no rescalping was done. Plant cover in the scalped areas was mostly scattered filaree (*Erodium* spp.) and was not considered a serious competitor of the oak seedlings.

Data Collection and Analysis

Treatment results for all 4 years of the work reported here are based on seedling height and survival measured periodically throughout the summer and fall (*figs. 1* to *3*). Seedling height was based on the height of the tallest live seedling per planting spot. The final evaluation for each planting cycle was usually obtained after December, with the exception of 1994-1995 when the last measurements were made in early December.

Survival data for the Regeneration Test were analyzed by logistic regression (SAS) that expressed probability of survival as a nonlinear function of age and treatment variables, with the control treatment as a reference. Height data were analyzed by multiple regression (MINITAB), again controlling for age. Plot replication differences were evaluated by a two-way analysis of variance.

Results

Regeneration Test

Seedling survival for the control and three treatments for the entire 4-year planting effort is shown in *figure 1*. Seedling emergence for the 1991-1992 cycle did not peak until mid-July for all treatments except the controls, whose survival had already begun to decline and continued to do so until replanting in 1993.

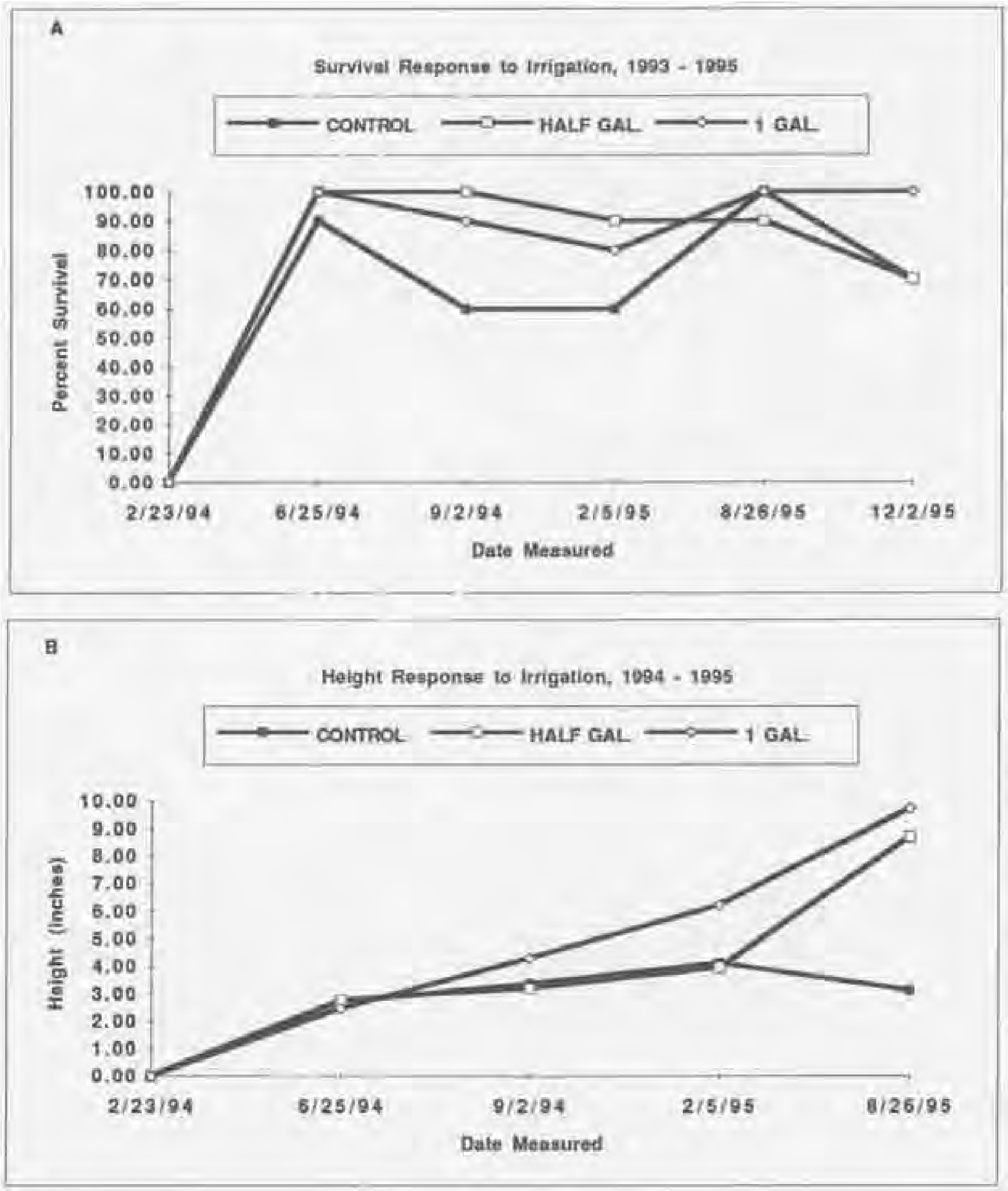

Figure 3—Percent survival (A) and average height (B) of coast live oak seedlings for the Irrigation Study 1994-1995 planting cycles. Monthly irrigation from June to October enhanced seedling height over the nonirrigated seedlings, but the effect of irrigation on seedling survival was not clearcut.

Emergence was relatively poor for all treatments, ranging from 42.9 percent for the controls to 62.9 percent for the tree shelters.

Seedling survival for the tree-shelter treatments remained constant until September 1; then there was a dramatic decline to only 14.3 percent by January 1, 1993. During this time, seedling survival for the litter treatment slowly declined, and by January 1993, it had dropped to 37.1 percent. The tree shelters initially stimulated modest height growth (*fig. 2*) over that obtained with the control and litter treatments. The high seedling mortality after September 1 did not change the height relationship among treatments. Extensive pocket gopher activity was present throughout the test area, but no seedling death was attributed to them. Most of the control and litter treatment seedlings showed signs of herbivory, and many of the tree shelter seedlings were infected with woolly aphids (*Stegophylla quercicola* Baker).

Seedling survival for the 1992-1993 cycle, which included surviving seedlings from the 1991-1992 cycle, was much higher than it was for the previous year, ranging from 80.0 to 91.4 percent on July 22. Planting in January and above-normal winter rainfall may have accounted for the increased level of survival that was enhanced by the surviving 1991-1992 seedlings. Again, there was a big decline in seedling survival for all treatments during the fall and winter (*fig. 1*). However, the seedlings in the tree shelters still maintained their height dominance.

The survival pattern for the 1993-1994 planting cycle was similar to that for 1992-1993, and 85 to 95 percent of the planting spots had live plants on June 15, 1994, except the litter treatment with only 71.4 percent. The pattern of survival was also very similar to that for 1991-1992 with a large decline after September 2. However, minimal seedling survival ranged from 48.5 to 71.4 percent, much higher than for the 1991-1992 cycle. By this time, average seedling height for the two tree-shelter treatments was about double that for the control and litter treatments and ranged from 9.0 to 10.5 inches (*fig. 2*) for the shelter and shelter-plus-litter treatments, respectively. Pocket gopher activity continued, and a few planting spots were almost completely surrounded by exit holes, but no seedling mortality was attributed directly to gophers. Most unprotected seedlings had some browsing. An extremely heavy infestation of grasshoppers was present all summer.

Seedling survival and height were measured only twice in 1995. The August 26 sampling was probably too late to obtain maximum seedling establishment, but the percent survival was still very high for both shelter treatments, ranging from 91.4 to 97.1 percent. Survival for the control and litter treatments was somewhat lower at 68.5 and 77.1, respectively. Seedling age at the beginning of 1995 varied from 1 to 3 years. However, most seedlings had died (replanting required) or were 2 years old. Logistic regression analysis indicated that seedling age, but not treatments, was a significant predictor of seedling survival ($P \leq 0.01$). Again, a major decline in seedling survival occurred after early September for the shelter treatments. Although 31 of the 70 tree-shelter seedlings were infested with woolly aphids, only three of the infected seedlings died after August 26. The amount of gopher activity was amazing. In some areas on and around the test site, exit holes were only 6 to 10 inches apart.

Average height for seedlings in the shelter-plus-litter treatment also declined because some of the seedlings that died were 2 years old and more than 40 inches tall. However, seedlings for both tree-shelter treatments were about twice as tall as the control and litter seedlings. There was no significant difference between shelter treatments, or between the control and litter treatments. An ANOVA of the replications indicated that there was no significant plot effect ($P \leq 0.05$).

Irrigation Study

Seedling survival for the 0.5- and 1.0-gallon irrigation treatments ranged from 80 to 100 percent for the entire test, except for a decline to 70 percent for the 0.5-gal. rate on the last sampling date in December 1995. Average percent survival for nonirrigated seedlings was generally less than for those that were irrigated (*fig. 3A*). Irrigation had a positive effect on seedling height, but there was no apparent difference between irrigation levels (*fig. 3B*).

Discussion

Attempts to artificially regenerate coast live oak in the Central Coast area of California have generally not been successful for the past several years (Plumb and Hannah 1991). Initial establishment has been excellent on some exposed grassy sites, but few coast live oak seedlings were alive 2 years later. Excluding damage and death by the many types of herbivory that have been reported on oaks, lack of coast live oak seedling survival can generally be attributed to unsatisfactory site conditions and to moisture stress specifically.

The study area had nearly uniform soils in and out of the oak stand and seemed like an ideal location to test some promising regeneration techniques. The natural expansion of the adjacent coast live oak stand over the past 80 years and the presence of advanced regeneration on the site indicated that this should be a suitable location to establish coast live oak. It was hoped that moisture stress from grass competition and low rainfall would have been counteracted by weed control, oak mulch, and/or irrigation.

Pocket gophers were a serious threat during the study, especially in 1995. The buried chicken wire exclosures seemed to provide adequate protection for the seedlings. The death of only a few seedlings could be directly attributed to gophers, and these were seedlings which gophers had extensively excavated around a planting spot. The potential threat to unprotected seedlings and advanced regeneration was demonstrated on the test site in August 1995 when a natural seedling at least 5 to 10 years old and 0.6 inches in diameter at ground level was completely severed a few inches below ground. The damage appeared to be exactly like that described by Lathrop and Yeung (1991) for Engelmann oak (*Q. engelmannii* Greene) and shows the need for long term protection where gophers are present. Unprotected seedlings have little chance of escaping gopher herbivory.

Tree shelters are used to promote height growth and reduce herbivory (Costello and others 1991, Manchester and others 1988). Both of these effects were obtained in this project. And, both tree-shelter treatments significantly enhanced average seedling height after 4 years of replanting (*fig. 2*). To the contrary, seedling survival was not enhanced by the shelters. Each year, there was a major decline in seedling survival in the fall. Ironically, the shelters produced the biggest seedlings and the lowest survival. What went wrong? Woolly aphids infested many of the these seedlings, but they usually do not cause plant death (Brown and Eads 1965). The micro environment in the shelters, which can be at least 4 to 7 °F warmer than the outside air (Costello and others 1991), apparently favored the aphid infestation.

Moisture stress would seem to be the obvious explanation for the fall seedling deaths. Irrigation was usually discontinued after September; this may have been too soon and watering probably should have been tailored to fall precipitation. Although early fall precipitation occurred in 1994, still many seedlings died during the fall and early winter. Were these deaths due to moisture stress or something else? The tree shelters promoted accelerated growth that may have ultimately contributed to the seedling deaths because of their greater water requirements.

The effectiveness of the irrigation methods was somewhat suspect because of the erratic discharge from the plastic containers and the variable amount of surface runoff that occurred from one seedling to another with hand watering. Using plastic containers in 1995 with drip emitters eliminated both of these problems. Other studies indicate mixed results with supplemental irrigation (Costello and others 1991, Gordon and others 1991), and Swiecki and Bernhardt (1991) even suggested that irrigated plants are more likely to be browsed than non-irrigated plants. In the irrigation study reported here, providing monthly amounts of either 0.5 or 1.0 gallon of water per seedling greatly enhanced height growth over that for the non-irrigated control plants (*fig. 3*). The effect of irrigation on survival was less obvious, though it was deemed to be worthwhile.

The effect of oak mulch to reduce moisture stress was not clearcut, although it did appear to enhance seedling survival at the end of the 1991-1992 and 1994-1995 planting cycles. Both Davis and others (1991) and Adams and others (1992) note the negative impact of annual grass on seedling survival. Controlling competing vegetation through a variety of methods, including scalping and mulching, can greatly improve the survival of planted seedlings (McCreary 1991). Because both scalping and oak leaf mulch were used in this test, the overall effect of scalping may have masked the effect of the mulch.

Finally, replanting this site for 4 consecutive years did not result in complete stocking. Although the overall percent survival for all treatments increased from 21.4 percent for the first planting cycle to 69.3 percent for the fourth planting cycle, this was only 7.9 percent higher than the overall survival at the end of the second planting cycle. The only significant factor affecting survival after 4 years was seedling age where the odds of survival were directly related to seedlling age (ln value of survival = 0.839 + 0.693 age). It seems reasonable to expect that seedlings that survived for 1 or more years would have a better chance of persisting another year than would a crop of new seedlings.

Conclusions

This work demonstrated that it can be extremely difficult to attain 100 percent survival (stocking) of coast live oak on a promising field site, even after repeated replanting. Little increase in stocking was gained after the second planting. It would be fiscally imprudent to repeat replanting until the cause of the late-fall, early-winter seedling death was identified.

Tree shelters enhanced coast live oak seedling growth and effectively prevented herbivory, but they did not promote greater seedling survival on this site. Late-fall, early-winter seedling death appeared to be related to moisture stress. Irrigation that was either more frequent, at a higher rate, or later in the fall might have prevented this decline in survival. Also, planting in 6- to 8-inch diameter shelters might have provided a better micro environment for the seedlings as they appeared to be crowded in the 3.5-inch diameter shelters used in this test.

Finally, although some natural seedlings near the test site have persisted and developed into saplings, it is not clear how they made it. To ensure satisfactory survival of artificial regeneration of coast live oak, we do know that it is essential to protect seedlings from above and below ground herbivory, but we are not yet certain about the level of irrigation that is needed or if irrigation is needed at all.

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References

Adams, Theodore E.; Sands, Peter B.; Weitkamp, William H.; McDougald, Neil K. 1992. **Oak seedling establishment on California rangelands**. Journal of Range Management 45: 93-98.

Barnhart, Stephen J.; McBride, Joe R.; Warner, Peter. 1991. **Oak seedling establishment in relation to environmental factors at Annadel State Park**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 25-30.

Bolsinger, Charles L. 1988. T**he hardwoods of California's timberlands, woodlands, and savannas.** Resource Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Brown, Leland R.; Eads, Clark O. 1965. **A technical study of insects affecting the oak tree in southern California**. University of California Agricultural Experiment Station Bulletin 810; 105 p.

Costello, L.R.; Schmidt, R.H.; Giusti, Gregory A. 1991. **Evaluating tree protection devices: effects on growth and survival -- first-year results.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 31-35.

Davis, Frank W.; Borchert, Mark; Harvey, L.E.; Michaelsen, Joel C. 1991. **Factors affecting seedling survivorship of blue oak (*Quercus douglasii* H. & A.) in central California**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 81-86.

Gordon, Doria R.; Rice, Kevin J.; Welker, Jeffery M. 1991. **Soil water effects on blue oak seedling establishment**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31- November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 54-58.

Griffin, Jim R. 1971. **Oak regeneration in the upper Carmel Valley, California**. Ecology 52: 862-868.

Lathrop, Earl W.; Yeung, Kevin P.C. 1991. **Pocket gopher damage to Engelmann oak on the Santa Rosa Plateau.** Oak's 'n Folks Newsletter: December; Integrated Hardwood Range Management Program, University of California; 4-5.

Manchester, Edwin H.; Roland, Felicia G.; Sims, Daniel H. 1988. **Tree shelters show promise for oak regeneration**. Management Bull. R8-M85. Atlanta, GA: Cooperative Forestry, Southern Region, Forest Service, U.S. Department of Aghriculture; 2 p.

McClaran, Mitchell P. 1987. **Blue oak age structure in relation to livestock grazing history in Tulare County, California**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986, San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 358-360.

McCreary, Douglas D.; 1991. **Artificially regenerating native oaks in California**. Oak's 'n Folks Newsletter: December; Integrated Hardwood Range Management Program, University of California; 3-4.

McCreary, Doug. 1993. **Tree shelters protect oak seedlings from cattle**. 1993. Oak's 'n Folks Newsletter: March; Integrated Hardwood Range Management Program, University of California; 3.

McCreary, Douglas D., Tecklin, Jerry. 1994. **Grasshoppers continue to hamper oak restoration efforts.** Oak's 'n Folks Newsletter: 9(2) 4-5; Integrated Hardwood Range Management Program, University of California.

Muick, Pamela C. 1991. **Effects of shade on blue oak and coast live oak regeneration in California annual grass lands**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 21-24.

Plumb, Tim R.; Hannah, Bennie. 1991. **Artificial regeneration of blue and coast live oaks in the Central Coast.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 74-80.

Potter, Mark J. 1988. **Tree shelters improve survival and increase early growth rates**. Journal of Forestry 86: 39-40.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A. 1991. **Minimum input techniques for restoring valley oaks hardwood rangelands**. Forest and Rangeland Resources Assessment Program; Calif. Dept. of Forestry & Fire Protection, Sacramento, CA; 79 p.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1990. **Impacts of diseases and arthropods on California's rangeland oaks.** Forest and Rangeland Resources Assessment Program; Calif. Dept. of Forestry & Fire Protection, Sacramento, CA; 94 p.

Tietje, William D.; Nives, Sherryl L.; Honig, Jennifer A.; Weitkamp, William H. 1991. **Effect of acorn planting depth on depredation, emergence, and survival of valley and blue oak**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 14-20.

Effects of Seedling Protectors and Weed Control on Blue Oak Growth and Survival[1]

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Abstract: *Two factors limiting successful recruitment of planted blue oak (*Quercus douglasii*) seedlings are dry soils and animal damage. Many approaches have been used to mitigate these factors including several types of protective cages and alternative methods of weed control. This study examined how treeshelters, screen cages and varying intensities of weed removal affect the establishment and growth of blue oak seedlings. After 5 years, seedlings protected with treeshelters had higher survival, greater diameter, and were taller than those in screen cages. Seedlings receiving no weed control had lower survival, shorter height, and smaller diameter than those with the two highest intensities of weed removal. This study suggests that treeshelters are a promising tool for regenerating blue oaks in California and that providing adequate weed control can improve the growth and survival of planted seedlings.*

Blue oak (*Quercus douglasii*) is one of several species of native California oaks that is reported to be regenerating poorly in some locations (Bolsinger 1988, Muick and Bartolome 1987). Recent studies indicate that a variety of factors limit natural recruitment, including herbivory by deer, livestock, and rodents; defoliation by insects; root clipping by gophers; girdling by voles; and limited soil moisture induced by competing vegetation. These same factors can also prevent successful establishment of planted seedlings or acorns (McCreary 1990).

Many devices are used to protect planted seedlings from damage by animals, with varying degrees of success. Some of the more common products are plastic mesh cages, cylinders made from aluminum window screen, cages of chicken wire, and hardwire cloth buried in the ground. One relatively new product is called a treeshelter. These are rigid, translucent, double-walled plastic cylinders, developed in England and used there for more than 10 years (Potter 1988). They are reported to not only protect seedlings from a variety of animals, but also stimulate aboveground growth.

Another factor that can severely limit the survival and growth of oak seedlings on many rangeland sites is severe competition from grasses and forbs. Such competition can create extremely dry soil conditions that can be lethal to both natural seedlings and planted oaks (Griffin 1971). Some researchers believe that plant competition on many hardwood rangelands is greater today than it was before the introduction and establishment of exotic Mediterranean annuals, which have displaced many native perennials (Welker and Menke 1987). These annual plants absorb more soil moisture in the spring than the native perennial grasses, and consequently, create a drier environment. This makes it more difficult for oak seedlings to become established. Because of the adverse effects of such competition, researchers and practitioners have found controlling weeds around oak plantings necessary to obtain adequate survival and growth. Without weed control, animal damage problems are also generally greater, because dense weeds provide a favorable habitat for animals such as grasshoppers and voles, which can seriously damage young plants (Tecklin and McCreary 1993).

A variety of techniques have been used to eliminate weeds, including mulch, herbicides, scalping and mowing. Though studies comparing weed control to no weed control have demonstrated the advantage of weed removal (Adams and McDougald 1995), we are aware of no research on the effectiveness of varying intensities of weed removal on the field performance of blue oak seedlings.

[1] An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Our objectives in this study were to determine how different types of aboveground protection, and different intensities and durations of weed control, would affect the growth and survival of transplanted blue oak seedlings.

Study Area and Methods

In early February 1991, we planted 160 1-year-old blue oak seedlings at the University of California Sierra Foothill Research and Extension Center, 30 km northeast of Marysville, California. Seedlings had been raised at the California Department of Forestry and Fire Protection Nursery in Davis, California, and were from acorns collected from a single tree growing approximately 5 km from the planting site. Seedlings were planted on a 2.1-m spacing in a fenced research area inaccessible to deer and livestock. Treatments included four levels of weed control (none, and weed-free circles of 0.6-, 1.2-, and 1.8-m diameter), and two types of protection (60-cm-tall screen cages or 1.2-m-tall treeshelters). Four blocks of 40 seedlings were established. Within each block, each weed-control treatment consisted of two adjacent 5-seedling rows, which were randomly positioned. One of these rows was randomly assigned to be protected with screen cages, while the other row was covered with treeshelters.

At the time of planting, through summer's end, the weed-free circles were created and maintained by scalping with hoes and occasional hand-pulling. Before planting, planting holes were augured to a depth of 60 cm using a tractor-mounted 15-cm diameter auger. A 21-g, slow-release fertilizer tablet (20-10-5 NPK) was placed approximately 30 cm deep within each hole. At the end of each of the next five growing seasons, we evaluated survival, total height, and basal diameter of all seedlings. During the second growing season, two of the four replications were randomly selected for a continuation of the weed-control treatments. That is, during this second season, those planting spots receiving the three weed-control treatments (0.6, 1.2, and 1.8 m circles) were maintained by a combination of hoeing and hand pulling. The other two replications were not treated, so there was a reinvasion of some weeds in the circles, though these areas had fewer weeds than the untreated areas. After the second year, no additional weed removal was provided.

All survival data were initially collapsed to frequencies and analyzed by a chi-square test. In instances where chi square indicated significant ($P \leq 0.5$) differences among weed-control treatments, survival percentages were calculated for all weed-control/protection combinations within blocks, transformed by an arcsine transformation, and analyzed by an analysis of variance for a split-plot design with protection treatments nested within weed-control treatments. Height and diameter data were also analyzed using ANOVA for a split-plot design. When we observed significant ($P \leq 0.05$) differences among weed-control treatments, a Tukey's multiple comparison test was performed to determine which treatments were significantly different from each other. We also tested for interactions between seedling-protection and weed-control treatments. To determine if there were significant differences between seedlings receiving weed control for either 1 or 2 years, a split-split plot ANOVA was performed. All differences stated as significant are at the $P \leq 0.05$ level.

Results

Survival

During each growing season, survival of seedlings in treeshelters or tubes was significantly higher than survival in screen cages (*table 1*). The absolute differences between shelter types increased each successive year: survival of seedlings in treeshelters remained relatively constant, while survival of seedlings in screen cages decreased each year. From the third year on, average survival in the treeshelters was twice that in the screens.

After the first growing season, no significant differences in survival among weed treatments were detected (*table 1*). By the second year, however, there were significant differences among weed treatments, with the control having significantly lower survival than the two treatments with the greatest intensities of weed removal. By the fourth growing season (1994), average survival of lowest intensity weed removal (0.6-m circles) was significantly greater than the survival of the no-weed-removal treatment. After the first growing season, average survival decreased 20 percent for seedlings where weed control was not maintained, but went down only 10 percent in blocks where the weed treatment was continued. After each subsequent growing season (when no further weed treatments were continued), survival decreased slightly, but at approximately the same rate for seedlings provided with weed control for either 1 or 2 years. There were significant interactions between protection and weed treatment in 1993 and 1995.

Height

From the first growing season onward, seedlings in tubes were significantly taller than those in screens (*table 2*). The absolute difference in height between these treatments also increased each successive growing season, and by the third field season, seedlings in tubes were, on average, approximately 1 meter taller than those in screens. During the first year of the study there were also significant differences among weed-control treatments, with seedlings receiving the greatest weed control being significantly taller than those having no weed control, or the smallest diameter weed-free circles (*table 2*). By the second growing season, these

Table 1—Average survival (pct) of seedlings protected with different devices, and receiving different intensities and intervals of weed control[1]

	Growing Season				
Treatment	1991	1992	1993	1994	1995
	pct				
Protection					
Screen cage	[a] 71.3	[a] 47.5	[a] 41.3	[a] 38.8	[a] 32.5
Treeshelter	[b] 90.0	[b] 83.8	[b] 83.8	[b] 81.3	[b] 81.3
Weed intensity					
None	67.5	[a] 42.5	[a] 40.0	[a] 37.5	[a] 32.5
0.6-m circle	80.0	[ab] 67.5	[ab] 57.5	[b] 60.0	[b] 57.5
1.2-m circle	87.5	[b] 75.9	[b] 75.0	[b] 70.0	[b] 65.0
1.8-m circle	87.5	[b] 77.5	[b] 77.5	[b] 72.5	[b] 72.5
Weeding interval					
1 year	71.3	[a] 51.3	[a] 48.8	[a] 47.5	[a] 42.5
2 years	90.0	[b] 80.0	[b] 76.3	[b] 72.5	[b] 71.3

[1] Growing seasons and treatment types with different letters are significantly different ($P \leq 0.05$) by a chi-square test for protection and weeding-interval treatments, and by a Tukey's test for weed-intensity treatments.

Table 2—Average height (cm) of seedlings protected with different devices, and receiving different intensities and intervals of weed control[1]

Treatment	Growing Season 1991	1992	1993	1994	1995
	cm				
Protection					
Screen cage	[a] 28.6[a]	[a] 33.0	[a] 71.6	[a] 76.4	[a] 94.0
Treeshelter	[b] 45.8	[b] 96.1	[b] 163.8	[b] 183.4	[b] 211.9
Weed intensity					
None	[a] 30.2	[a] 39.2	[a] 81.1	[a] 105.0	[a] 106.8
0.6-m circle	[a] 30.7	[ab] 54.7	[ab] 113.1	[a] 110.9	[ab] 149.9
1.2-m circle	[ab] 39.9	[bc] 71.4	[bc] 127.4	[ab] 137.0	[b] 162.0
1.8-m circle	[b] 48.0	[c] 94.8	[c] 149.4	[b] 166.7	[b] 192.9
Weeding interval					
1 year	36.4	[a] 56.7	[a] 105.1	114.5	151.5
2 years	38.0	[b] 72.3	[b] 129.0	139.2	157.5

[1] Growing seasons and treatment types with different letters are significantly different ($P \leq 0.05$) by Analysis of Variance for protection and weeding-interval treatments and by a Tukey's test for weed-intensity treatments.

differences were even greater. The absolute difference between controls and weed-removal treatments was greatest after the fifth growing season. In the second growing season (1992), half of the plots received a second year of weed removal. Seedlings that were maintained weed-free for 2 years were significantly taller after the second and third growing seasons. During the next two growing seasons, differences in height between these two groups were no longer significantly different. There was a significant interaction between protection and weed treatment in 1992 only.

Diameter

Patterns in basal diameter were similar to those for height, but did not commence as early. During the first field season, no difference in diameter between seedlings with different protectors was detected (*table 3*). By the second growing season, however, seedlings in treeshelters had significantly larger diameters. Over time, the differences between these two treatments continued to increase, and by the fifth year, average diameter of seedlings in treeshelters was approximately 2.5 times greater than the diameter of those in screens.

During the first year, we detected significant differences in diameter among weed-control treatments; seedlings from the two treatments with the most weed removal were significantly greater in diameter than the two with the least (*table 3*). The absolute difference in diameter between treatments tended to increase over successive years. In contrast to height, the most pronounced increases in average diameter between seedlings that received weed removal for either 1 or 2 years were during the last two growing seasons. There were no significant interactions.

Discussion

Our data suggest that both shelter type and the intensity and duration of weed control can dramatically affect the field performance of planted blue oak seedlings. From the first growing season, seedlings protected with treeshelters grew much taller than seedlings in screens. This is consistent with results from a previous study that compared these shelter types for valley oak (*Q. lobata*) (McCreary and Tecklin 1993). In another study with blue, valley, and interior live oaks (*Q. wislizenii*), however, there was little difference in survival or height growth between seedlings protected with treeshelters and those protected with screen cages (Costello and others 1996).

Our study also found that seedlings in treeshelters did not initially have larger diameters, and as a result, were somewhat spindly. Some early studies with oaks in England found that if shelters were removed after only 3 years, a proportion of the seedlings had not attained sufficient girth to support the crown and needed to be staked to the treeshelter stakes to keep them upright (Potter 1991). Our results suggest that treeshelters do cause an initial reduction in the diameter-to-height ratios of blue oaks. However, even during the second growing season, seedlings in tubes began to increase in diameter at a far greater rate than those in screen cages. By the fifth growing season, seedlings in tubes had not only larger height and diameter, but larger diameter-to-height ratios as well. In late fall 1995, we removed all but the bottom 20 or 40 cm of all treeshelters (which we left to protect the bases of the seedlings from voles and to compare the effectiveness of different heights in providing this protection). None of the seedlings fell completely over, though four or five did lean somewhat afterwards. These were all very small seedlings that had small (<1.5 cm) basal diameters and either were shorter than the tops of the tubes or had grown only slightly above. All of the other larger seedlings were not affected by removal of the tubes. Our general impression is that once the seedlings grow above the top of the treeshelters and begin to move in response to wind, they allocate more energy to

Table 3—Average basal diameter (mm) of seedlings protected with different devices, and receiving different intensities and intervals of weed control[1]

Treatment	Growing Season 1991	1992	1993	1994	1995
	mm				
Protection					
Screen cage	4.8	a 4.9	a 7.8	a 9.2	a 10.8
Treeshelter	4.8	b 6.7	b 10.5	b 15.8	b 24.7
Weed intensity					
None	a 4.2	a 4.4	a 6.1	a 7.5	a 6.7
0.6-m circle	a 4.3	b 5.3	ab 8.1	a 10.4	b 17.6
1.2-m circle	b 5.2	ab 5.8	b 9.6	a 13.1	b 19.7
1.8-m circle	b 5.7	b 7.7	c 12.8	b 19.0	b 26.8
Weeding interval					
1 year	4.8	5.0	a 8.2	a 10.2	a 15.6
2 years	4.9	6.5	b 10.1	b 14.4	b 20.4

[1]Growing seasons and treatment types with different letters are significantly different ($P \leq 0.05$) by Analysis of Variance for protection and weeding-interval treatments and by a Tukey's test for weed-intensity treatments.

radial growth and their diameter increases. Simultaneously, the rate of height growth slows down. The overall result is that by the second or third growing season, the seedlings are simply much larger than their screened counterparts. We believe that in a wildland setting, a greater initial growth rate will confer a substantial advantage to seedlings, because they will grow more rapidly to a height at which they can withstand browsing pressures. Without protection, oak seedlings can remain stunted for years (White 1966). By providing a method to stimulate initial growth, treeshelters may not only improve the chances that a young seedling will eventually become a tree, but greatly hasten the process as well. However, it is important to leave the shelters in place until the seedlings have grown well above the tops of the tubes, so that they develop sufficient diameter to support the crown.

Determining exact causes for faster growth of seedlings in treeshelters versus screened cages is somewhat difficult. Treeshelters have been reported to stimulate aboveground growth of trees through a combination of moisture conservation, increased temperatures, and elevated carbon dioxide levels (Potter 1991). However, we observed that animals can also influence seedling growth rates. Because ground vegetation surrounding the scalped circles was not controlled, vegetative cover near seedlings was extensive. This apparently provided a favorable habitat for both voles and grasshoppers. The screens were much harder to maintain than the tubes, and consequently these animals damaged seedlings in the screen cages more frequently than seedlings in the tubes. Despite efforts to secure screen cages to the ground, voles were able to get underneath, strip bark, and even completely girdle several seedlings. Similarly, grasshoppers gained access to seedlings in screens after they grew out the tops, and then consumed considerable amounts of foliage. Neither of these animals seriously damaged seedlings in the treeshelters. Because we sunk the tubes several inches into the ground, voles were unable to burrow underneath. The ability of treeshelters to prevent vole damage to oak seedlings has been reported previously (Davies and Pepper 1989). While the grasshoppers ate some foliage that grew over the tops of the tubes, the seedlings were so large by this time that overall damage was minimal. By modifying temperature, humidity, etc. and protecting seedlings from insect and rodent damage, the treeshelters provided a much more favorable environment, resulting in greater growth and survival.

In all three instances where we detected significant interactions, the rankings of protective types within weed treatments were the same—that is, the average survival and height were greater for seedlings in treeshelters than in screen cages for each of the weed-removal treatments. However, the magnitude of the difference varied, causing the interaction. For survival, seedlings in screens and tubes had similar survival under the greatest intensity of weed removal, but much higher survival in treeshelters under lesser intensities. The average 1992 height of seedlings in tubes for weed treatment 3 (1.2-m circles) was more than five times that for seedlings in screens, while for the other three weed treatments, it was only approximately two to three times as great.

There was a general trend for seedlings to grow in proportion to the initial level of weed control. Though the average basal diameter of seedlings from the 1.8-m treatment was only significantly greater than that of seedlings from the 1.2-m treatment in the third growing season, it appeared that both diameter and growth tended to be greater for the larger circles. We therefore do not know how large circles should be to promote maximum growth. It may be that circles even larger than 1.8 m would stimulate even greater growth. However, the benefits of larger circles must be weighed against the costs or difficulty of providing the treatment. In this study, weed control was by hand scalping, which was both difficult and time consuming. The 1.8-m circles took approximately twice as long to scalp as the 1.2-m ones. The gain from such scalping may not be worthwhile.

In such situations, we recommend 1.2-m circles. However, if herbicides are used for weed control, we recommend circles of at least 1.8 m in diameter, because the additional expense and effort would likely be minimal.

As indicated previously, all weed-control treatments were discontinued after the second year. There appeared to be an initial benefit from providing a second year of weed control, not only for survival, but also for height and diameter growth. However, the benefits of this second year of treatment—at least in terms of survival and height—tended to diminish over time, in that the average survival of seedlings from both groups remained relatively constant after the second year, and height increments were similar. Thus, though an additional year of weed control may offer some benefits in field performance, these benefits are likely to be most pronounced during the first 2 years the seedlings are treated differently.

Though it took some time for the weeds to return to the scalped circles, differentiating between treated and untreated areas is difficult today. Both have a thick covering of weeds. Despite this similarity, seedlings in the treated plots continue to grow faster than those from untreated plots. Clearly, these plants obtained an initial advantage from which they continue to benefit. These data suggest that continued weed control is unnecessary for adequate growth and survival once seedlings are established. However, in a slightly older research plot within 100 m of this study area, where weed control has not been maintained, saplings more than 2.5 m tall and 4 cm in diameter have been girdled by voles, and bark has been removed more than a meter up on the stem. We believe that vole populations increased dramatically when we stopped controlling weeds several years ago, and that without protection, the saplings were vulnerable. So while it may not be necessary to continue weed control after 2 years to limit vegetative competition, failure to do so may promote such a favorable habitat for rodents that even large unprotected saplings may be seriously damaged.

Conclusions

This study indicates that treeshelters can promote substantially greater survival and growth of blue oak seedlings planted on hardwood rangelands in California. Treeshelters appear to protect seedlings from at least two damaging animals and stimulate aboveground growth. We believe this rapid, initial growth is highly beneficial because it can reduce the time needed for seedlings to grow to a size at which they are less vulnerable to browsing pressures. Additionally, intensity of weed control significantly affects performance. Generally, weed-free circles with larger diameters promote higher survival and faster growth. We believe these circles should be a minimum of 1.2 m in diameter. Maintaining weed-free areas around seedlings for two complete growing seasons results in greater survival and growth than treatment for only 1 year. However, it appears that the benefits of this additional treatment tend to subside over time.

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References

Adams, Theodore E.; McDougald, Neil. 1995. **Planted blue oaks may need help to survive in the Southern Sierras**. California Agriculture 49(4): 13-17.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands and savannas**. Resour. Bull. PNW-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Costello, Laurence R.; Peters, Amy; Giusti, Greg A. 1996. **An evaluation of treeshelter effects on plant survival and growth in a Mediterranean climate**. Journal of Arboriculture 22(1): 1-8.

Davies, R.J.; Pepper, H.W. 1989. **The influence of small plastic guards, tree-shelters, and weed control on damage to young broadleafed trees by field voles (*Microtus agrestis*)**. Journal of Environmental Management 28: 117-125.

Griffin, James R. 1971. **Oak regeneration in the upper Carmel Valley, California**. Ecology 52: 862-868.

McCreary, Douglas D. 1990. **Native oaks—the next generation**. Fremontia 19(3): 44-47.

McCreary, Douglas D.; Tecklin, Jerry. 1993. **Treeshelters accelerate valley oak restoration on grazed rangelands**. Restoration and Management Notes 11(2): 152-153.

Muick, Pamela C.; Bartolome, James. 1987. **Factors associated with white oak regeneration in California**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 86-91.

Potter, Mark J. 1988. **Treeshelters improve survival and increase early growth rates**. Journal of Forestry 86: 39-41.

Potter, Mark J. 1991. **Treeshelters**. Forestry Commission Handbook 7. London, England: HMSO Publications Centre; 48 p.

Tecklin, Jerry; McCreary, Douglas D. 1993. **Dense vegetation may encourage vole damage in young oak plantings**. Restoration and Management Notes 11(2): 153.

Welker, Jeffrey M.; Menke, John W. 1987. ***Quercus douglasii* seedling water relations in mesic and grazing-induced xeric environments**. In: Proceedings, International conference on measurements of soil and plant water status. July 6-10, 1987, vol. 2, Plants, Utah State University, Logan, UT; 229-234.

White, Keith L. 1966. **Structure and composition of foothill woodland in central-coastal California**. Ecology 47(2): 229-237.

Sunshine Canyon Mitigation Oaks—A Success Story[1]

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***Abstract**: In 1987 Browning-Ferris Industries (BFI) proposed expanding the Sunshine Canyon Landfill located on the north side of the San Fernando Valley, CA. The extension plans called for the removal of approximately 3200 coast live oaks (*Quercus agrifolia*). Tree removal regulations in Los Angeles County clearly specified the replacement requirements for oak tree removal within the County. The ordinance was aimed at subdivision development and not a landfill. To meet the intent of the ordinance and to use a wildland approach to replacement plantings, negotiations were conducted with the Los Angeles County Forester. The negotiated agreement set the following specific goals: (1) within 1 year after the tree(s) are removed, two replacement trees shall be planted for each tree removed; (2) a 5-year maintenance period following planting, including annual monitoring reports, are required; and, (3) local seed sources shall be used. BFI established the on-site Plant Materials Center in 1989 to produce the trees and outplantings began in 1991. This project has clearly demonstrated that excellent survival and rapid growth of coast live oak is possible. Proper planting methods and prudent maintenance formed the foundation for the success of this project.*

Sunshine Canyon Landfill is a large sanitary waste facility located on the northerly rim of the Los Angeles Basin, California, adjacent to Interstate 5 and Granada Hills. The landfill was originally opened in 1958 to serve the local area. At the time of its closing in September 1991 it was operated as a major waste disposal facility by Browning-Ferris Industries of California (BFI). Reopening of landfill operation within the County of Los Angeles expansion area is scheduled for summer 1996. The expansion area grading caused the removal of some 3,200 native coast live oak (*Quercus agrifolia*) trees. A total of 215 acres were disturbed for project development. Eight mitigation sites on the surrounding ridge and canyon areas totaling 94.3 acres were approved for planting by the County. Based on 20- by 20-ft spacings, 10,269 mitigation trees could ultimately be planted.

In 1982, Los Angeles County Board of Supervisors adopted Ordinance 81-1068, commonly known as the Oak Tree Ordinance. This ordinance set the criteria for oak tree mitigation for trees removed as a result of construction in the County. These guidelines specified landscape size plant materials, including 15-gallon size “standard” as replacement trees. For this wildland project, it was clear to the Registered Professional Foresters involved that planting such large stock was disadvantageous and also was excessively costly. Extensive negotiations were held with the County Forester to adjust the regulations to allow for the planting of smaller stock with a higher replacement ratio, namely, 2 replacement trees for each oak tree removed instead of the 1 to 1 ratio specified in the Ordinance. In addition, the trees had to have a 1-inch caliper measured 1 foot above the ground within 1 year of the time the original trees were removed by construction. To ensure survival, the County also required a 5-year maintenance program which included annual monitoring and reporting to confirm survival and required growth. The County also required that onsite seed sources be used for all mitigation plantings.

It was clear early on that BFI could not be assured that saplings from the desired seed source in natural growth form were available from commercial nursery stock. Therefore, in 1989, BFI management decided to open an onsite facility to produce the seedlings required for the total project. The Sunshine

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Canyon Plant Materials Center was established in 1989 and the first crop of seedlings became available in February of 1991. Due to permit processing and legal delays, field planting did not begin until late summer 1991. Since 1991, tree planting has continued annually and the number of saplings planted exceed the Los Angeles County requirements.

Methods

Nursery Facilities

The Sunshine Canyon Plant Materials Center was established on a 1.5-acre site central within the property. The operating landfill was located to the south of the nursery and the proposed expansion and mitigation areas were located to the north. A pre-fabricated 16- by 20-ft greenhouse was assembled and a 20- by 40-ft shadehouse, including raised benches, was constructed. A small portable office building was moved in to provide for tool and equipment storage plus administrative activities. Water was available to the site; an automatic irrigation system was installed. Later expansion included doubling of the shadehouse to 40 by 60 ft plus approximately 2 acres of adjacent growing grounds. Irrigation was provided to each pot with drip emitters. The entire irrigation and fertilization system was automated.

Using casual labor crews, seed was collected within the native stands of oaks growing in the undisturbed canyon areas on the property. Fortunately, acorn crops for the first 2 years were excellent. Following collection of the seed, pre-treatment included floating, stratification, and pre-germination. The acorns were placed in plastic bags and refrigerated for 6 weeks at 36-40 °F or until germination began. The germinated acorns were placed in 2-inch by 2-inch by 10-inch open-ended paper planting sleeves. The sleeves were placed in trays for initial growth in the greenhouse. Following leaf formation, the germinants were transferred to the shadehouse. It was the original intent of the foresters to plant these liner-size trees in the field in the interest of economy, and to establish naturally formed trees. However, because of the permitting delays, the 2-inch by 2-inch seedlings were transplanted into 3-gallon size containers. The 3-gallon size was chosen because it facilitated field handling and formation of a deeper root system when compared to a standard 5-gallon container. Three gallon pots measure 8 inches in diameter and 16 inches deep. Workers typically carried four or more 3-gallon size containers to the planting sites instead of only two 5-gallon size containers. Hole digging was also easier for the smaller pot diameters and rooting was facilitated with the greater hole depth. The soil mix in the container was highly organic. BFI requested we use their recycled green waste mulch produced at an adjacent Company facility. This recycled composted material was mixed with sand to produce a 70 percent organic, 30 percent sand planting mix.

The Los Angeles County permit required that all seedlings be natural in shape without pruning or shaping into a standard or “lollipop” form. Minor pruning was completed to reduce wild limb growth on the trees grown at the site. Due to the diameter requirements in the permit, an initial planting of 5-gallon and 15-gallon size stock was completed because the nursery stock grown on site were not of sufficient size. Since that initial planting, all seedlings have been planted from the 3-gallon size containers. Both 5-gallon and 15-gallon size trees were purchased from Franz Nursery in Hickman, CA. The seed source was unknown. The Registered Professional Foresters realized the characteristic oak attribute of sprouting following severe crown damage. To eliminate the standard look, all purchased trees were topped at between 3 and 4 ft to remove the entire “lollipop” crown. Within a few weeks, dormant buds developed and produced new branches on the bare stem. Pruning response was excellent and natural formed crowns soon developed.

The nursery has proven to be extremely successful. To date, the Sunshine Canyon Plant Materials Center has produced over 34,000 coast live oaks, 2,000 canyon live oaks (*Quercus chrysolepis*), 200 valley oaks (*Quercus lobata*), 2,000 big cone Douglas-fir (*Pseudotsuga macrocarpa*), 300 sycamore (*Plantanus racemosa*), 250 big leaf maple (*Acer macrophyllum*) and 1,000 black walnut (*Juglans californica*). Although the permit requirement was for only coast live oak, BFI wanted to provide a greater diversity of overstory habitat, hence the other tree species were also grown and outplanted in selected areas. No growth records were maintained for the other species.

Irrigation

At the time of installation, all planting holes were thoroughly soaked. Following planting, the area was again soaked. Drip irrigation was then installed with the emitters placed in the wire cages.

Without onsite power and without a water source onsite, a gravity flow system was designed to provide water. Water was transported by water truck to the upper-most tanks for distribution into the lower tanks and to planting sites. Presently, over 30,000 gallon storage capacity is available between several banks of tanks. The tanks are connected with 10 miles of irrigation main lines, including a series of battery operated electric control valves. Distribution to each planting site is accomplished with over 35 miles of drip irrigation line. Two 1-gallon per hour drip emitters regulate the flow to each of the 5,500 trees.

The irrigation system included a Dositron® fertilizer pump which was used for fertigation both in the nursery and in the field planting areas. Plumbing was adapted to connect the pump at several locations. The pump operates hydraulically by the flow of the irrigation water, which made it ideal for remote operation in the field. Field fertigation used a soluble 20-20-20 fertilizer blend. Application was calculated to apply 0.25 pounds of fertilizer per plant for each fall and spring application. The soluble fertilizer was dissolved in a 55-gallon drum for proportional pumping into the drip irrigation system. Application was generally uniform using this system; however, an uneven application was acceptable since the resulting varied-size trees imitated nature.

Field Planting

The field planting sites are a series of ridge tops surrounding Sunshine Canyon on the rim of the Los Angeles Basin. An additional planting area was identified in East Canyon located adjacent to Sunshine Canyon. The droughty sites are very harsh with little available water and relatively shallow soils. Soils were classified into the Millsholm loam, 30-50 percent slopes, derived from sandstone (USDA, 1980). Annual precipitation is about 18 inches, often coming in intense storm events. Drying Santa Ana winds in excess of 100 miles per hour were measured on the adjacent landfill (Ultrasystems, 1989). Surface runoff was rapid and erosion hazard was high. Although the records were not clear, these open ridge top planting areas were probably cleared by the Los Angeles County Fire Department as part of their early fire break management program. Similar clearing patterns were observed on nearby ridges. Soil conditions were similar on each side of the ridge planting areas. No site conditions were observed that would preclude historic natural oak stands in these areas.

Wise use of water and irrigation monitoring were very important. To ensure an appropriate irrigation regime, a pressure chamber was used to determine the internal moisture stress of the planted saplings and that of the surrounding mature native trees. A simple sampling scheme was designed to sample native oak trees growing nearby and the planted stock. Trees were measured when daily moisture stresses were at minimum levels (Cleary, 1984). The morning period of 4:30 a.m. to 6:00 a.m. was selected. Native trees on the ridge top growing adjacent to the planted area, native oaks in the adjacent canyon bottom, the planted saplings and individuals in the nursery were systematically sampled, prepared, and analyzed. For contrast, the same procedure was completed at mid-day (2:00 to 4:30 p.m.) to determine maximum stress. *Table 1* depicts the average range of values for the monitoring period.

Table 1—Plant moisture stress values

Trees sampled	Average pre-dawn[1] values measured in bars[3]	Average mid-day[2] values measured in bars
Irrigated saplings	1.8	25.5
Native ridge top	2.6	30.0
Native canyon bottom	3.1	23.0
Nursery containers	1.4	20.3

[1]4:00 a.m. - 6:30 a.m.
[2]2:00 p.m.–4:30 p.m.
[3]A bar is equal to the average air pressure at sea level or 14.7 pounds per square inch.

The field sampling schedule was repeated on a 4-day interval through the month of July 1993. The preliminary unpublished data showed the 4-day irrigation cycle could be extended to every 16 days during moderate weather. However, temperature and winds were often unpredictable on the ridgetop sites. To error on the conservative side, the cycle was increased from 4 days to 8 days. Utilizing the data derived from the pressure chamber, the initial irrigation schedule was halved, resulting in a 50 percent savings in the trucked water. The irrigation continued for three growing seasons. It appeared that within 2 years the coast live oak on this site were utilizing deeper existing soil moisture, thus reducing dependency upon irrigation water.

Planting

The planting process included both machine augered and hand-dug planting holes. Machine access was limited due to steep and uneven terrain in much of the planting areas.

At the time of planting, a root protection cage of 1-inch galvanized poultry wire folded closed at the bottom was placed around each of the root balls. Concern was expressed by the County and others that the poultry netting would restrict root growth or possibly cause root girdling. Our experience indicated that poultry netting lasts about three years before it rusts and is no longer effective for rodent control, and therefore should not damage roots.

The 1993 Northridge earthquake caused a landslide through part of the planting area. Several saplings were lost due to earth movement and the roots were exposed on more. The roots of these disturbed trees were closely inspected. Some partial imbedment by the wire was noted, however, root restriction or girdling was not observed. The trees rooted freely through and outside the wire cages.

Initial fertilizer was provided by four 0.95 ounces Agriform (20-10-5) tablets with one placed beneath and three around the plant root wad about 12 inches below the ground surface. Spring and fall fertigation (see Irrigation) is now provided to accelerate growth and development.

Following planting and installation of the irrigation, each planting site was mulched with green waste from tree trimmings. The mulch was applied approximately 6 to 10 inches deep with a radius of 2–3 ft around each plant. This mulch effectively controlled the weeds and reduced soil temperatures during the hot summer days. No doubt it also helped conserve soil moisture by reducing surface evaporation.

Maintenance

Maintenance is a vital and ongoing process. Weed control, irrigation maintenance and rodent control were primary concerns. Because of the magnitude of the rodent populations, the Los Angeles County Agricultural Office provided contract services for rodent control. Their services proved very effective. Weed control was completed with manual removal from within the root protection cages and by mulching to a greater depth. Larger areas of weeds were mowed to facilitate irrigation inspection and reduce the fire hazard. The chipped mulch appears to last about 2 or 3 years depending on the amount of solid wood within the mulch. Reapplication is required every 3 years. Routine irrigation maintenance is accomplished by walking the pressurized irrigation lines to ensure that the trees were receiving water and that no breaks in the system existed. If problems were noted, repair was completed immediately.

Results and Discussion

Growth and survival exceeded expectations and far exceeded permit requirements set forth in the Los Angeles County Oak Tree Ordinance. As of the 1994 monitoring, 5,176 trees were planted and 4,943 survived with 3,990 of the surviving trees being 1 inch or greater in diameter at 1 foot above the ground. The 1995 monitoring recorded 4,883 trees surviving with 4,374 over 1 inch in diameter. Overall survival since 1995 is approximately 90 percent. The maximum tree height was 15 ft at the end of the 1994 growing season and the maximum 1995 annual elongation was 72 inches. The applications of fertilizer were made to better achieve the size requirements as set by the permit. *Tables 2, 3* and *4* depict average height, diameter and diameter increment, respectively, of surviving seedlings, averaged over all planting years.

The growth and survival to date have been encouraging. Problems resulting from rodent populations were controlled. Vandalism and cattle rubbing and trampling damage continue to occur since the area is open range, but the damage is acceptable. After 3 years of burial in the ground, the poultry netting had weakened sufficiently to allow for gopher intrusion into the rooting area. It appears that gophers were attracted to the irrigation moisture and the light textured potting mix since many of the roots outside the wire cage were left alone. In areas where the irrigation was turned off, the rodent problem was reduced. It was estimated that over 90 percent of the mortality was due to gophers.

Table 2—Coast live oak height comparison by location and year

	Monitoring years		
Average height (ft)	1993	1994	1995
Area 1	4.66	5.37	6.89
Area 2	4.06	4.49	5.85
Area 7	3.67	4.16	5.47
Area 8	5.03	5.74	7.58

Table 3—Coast live oak diameter comparison by location and year

	Monitoring year		
Average diameter (inches)	1993	1994	1995
Area 1	0.92	1.22	1.68
Area 2	0.62	0.98	1.31
Area 7	0.58	0.78	1.24
Area 8	1.11	1.53	2.20

Table 4—Coast live oak annual diameter increment by location and year

	Growing season	
Average diameter increment (inches)	1993-94	1994-95
Area 1	0.30	0.46
Area 2	0.36	0.33
Area 7	0.20	0.46
Area 8	0.42	0.67

Conclusion

Successful oak planting and mitigation in a wildland setting were demonstrated to be both feasible and achievable. Proper and professional site evaluation, quality planting stock and proper planting methods were critical to the success of this project. Consistent maintenance by trained and dedicated personnel was vital to ensure the survival and growth of the saplings. Budgets had to include quality maintenance for a minimum of 5 years. In this climatic regime, irrigation was essential to assure survival and to meet the permit requirements.

Acknowledgments

This project has been a cooperative effort between BFI, Los Angeles County Forester and Fire Warden, Oregon State University, Angeles National Forest and Ralph Osterling Consultants, Inc. A team effort was important. The combined experiences and expertise of the professionals played important roles in the success of this project. Using similar methodologies the author completed additional planting projects in the Los Angeles Basin.

References

Cleary, B.; Zaerr, J. 1984. **Guidelines for measuring moisture stress with a pressure chamber**. PMS Instrument, Co. Corvallis, Oregon.

Ultrasystems, 1989. **Informational Summary of Draft Environmental Impact Report Sunshine Canyon Landfill Extension.** Irvine, CA: Ultrasystems; 1.

United States Department of Agriculture. 1980. **Soil survey of Los Angeles, California, West San Fernando Valley Area, January 1980**; 25, 32.

Status of Transplanted Coast Live Oaks (*Quercus agrifolia*) in Southern California[1]

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Abstract: *Twenty-five coast live oaks (*Quercus agrifolia*) ranging in size from 15 to 100 cm (diameter at breast height), transplanted to accommodate housing developments at three different sites in Calabasas, Calif., were studied for 3 to 4 years after boxing. Transplanted trees, plus 15 native control trees, were monitored quarterly. Water potential, shoot and root growth, and visual condition were measured. Although all 15 controls remained healthy, 16 percent of the transplanted trees died, 20 percent were nearly dead, 24 percent were in decline, 32 percent were stable, and 8 percent were improving. If declining transplants fail to stabilize, then the projected long-term survival rate would be approximately 10 to 40 percent.*

Transplantation of mature coast live oak trees (*Quercus agrifolia*) as mitigation for loss due to development has become increasingly controversial as the extent of oak woodlands in Southern California decreases. In addition to concern over the protection of one species while ignoring the complex associated community, there are also questions of cost effectiveness and long-term tree survival. The cost of moving an oak tree varies with box size and site accessibility, ranging from around $1,000 to more than $100,000.

To date, few studies have examined transplantation or the physiological consequences of root injury. Roberts and Smith (1980) did a one-year study of water potential and stomatal conductances of oak trees impacted by root removal due to trenching and terracing associated with development. Scott and Pratini (1992) followed 593 transplanted trees in Orange County, Calif., for more than 4 years. However, their observations did not include quantitative physiological evaluation. Our study used both quantitative and qualitative evaluation to assess establishment of transplanted oaks in landscaped settings.

Calabasas Transplant Study

The City of Calabasas (Los Angeles County), California, Oak Tree Protection Ordinance discourages transplanting and requires mitigation for tree removal. In addition, monitoring of trees that are moved was required for 5 years. In January 1992, monitoring of transplanted trees began at Site 1, followed by the addition of two more sites in April 1993, either as the trees were being boxed, or immediately afterward. All portions of the sites to which trees were moved experienced extensive grading and drainage changes before replanting. Sites 1 and 2 were originally north-facing hillside drainages with intermittent streams, clay soil, and mixed chaparral vegetation. Site 3 was a level riparian area. The perimeter of all three sites had been affected by previous development. Trees were selected for transplanting by the tree-moving company and their associated arborists. Concurrent with root pruning and side boxing, the canopies of the selected trees were pruned, removing 30 to 70 percent of living tissues. Deadwood, inner foliage, and terminal buds were trimmed, leaving a thin shell of foliage on the perimeter of the canopy.

A backhoe was used to trench all four sides around each tree at once. Box sizes ranged from 1.5 × 1.5 × 1 m to 8.5 × 8 × 2.5 m. Bottom boxing was completed 3 to 6 months later. Irrigation while trees were boxed was carried out weekly or

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more often by water trucks, as determined by the tree-moving company. All trees were planted in holes dug by backhoes, usually 1 to 2 m wider than the box and approximately the same depth as the root ball. The box bottoms were left in place, the sides removed, and backfilling done by backhoe and hand labor. Irrigation was installed at Site 2 and modified seasonally. The other two sites continued to be watered by truck once or more weekly.

Monitoring Methods

The protocol included quantitative and qualitative observations of both transplanted and control trees on a quarterly, then on a semi-annual basis. Every time the trees were observed, each tree was given a vigor rating using the International Society of Arboriculture standard condition evaluation for landscape trees which is based on canopy, foliage, trunk, and root condition (*table 1*). Trees were categorized as very healthy (6), improving/fairly healthy (5), stable/no change (4), declining (3), nearly dead (2), dead (1).

Table 1—Vigor rating scale

Vigor rating	Description	Criteria for evaluation
1	Dead	No living canopy, severe root and trunk defects, severe infestation or disease
2	Nearly dead	Less than 25 percent growing canopy, major root and trunk defects, severe infestation or disease
3	Decline	25-50 percent growing canopy, some root and trunk defects, moderate infestation or disease
4	Stable	Greater than 50 percent growing canopy, few active root or trunk defects, minor infestation or disease
5	Improving	Greater than 75 percent growing canopy, fairly healthy, no root or trunk defects, minimal infestation or disease
6	Very healthy	Well balanced, symmetrical canopy, no root or trunk defects, minimal infestation or disease

Water potential was measured to monitor water stress. On each tree, mid-day readings of five sample twigs (5 to 13 cm long) taken from four compass points in full sun were followed by five pre-dawn samples, using either a PMS Scholander Pressure Chamber (PMS Instrument Company, Corvallis, Oreg.), or Model 3005 Plant Water Status Consule (SoilMoisture Equipment Co., Santa Barbara, Calif.).

Soil probing (30-cm depth) for roots started 1 m from the trunk of transplanted trees. Probes were also taken halfway out to the crown, at the dripline, at the perimeter of root ball, just outside the box edge, and 1.5 m farther out. Control trees were probed halfway out to the crown, at the dripline and 1.5 m outside. Samples were examined in the field, noting presence, size, and density of roots.

Results

Control trees maintained a stable, healthy condition during the 4-year study while transplanted trees declined steadily (*fig. 1*). By October 1995 four transplanted trees had died, five were nearly dead, six were in decline, eight were stable, and only two were improving.

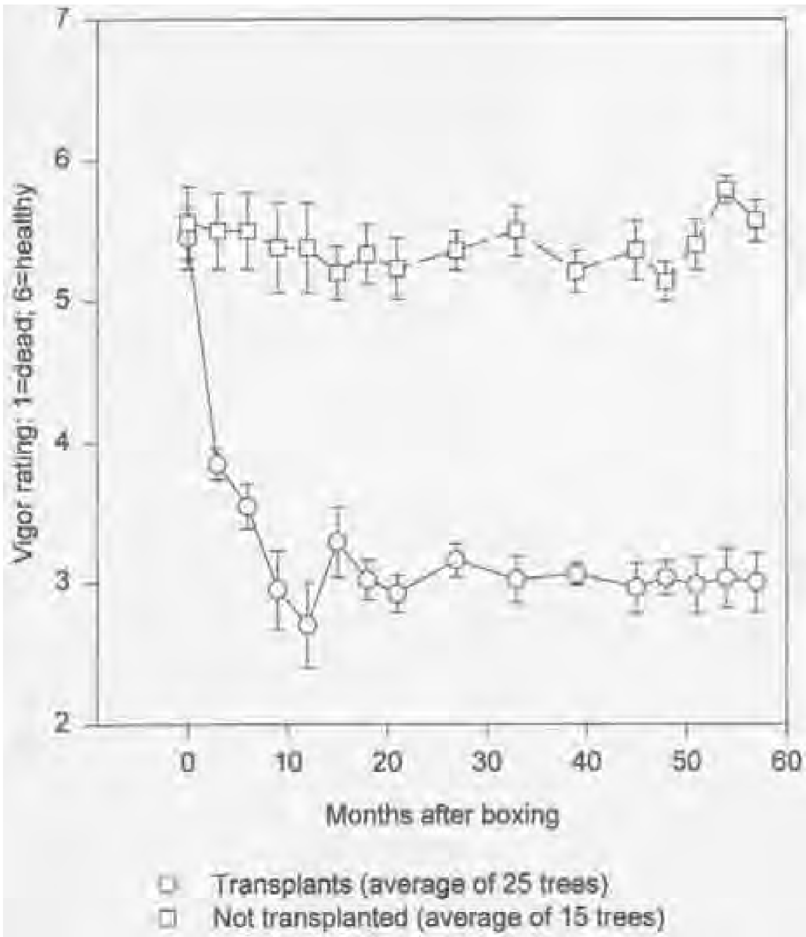

Figure 1—Effect of transplanting on vigor of *Quercus agrifolia*. *Bar is standard error of the mean.

We found canopy condition and vigor to be closely related. Control trees maintained a dense canopy and normal branching structure, with few epicormic sprouts. Transplanted trees, on the other hand, had little apical growth. Instead, epicormic sprouts emerged from the trunk, scaffold branches, and all branches close to the tree interior (*fig. 2*). Transplanted tree canopies remained characteristically thin, open, and often chlorotic. Trees showing improvement had expanded epicormic growth from the center of the tree out toward the edge, and slowly increased their interior density.

The majority of control trees had visible growth cracks in the trunk bark, indicating active radial growth. Such cracks on the transplants were smaller and fewer in number. The diameter of eight control trees increased over 2-3 years, five remained the same, and only one tree became smaller. Conversely, only three transplanted trees expanded, 13 remained the same, and nine decreased (*table 2*).

On the basis of the soil probe observations, only the two transplanted trees showing signs of improvement had roots extending outside the planting hole. Most transplanted tree roots were sparse and limited by the box size. By contrast, the control trees had dense mats of roots at all areas probed.

Figure 2—Trees indicating vigor and canopy condition: (a) Transplanted tree, vigor rating 1 (dead), (b) Transplanted tree, vigor rating 2 (nearly dead), (c) Transplanted tree, vigor rating 3 (declining), (d) Transplanted tree, vigor rating 4 (stable/ no change), (e) Transplanted tree, vigor rating 5 (improving/ fairly healthy), and (f) Control tree, vigor rating 6 (very healthy).

A

C

E

B

D

F

Water potentials of control trees did not correlate with final vigor ratings ($r^2 = 0.0008$). However, a few trends were apparent. The data indicated a higher degree of

Table 2—Growth of **Quercus agrifolia** *after boxing, 1992/93–Oct. 1995*

Treatment	Change in dbh (cm^2)		
	Site 1	Site 2	Site 3
Boxed	-0.59	0.39	-0.2[a]
Controls (not boxed)	2.19	0.12	1.0[a]

[a] Means are significantly different according to *t*-test at $\alpha = 0.05$.

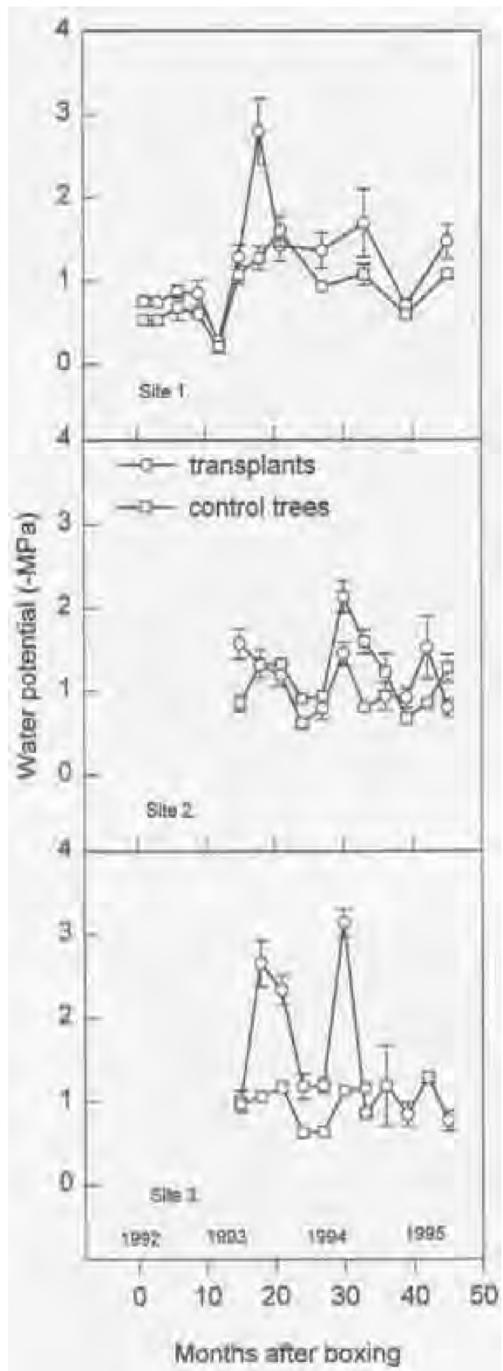

Figure 3—Predawn stem xylem potentials. *Bar is standard error of the mean.

variability among the transplants, with control trees remaining more consistent at any given time (*fig. 3*). Control trees did show more negative summer/fall water potential (July and October), but they rarely dropped below a pre-dawn potential of –2.5 MPa. By contrast, declining transplanted trees routinely exceeded that limit and had much more negative water potential at mid-day. In nearly dead trees, pre-dawn water potentials exceeded those at mid-day.

Discussion

Distributed throughout the coastal regions of the state, coast live oaks can be found in a wide variety of locations, from sea level to 1525 m. Despite tremendous adaptability, there appear to be physiological limiting factors that were difficult for the trees to exceed. In order to understand the response of this species to the impacts of transplantation, it was important to review relevant aspects of oak tree biology.

Adapted to the Mediterranean climate, coast live oaks are nonetheless greatly affected by the availability of water. Despite the worst statewide drought of this century, which has had severe impacts on native trees since 1986 (Tietje and others 1993), the control trees were able to utilize available water resources and thrive. Local rainfall patterns during this study have been above average. Torrential storms in 1991-92 deposited more than 130 cm of rainfall in the Calabasas area. The winter of 1992-93 was slightly above average at 40 cm. The rainy season for 1994-95 was heavy again, with more than 155 cm recorded in the area.

Vigor ratings were strikingly different between the control and transplanted trees. We observed steady tree decline associated with the large canopy and root mass loss resulting from transplantation. Neither root nor canopy recovery has occurred for the majority of transplanted trees. However, control trees remained vigorous.

Watson (1985, 1994) found that root recovery was related to stem diameter. For each 2.54 cm of trunk diameter, root replacement following removal took approximately one year in the Midwest. Given a longer growing season in southern California, optimal conditions may allow slightly faster recovery. However, our study found that only two trees (dbh = 44 cm, 64 cm) had evidence of roots extending outside the planting hole. The inability to extend rooting area could be due to the differences in boxed storage time, soil compaction, as well as delayed ability to regenerate lost roots and shoots following traumatic loss.

Hagen (1989) documented that root-related impacts are extremely damaging to most trees, including oaks. A study of coast live oak root pruning at North Ranch, Thousand Oaks (Ventura County), Calif., indicated that while initial water stress was not devastating, accumulation of stress could precipitate decline. "Drastic" root pruning immediately disrupted stem xylem tension, indicating that there were limitations to the amount of root damage that could be sustained before the tree died (Roberts and Smith 1980). In undamaged trees, absorbing roots can extend more than 30.5 m from the trunk (Gilman 1988, Perry 1982). Root-related impacts in southern California can cause stress in trees up to 300 feet away (Kelley 1995). Boxing was done in late summer and fall to take advantage of root growth at this time, stimulated by the auxins produced in the less active terminal buds.

In spring, the roots produce hormones stimulating shoot growth in the terminal buds (Coder 1994). Between three and five shoots erupt from each bud, reaching lengths of 30 to 60 cm if rain is plentiful. Griffin (1973) found that a typical response of oaks to water stress was failure of buds to mature. Transplanted trees in our study had limited apical growth (data not shown), supporting this observation.

Impacts on photosynthate production and resultant canopy condition have been shown to be important in maintaining overall vigor. It has been found that as new leaves photosynthesize, carbohydrate reserves were stored in the roots and trunk during wet years to help sustain the oaks through dry periods (Rundel 1980). Oaks moderated transpirational loss by stomatal regulation according to environmental stress (Roberts and Smith 1980). As summer progressed and soil moisture was limited, photosynthesis on the perimeter of the canopy was reduced while it continued in the humid interior. The photosynthetic activity of the larger, inner canopy leaves produced the extra carbohydrates needed to exceed the baseline metabolic requirements of the tree and provided reserves for storage (Hollinger 1992).

Other studies have used water potential as an indication of stress (Shackel 1993), which varied according to available soil moisture, as well as the ability of the tree to access that water. Low root density has been associated with high internal resistance of water moving through the xylem, even if the soil reached field capacity (Cowan 1965).

In this study, similar water potentials in both control and transplanted trees were noted. Until the transplants were nearly dead, it was not possible to accurately predict their survival using only water potential as an indicator.

While the seasonal trends of water potential between controls and transplants appeared close, the effect on tree vigor was dramatically different. Control trees periodically hit limits of –2.5 MPa and still maintained overall health and vigor. It has been previously documented that water potentials more negative than –2.5 MPa resulted in catastrophic emboli (air bubbles in the xylem water columns reducing conductance) causing more than 50 percent loss of conductance (Tyree and others 1994). When these limits were repeatedly exceeded, tree mortality resulted (Griffin 1973). In our study, however, control trees apparently had sufficient energy reserves to replace damaged tissue, and xylem function continued (Davis 1996). By contrast, transplanted trees in decline routinely had a water potential more negative than –2.5 MPa and showed no signs of recovery, despite irrigation. If embolized tissues cannot be replaced, then continued dieback occurs. Our vigor ratings suggested that the transplants were not able to replace lost conducting vessels as easily, resulting in cumulative decline.

The transplanting techniques commonly used for oaks in southern California (simultaneous trenching on all 4 sides with extensive canopy reduction, followed by relocation within 3-6 months) do not appear to be conducive to long term survival. Transplanting techniques used in other areas (Himelick 1981) may offer some alternatives to improve establishment. Root preparation by trenching one side at a time more than 6-9 months may allow greater root recovery before relocation. Allowing the canopy to die back naturally to that which can be supported by the root mass may not disrupt photosynthesis and hormonal balance as much and may permit terminal buds to expand. Removal of deadwood and any severely injured branches should be sufficient canopy reduction. Careful storage of boxed trees until planting and placement in a suitable new location sharing soil, drainage, and exposure characteristics of the original site may also improve survival.

Conclusion

Only 8 percent of the transplanted trees in this study showed signs of establishment. An additional 32 percent were stable, while the rest were declining. All continued to require extensive maintenance. Thus it appears that long-term survival for these transplants would be no more than 40 percent, and perhaps considerably less.

Our data were consistent with trends documented by Scott and Pratini (1992). They observed that between 40 and 60 percent of transplanted trees died soon after boxing, approaching 100 percent when root preparation was poorly done. This initial mortality was frequently ignored when statistics about tree survival were quoted.

Observations of vigor and canopy condition were valuable indicators of overall tree condition. Water potential measurements allowed irrigation modification and indicated tree recovery over time, but alone were not sufficient to predict survivability. Combined with vigor ratings and evaluation of canopy condition, a more complete assessment of tree status was obtained.

Even with improvements to the transplanting procedure, it may be that the highest attainable level of care would not be sufficient to overcome the trauma of transplantation for mature coast live oak trees. While the transplanted trees remained alive, they were no longer self-sustaining natives, but rather high-care exotics that required intensive, long-term maintenance.

Given the high cost of moving (over $450,000 for 25 trees) and maintenance and monitoring (approximately $40,000 per year), it appears that a low long-term survival rate fails to justify the expense. If the goal of mitigation is to replace lost resources, then the cost-effectiveness of transplanting oaks needs to be carefully examined.

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References

Coder, Kim. 1994. **Regulation of tree growth: keeping the green side up**. Arborist News 3: 33-36.

Cowan, I.R. 1965. **Transport of water in the soil-plant-atmosphere system.** Journal of Applied Ecology 2: 221-239.

Davis, Stephen D., Professor of Biology, Pepperdine University. [Telephone conversations with R. Dagit]. 1996.

Gilman, E.F. 1988. **Tree root spread in relation to branch dripline and harvestable root ball.** HortScience 23: 351-353.

Griffin, James R. 1973. **Xylem sap tension in three woodland oaks of central California.** Ecology 54: 152-159.

Hagen, Bruce W. 1989. **Tree roots—major considerations for the developer.** Tree Notes, No. 2, January 1989. 2 p.

Himelick, E.B. 1981. **Tree and shrub transplanting manual.** Savoy, IL: International Society of Arboriculture; 78 p.

Hollinger, David Y. 1992. **Leaf and simulated whole-canopy photosynthesis in two co-occurring tree species.** Ecology 73: 1-14.

Kelley, Alden, Consulting Arborist. [Telephone conversation with R. Dagit]. 1995.

Perry, Timothy O. 1982. **The ecology of tree roots and the practical significance thereof**. Journal of Arboriculture 8: 197-211.

Roberts, Stephen W.; Smith, Robin I. 1980. **Aspects of water relations in coast live oaks and valley oaks subjected to root damage from land development operations.** In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979; Claremont, CA. Gen. Tech. Rep. PSW-GTR-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 171-175.

Rundel, Philip W. 1980. **Adaptations of Mediterranean-climate oaks to environmental stress.** In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on the ecology, management, and utilization of California oaks; June 26-28, 1979; Claremont, CA. Gen. Tech. Rep. PSW-GTR-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 43-54.

Scott, Thomas; Pratini, Nannette. 1992. **Efficiency of transplanting oak trees for woodland habitat restoration.** Unpublished draft supplied by authors.

Shackel, Kenneth A. 1993. **Stem water potential as a diagnostic for irrigation management.** In: Proceedings 1993 California Plant and Soil Conference, January 25-26 1993, Sacramento, CA. California Chapter of American Society of Agronomy; 91-94.

Tietje, William; Weitkamp, William; Jensen, Wayne; Garcia, Sergio. 1993. **Drought takes toll on Central Coast's native oaks.** California Agriculture 47: 4-6.

Tyree, Melvin T.; Davis, Stephen D.; Cochard, Herve. 1994. **Biophysical perspectives of xylem evolution: is there a trade-off of hydraulic efficiency for vulnerability to dysfunction?** International Association of Wood Anatomists Journal 15: 335-360.

Watson, Gary W. 1985. **Tree size affects root regeneration and top growth after transplanting.** Journal of Arboriculture 11: 37-40.

Watson, Gary W. 1994. **Root development after transplanting.** In: Watson, G.W; Neely, D., eds. The landscape below ground. Savoy, IL: International Society of Arboriculture; 54-68.

Rehabilitation of a Blue Oak Restoration Project[1]

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Abstract: *Two remediations were tested for improving height growth and survival on a 2-year-old, failing, blue oak (*Quercus douglasii*) restoration project. Replanting acorns and seedlings with plastic treeshelters resulted in 75 and 88 percent survival, respectively, in areas previously showing almost total mortality. After 3 years, average height of replants (141 cm) exceeded the original planting (19 cm). In a second remediation, treeshelters retrofitted onto original planting survivors showed highly significant differences in height (*$P < 0.0001$*) and survival (*$P = 0.0001$*) between protected and unprotected pairs. Protected survivors were almost five times taller than unprotected, and averaged nearly an eight-fold height increase (130 cm), while average height of unprotected plants had not quite doubled (28 cm). Treeshelters inhibited vole, but not grasshopper predation. Results indicate treeshelters release stunted seedlings and could rehabilitate poorly performing projects.*

Natural regeneration of two endemic California oaks, blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*), has been widely recognized to be a problem statewide on many sites (Bolsinger 1988, Griffin 1971, Muick and Bartolome 1987, Swiecki and Bernhardt 1993). Lack of recruitment to the sapling stage has been identified as a widespread occurrence. This has created great interest in developing techniques for artificial regeneration of these species (see Adams, and Plumb and DeLasaux in these proceedings for general reviews). At the Sierra Foothill Research and Extension Center (SFREC), located 27 km northeast of Marysville, California, we have been able to grow blue oaks to sapling size within 5 years on small (approximately 0.25-ha) plots inside cattle exclosures. This has been accomplished using weed control and with little or no irrigation, with and without screen protection of seedlings (McCreary 1991). When attempting to expand these successful attempts on a larger scale, however, we encountered setbacks. In a 1.6-ha plot intended as a demonstration for oak woodland landowners, we found that we could not duplicate the rapid height growth we had experienced previously, and that herbivory by insects and mammals was greater than anticipated. Since a large number of restoration and mitigation oak plantings have been established in the past decade throughout the state in response to perceived oak regeneration problems, we believed it likely that some of these efforts might be similarly frustrated in meeting their goals. We therefore attempted to rehabilitate our original planting, in order to evaluate readily available measures applicable to improving oak restoration efforts.

Methods

Two remedial measures were tested, both utilizing rigid plastic treeshelters (Supertubes). Both were conducted on the original planting which we deemed to be performing below expectations. This original planting was on 1.6 ha at the SFREC, on a northeast aspect at 300-m elevation. The site had been cleared with herbicides and burning in the mid-1960's. Before that time it had been oak woodland with a dense shrub component. It had been grazed by cattle continuously since 1967. The original demonstration planting, completed in 1990-91, consisted of 1440 blue oaks. Three stock types and five types of weed control

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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were evaluated, and the plot was fenced to exclude cattle. Planting spots were spaced 3 m apart in 36 rows, comprising six replications. End-of-season height and survival were taken in 1991 and 1992 and tested using a split-block ANOVA, with weed control treatments as main plots and stock types as subunits. Where significant differences were found ($P \leq 0.05$), a Fisher's Least Significant Difference test was conducted ($P \leq 0.05$). *Tables 1, 2* are given here as an illustration of the status of the plot when remediation was first employed. Our decision to employ remediation was subjectively arrived at, considering repeated die-back and mortalities caused by mid-summer grasshopper (*Melanoplus devastator*) herbivory in both years. Vole-caused (*Microtus californicus*) mortalities were also extensive and seemed to be rising because of increasingly dense vegetative cover in non-herbicide treated areas and our exclusion of cattle grazing.

Table 1—Percent survival of original restoration planting after 2 years, before remediation treatments[1]

	Survival	
	1991	1992
Stock type	---------- *pct* ----------	
Acorns	^{a}67	^{a}49
Bareroot	^{b}45	^{b}26
3-month seedlings	^{c}19	^{c}14
Weed control		
None	^{a}23	^{a}9
Plastic mat	^{ab}36	^{b}23
Scalping	^{c}54	^{bc}32
Glyphosate once	^{c}56	^{d}45
Glyphosate twice	^{bc}50	^{cd}42
Plot pct survival	44	30

[1]Different superscript letters in Stock Type and Weed Control categories within columns indicate significant differences ($P \leq .05$) by a Fisher's Protected Least Significant Difference test.

Table 2—Average heights of the original restoration planting after 2 years, before remediation treatments[1]

	Mean height, 1992
Stock types	----- *cm* -----
Acorns	14
Bareroot	16
3-month Seedlings	18
Weed treatment	
None	^{a}16
Plastic mat	^{b}21
Scalping	^{a}13
Glyphosate once	^{a}15
Glyphosate twice	^{a}16

[1]Different superscript letters in Stock Type and Weed Control categories indicate significant differences ($P \leq .05$) by a Fisher's Protected Least Significant Difference test.

The first remedial measure was a partial replanting of the least successful original treatment. Our objective was to raise our stocking level, while comparing treeshelter protected acorn and seedling replants in our predator-rich plot. Sixty pre-germinated blue oak acorns and 60 3-month-old seedlings from the same source were planted in January and March of 1993 into the same spots where there had been no initial weed control and almost complete seedling mortality. Ten acorns and 10 seedlings were planted into each of the six replications that had been controls in our previously designed restoration study. All plantings were protected with a 1.2-m (4-ft) plastic treeshelter sunk 8-10 cm into the soil. Glyphosate (1.5 percent) was sprayed in a 1-m radius around each treeshelter. Spraying was repeated in spring of 1994 and 1995. We assessed height and survival annually. Differences in survival and height between stock types were tested with a one-way analysis of variance (rejection level, $P \leq 0.05$).

The second remediation tested whether better performance of surviving seedlings from the original planting could be stimulated by the addition of treeshelter protection. Eighty-three pairs of survivors were matched by replication, treatment group, proximity to one another within the replication, and height. In spring 1993, one of each of the 83 pairs was randomly selected and fitted with a treeshelter; the other was left unprotected. Average height of the two groups was nearly the same at this time (protected group 17 cm, unprotected 16 cm). Each pair continued to receive the weed treatment it originally had been assigned. Treatments were maintained for 3 years, and height and survival were assessed annually. Heights of stems were found to be normally distributed using the Wilk-Shapiro statistic and were then tested with a paired *t*-test (rejection level, $P \leq 0.05$). A chi-square test for independence was used to evaluate the differences in numbers of survivors from the protected and unprotected groups in each of the 3 years.

Each year, heights were measured to the maximum height reached that season. For seedlings greatly damaged by voles or grasshoppers, mainly those unprotected, this gave the most optimistic estimate of their potential for future growth, since many of these plants were so badly damaged that they would resprout only from the root crown in succeeding years. Similarly, survival was assessed in the most optimistic manner. Survival for 1995 could only be truly determined by resprouting in spring 1996 (which is yet to come), so survival was assumed for all plants whose status was questionable at this time.

Results

After 3 years, average height of replanted acorns and seedlings had exceeded the original planting (*table 3*), though the latter group had 2 more years of field

Table 3–Average height and survival of acorn and seedling replants after 3 years, compared to unremediated original planting[1]

	Mean height			Survival		
	1993	1994	1995	1993	1994	1995
	cm			*pct*		
Original plot	17	20	19	16	16	16
Acorn replants	91	133	141	[a]78	[a]80	75
Seedling replants	91	140	141	[b]95	[b]93	88
P-values, ANOVA	0.96	0.27	0.99	0.01	0.03	0.06

[1]Different superscript letters indicate significant differences ($P < .05$) for acorn and seedling replants by a one-way ANOVA performed on acorns and seedlings for each year. Original plot averages were not part of this test.

growth. Average height of replants (141 cm) was more than seven times greater than the original planting (19 cm). There were no significant differences between heights of acorn or seedling replants, and after 3 years they had identical average heights. While seedlings had statistically significant higher survival (88 percent) than direct seeded acorns (75 percent), both of these protected replants exceeded the original planting, which had stabilized at 16 percent survival.

The original restoration planting continued to be attacked by both voles and grasshoppers. Forty-four percent of these unprotected seedlings showed severe damage clearly attributable to voles, and this did not include those plants clipped off entirely (an ambiguous sign of vole predation), for which no sure cause of damage was evident. None of the protected replants received vole damage, but all that grew above the 1.2-m treeshelter height were annually defoliated by grasshoppers. While apparently severe, this defoliation was followed by refoliation generally within 2 months. In 1995, for example, all plants were stripped of their leaves between August 1 and August 22. During October, they refoliated and even experienced some late season growth flushes. Few of the unprotected plants of the original planting, which were attacked with equal severity, refoliated in this manner.

In our second remediation, evaluating protected versus unprotected pairs, there were clear benefits of treeshelter protection. Height and survival differences between pairs were highly significant for all 3 years ($P < 0.001$). Mean height of the unprotected group increased only slightly in the first season (average height at start = 16 cm), while their protected counterparts (average height at start = 17 cm) showed more than a three-fold increase in height (*table 4*). After 3 years, unprotected seedlings had not quite doubled in height, while protected ones had grown more than seven times taller than their initial height.

Table 4—Average height and survival after 3 years for pairs of survivors of original restoration planting with and without retrofitted treeshelter protection

	Mean height			Survival		
	1993	1994	1995	1993	1994	1995
		cm			*pct*	
Unprotected (n=83)	20	29	28	87	77	76
Protected (n=83)	60	98	130	100	99	98
P-values[1]	<0.0001	<0.0001	<0.0001	0.0006	<0.0001	0.0001

[1]P-values for height in each year resulted from paired t-tests; P-values for survival resulted from Chi-Square tests on numbers of survivors.

Survival in the unprotected group continued to decline, but not dramatically. Even so, 98 percent of protected plants survived, while 76 percent (best case) of the unprotected survived after 3 years. According to our chi-square analysis, these were highly significant differences. By the third year of this study, no protected plants showed signs of vole predation, while 23 percent of those unprotected showed definite signs of vole damage or mortality. Grasshopper defoliation and subsequent refoliation were similar to the replanting remediation above.

Discussion

Since the early 1980's, evidence has been mounting for the use of treeshelters to increase growth and survival of oaks. Windell's (1992) review of the literature and reprinting of some of the early research papers reports overall beneficial results for a number of British and eastern U.S. oak species. Our results concur with these generally positive findings, but the California experience does not present a uniform picture. Enhanced height growth and survival of blue oaks grown in treeshelters at the Sierra Foothill Research and Extension Center (McCreary and Tecklin 1993; McCreary and Tecklin, these proceedings), which inspired the use of these devices to rehabilitate our demonstration planting, have not been duplicated at the Hopland Center (Costello and others 1991, 1996). In that north coastal California setting, blue oaks grew and survived better in treeshelters only if irrigated, and valley oaks responded more favorably than blue oaks. Plumb and DeLasaux (these proceedings) in central-coastal California, moreover, found that treeshelters enhanced height growth of coast live oak (*Quercus agrifolia*), but not survival, probably due to micro-climate-induced pest problems inside the shelters. It remains to be clarified if these are regional, specific, or other differences.

In replanting our plot with treeshelter-protected acorns and seedlings, we attempted to overcome what we perceived to be a vole predation problem in the densest cover on our plot where there was almost complete initial seedling mortality. The simple technique of sinking the treeshelters 8-10 cm into the soil was meant to inhibit vole access. This technique seems to have succeeded, but the rapid height growth and improved survival that we report in this remediation could be confounded by the weed treatment they received and may not be solely attributable to a treeshelter effect. In the case of our treeshelter retrofitted pairs, however, plants tested were from all weed treatments and stock types, although a smaller sampling was from the least effective weed treatments. We are, thus, more confident in ascribing the improved height growth and survival the first year after treatment and thereafter to treeshelters. We were never able to achieve comparable height growth among unprotected plants elsewhere in the plot, even with thorough weed control treatment.

The complete absence of vole predation of our protected replants is consistent with the experience of others who have tested treeshelters as effective protection against voles (Davies and Pepper 1989). Though treeshelters did not completely protect seedlings against grasshopper defoliation, there was a difference in the severity of attack on protected and unprotected plants. Unprotected plants were vulnerable to defoliation, regardless of age or height. Young, thin stems were often girdled, at best setting growth back to root crown level. So long as protected plants were below the tops of their treeshelters, they were rarely defoliated by grasshoppers. Once they over-topped their treeshelters as older, thicker-barked plants, they may have been more resistant to severe grasshopper damage, and thus refoliated quickly, as was observed.

Retrofitting treeshelters onto surviving oaks in restoration plantings offers possibilities for improving the performance of these seedlings that have been able to overcome the often unpredictable environmental challenges of the planting site. Such seedlings are a valuable resource for successful restoration, and our results indicate it is possible to release them from a stunted condition. We are aware of only two other studies that retrofitted survivor seedlings, but these were carried out on eastern U.S. and British species. One reported a doubling of height after one year (Myers and others 1991), and the other showed a four-fold increase after 2 years (Tuley 1985). Both are consistent with our findings.

Under adverse natural conditions, blue oak seedlings often persist for many years, perhaps as advance regeneration, but exhibit little height growth and finally die (Allen-Diaz and Bartolome 1992, Swiecki and others 1991). While numerous seedlings can be found on most sites, it is common to find sites lacking sapling-sized blue oaks, or with low sapling-to-tree ratios (Bolsinger 1988, Muick and Bartolome 1987, Swiecki and Bernhardt 1993). Could natural regeneration be enhanced with treeshelters, as our study indicates is possible with planted stock? Where this has been tried with northern red oak (*Quercus rubra*), the results were not promising (Walters 1991), but we have yet to evaluate how naturally recruited blue oak seedlings in California might respond.

Conclusions

Extensive planting of oaks is recent to California: most projects are no more than 5 years old. There are published accounts of successful larger-scale establishment of oaks (Bernhardt and Swiecki 1991, Griggs, Costello and others, both in these proceedings), but assessment of the long-term success of artificial regeneration of oaks in California continues. Accounts of the eastern U.S. experience (Lorimer 1993, Pope 1993) should alert us to expect some failures in these efforts.

Should oak restoration projects fall short of their objectives, restorationists should consider retrofitting survivors or replants with treeshelters. The price of treeshelters has decreased; a 1.2-m treeshelter currently costs less than $2. They are proving to be effective protection of trees from rodents, a consideration on most sites. In addition, seedlings in shelters grow far more rapidly, and it is much easier to spray herbicides around protected seedlings for weed control. They may not be the "silver bullet" for oak restoration, but further use of these devices will give us a better idea of their utility for California conditions. Further experiments should also test their applicability in growing seedlings, both planted and of natural occurrence, to the sapling stage, a vexing problem in California.

References

Allen-Diaz, Barbara H.; Bartolome, James W. 1992. **Survival of *Quercus douglasii* (Fagaceae) seedlings under the influence of fire and grazing**. Madroño 39(1): 47-53.

Bernhardt, Elizabeth A.; Swiecki, Tedmund J. 1991. **Minimum input techniques for valley oak restocking.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 2-8.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands and savannas**. Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Costello, Laurence R.; Peters, Amy; Giusti, Gregory A. 1996. **An evaluation of treeshelter effects on plant survival and growth in a mediterranean climate**. Journal of Arboriculture 22(1): 1-9.

Costello, L.R.; Schmidt, R.H.; Giusti, Gregory A. 1991. **Evaluating tree protection devices: effects on growth and survival—first-year results**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 31-35.

Davies, R.J.; Pepper, H.W. 1989. **The influence of small plastic guards, treeshelters and weed control on damage to young broadleaved trees by field voles (*Microtus agrestis*)**. Journal of Environmental Management 28: 117-125.

Griffin, J.R. 1971. **Oak regeneration in the upper Carmel Valley, California**. Ecology 52: 862-868.

Lorimer, Craig G. 1993. **Causes of the oak regeneration problem.** In: Loftis, David L.; McGee, Charles E., ed. Oak regeneration: serious problems, practical recommendations: symposium proceedings; September 8-10, 1992; Knoxville, Tenn. Gen. Tech. Rep. SE-84. Asheville, NC: Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 14-39.

McCreary, Douglas D. 1991. **Seasonal growth patterns of blue and valley oak seedlings established on foothill rangelands**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 36-40.

McCreary, Douglas D.; Tecklin, Jerry. 1993. **Treeshelters accelerate valley oak restoration on grazed rangelands.** Restoration and Management Notes 11(2): 152-153.

Muick, Pamela C.; Bartolome, James. 1987. **Factors associated with white oak regeneration in California**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986. San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 86-91.

Myers, Richard D.; Pope, Phillip E.; Gillespie, Andrew R.; Fischer, Burnell C. 1991. **Rehabilitation of a young northern red oak planting**. Reprinted in: Windell, Keith, ed. 1992. Tree shelters for seedling protection. Missoula, MT: Technology and Development Program, Forest Service, U.S. Department of Agriculture; 77.

Pope, Phillip E. 1993. **A historical perspective of planting and seeding oaks**. In: Loftis, David L.; McGee, Charles E., ed. Oak regeneration: serious problems, practical recommendations: symposium proceedings; September 8-10, 1992; Knoxville, Tenn. Gen. Tech. Rep. SE-84. Asheville, NC: Southeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 224-240.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A. 1993. **Factors affecting blue oak sapling recruitment and regeneration**. A report by Forest and Rangeland Resources Assessment Program, California Department of Forestry and Fire Protection. Sacramento, CA; 132 p.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1991. **Insect and disease impacts on blue oak acorns and seedlings**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 149-155.

Tuley, Graham. 1985. **The growth of young oak trees in shelters**. Forestry 58(2): 180-195.

Walters, Russell S. 1991. **Progress report for study plan 157, tree shelters for protecting northern red oak seedlings**. In: Windell, Keith, ed. 1992. Tree shelters for seedling protection. Missoula, MT: Technology and Development Program, Forest Service, U.S. Department of Agriculture; 97-116.

Windell, Keith. 1992. **Tree shelters for seedling protection**. Missoula, MT: Technology and Development Program, Forest Service, U.S. Department of Agriculture; 142 p.

Restoration Management of Northern Oak Woodlands[1]

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***Abstract**: Northern oak (*Quercus garryana*) woodlands at Annadel State Park are experiencing an invasion of Douglas-fir (*Pseudotsuga menziesii*) owing to changes in livestock grazing, firewood cutting, and fire suppression occurring since before the park was established in 1972. To curtail this invasion, a restoration management plan was developed based on studies of northern oak and Douglas-fir seedling establishment, stand-age analysis, and fire history. Management techniques involved in the restoration plan include prescribed burning, manual removal of Douglas-fir saplings, and girdling of larger Douglas-fir trees. Results of the management activities to date are reported in terms of the area of northern oak woodlands treated; the numbers of Douglas-fir trees, saplings, and seedlings killed by treatments; and changes in understory conditions including oak (*Quercus garryana*) and bay (*Umbellularia californica*) seedling establishment.*

Annadel State Park is located in Sonoma County, California, approximately 1 mile east of Santa Rosa. The Annadel State Park brochure describes the park as "a wilderness at your doorstep." Annadel is one of the largest State Parks in Sonoma County. The park unit encompasses 5060 acres of land located in the heart of a growing metropolitan area of approximately 250,000 residents. It is bounded on the east by the Valley of the Moon, on the north by Rincon Valley, and on the south and west by Bennett Valley. It is visited annually by between 150,000 to 170,000 hikers, equestrians, mountain bikers, and runners.

Annadel State Park includes significant historic, archeological, geologic, wildlife, and vegetation features. One hundred twenty Native American and historic Euro-American sites have been recorded. Most of the Native American sites are associated with the processing of stone material to make tools. The many historic Euro-American sites found within Annadel consist of andesite and basalt quarries, rock walls, fence lines, homestead foundations, and access roads. The vegetation of the park is typical of the southern North Coast Range, with representation of coastal prairie, chaparral, northern oak woodland, mixed evergreen forest and coniferous forest community types (Amme 1987).

It is the policy of the California State Parks to prescribe and execute a program of resource management based on current and continuing scientific research. This management is designed to perpetuate a park's unique values. Research conducted during the late 1980's at Annadel documented several vegetation changes within the park. These investigations included a characterization of the park's vegetation types, an assessment of forest, woodland, chaparral and grassland fuels, and the effects of prescribed burning on these fuels and vegetation. Further studies included stand age analysis within the forest and woodland types, factors responsible for the establishment of tree seedlings and a fire history of the park (Barnhart and others 1996). Permanent plots were established to observe the response of the oak woodland type to management activities.

Some of the finest examples of the northern oak woodland within California are found at Annadel. Approximately 1050 acres of this northern oak woodland dominated by Oregon white oak (*Quercus garryana*) are threatened by the invasion of Douglas-fir (*Pseudotsuga menziesii*). Causal factors which fostered the establishment of Douglas-fir include changing understory conditions owing to increased oak densities and the suppression of fires in recent decades (Barnhart

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and others 1987). Stand age analysis revealed that all oak species sampled within the park were consistently much older than the oldest Douglas-fir observed (Barnhart and others 1996). During the past 50 years, fire exclusion in these sites encouraged Douglas-fir invasion into the oak woodland. In turn, the oak woodland has succeeded to the Douglas-fir type where the Douglas-firs have overtopped the oaks, resulting in oak mortality.

The historical fire frequency within the Sonoma Valley and Annadel has been analyzed through fire scars on redwoods adjacent to northern oak woodlands. Finney and Martin (1992) reported that the mean fire intervals from all stumps varied from 6.2 to 20.9 years, with many intervals between 2 and 10 years. The northern oak type flourished under this historical regime of relatively low-intensity frequent fire. Since the early 1900's modern fire suppression activities prevented most fires within the Sonoma Valley from spreading. Only two lightning-caused ignitions have been recorded since 1939. It is unlikely, though, that lightning was the sole ignition source responsible for the short fire intervals before settlement. Several sources document the indigenous use of fire. The short fire intervals evidenced at Annadel suggest the surface fuels and understory vegetation were systematically and intentionally burned by Native Americans. The impacts of consistently short fire intervals recorded between the late 1300's and mid-1800's would have markedly influenced the composition and structure of the park vegetation (Finney and Martin 1992). Since 1939, when fire records were first maintained, 39 fires have burned within Annadel's boundary. Most of these were suppressed as small fires less than 2 acres in size. The approximate 50 years of fire suppression have allowed Douglas-fir to be spared fire-caused mortality. As a result of the expansion of Douglas-fir, essential wildlife habitat, biodiversity, and the open character provided by the park's oak woodlands are being lost.

Development of a Restoration Method

Documentation of the Douglas-fir invasion at Annadel State Park (Barnhart and others 1987, Barnhart and others 1996) led park officials to initiate an active oak woodland management program during the late 1980's. Prescribed burns were conducted within targeted high-priority locations in the park. Manual removal of Douglas-fir also took place. Approximately 460 Douglas-fir trees, 6 inches DBH (diameter at breast height) and larger, were marked within a 550-acre area of oak woodland. Private contractors applied a 50 percent solution of glyphosate, under the trade name of Roundup, to shallow frill cuts made into the cambium layer. Smaller-diameter Douglas-fir trees were felled, with the slash lopped and scattered within the same 550-acre area. A 100-ft visual buffer zone was established adjacent to the park roads and trails within the management area. Within this corridor, no Douglas-firs were treated to ensure that trees would not be killed in areas that were highly visible.

Manual Tree Removal

In 1993, after several years of curtailed activities due to park budget constraints, increased attention was again given to Annadel's oak woodlands. A volunteer team was formed to complement prescribed burning efforts. Trained in the safe operation of chain saws and hand tools, the volunteers applied frill cuts to Douglas-fir trees with more than 6 inches DBH. This was accomplished by applying a single chain saw cut through the cambium of the tree. No herbicide was applied. Smaller trees were felled, and the slash was lopped and scattered. Many very small trees were simply pulled out of the ground. Average attendance at monthly team work parties was between 8 and 12 volunteers. Additional volunteers were actively sought to augment the initial core group of team members. Approximately 100 acres were treated during the first year the volunteer team was in place. A preliminary assessment of frill-cut tree mortality was conducted in 1994 and 1995.

Prescribed Burning

The acreage of prescribed burning has greatly increased since the program was initiated in the 1980's. In July 1994, a 242-acre compartment of oak woodland was burned. The burn was accomplished on 2 consecutive days. The fire was started around the perimeter of the compartment. Complete ignition around the perimeter was achieved within a few hours. This allowed the interior fuels to burn out as wind and topography dictated. The weather for July was ideal: high temperature was 88 ˚F; minimum relative humidity was 30 percent with mild winds. The second day's firing operations were conducted in much the same way. Ignition occurred along two concurrent flanks with a perimeter fired out within a few hours of the initial ignition. Again, the interior fuels burned out over the next several hours. A subsequent survey of the area indicated about 2 percent of the area within the burn boundary did not burn.

An additional 95 acres were burned during similar conditions during July 1995. The high temperature was 89 ˚F, with the minimum relative humidity of 29 percent. Winds were very calm, which prohibited active fire spread in some locations. This weather, coupled with the insufficient fuel provided by oak litter and Douglas-fir needles, left approximately 5 percent of the burn compartment with live Douglas-fir remaining following the burn.

Post-Fire Assessment

A post-burn monitoring protocol was developed immediately after the 1994 burn. Twenty-three transects were installed to assess tree seedling and sapling survival and post-burn seedling establishment. Seedlings were defined as plants less than 2 ft tall. Saplings were defined as plants more than 2 feet tall but less than 10 ft in height. Transects were 10 feet wide and ran from one side of the burn to the other along north-south lines. Data were recorded for 100-foot long sections of each transect.

Results

Manual Tree Removal

The results of the Douglas-fir killing contracts from the 1980's are variable. All of the trees treated with shallow frill cuts and herbicide died. Establishment of a visual buffer zone adjacent to the park roads and trails proved to be a poor management decision. Douglas-fir seed production from trees in the buffer zone continued, and currently a dense stand of Douglas-fir survives the contracted work. In addition, many of the smaller trees felled during this time have not died. The stumps were left too high, and dormant buds below the cuts were stimulated to produce new shoots. These new shoots have become new trees in many cases.

The results of the volunteer teamwork within the treated 100 acres are generally very favorable. One year after treatment, the girdled Douglas-fir trees have thinning crowns, needle discoloration, and needle drop. Some trees are dead. A few isolated Douglas-fir trees of 12-inch DBH or greater have not been killed by the girdling work. Some of the cuts made with chainsaws were too shallow to sever the cambium layer. If chainsaw cuts are deep enough, herbicide use is unnecessary. All trees properly treated will die. The new Douglas-fir trees that have become established within the treatment areas, along with the dense

Douglas-fir regeneration along the park roads and trails, are being treated by volunteers. Currently, volunteers are taking great care to remove all Douglas-fir, regardless of their location within the oak woodland, and to make cuts below the lowest branch node.

Prescribed Burning

Post-fire data collected in 1994 showed an average mortality of 38.9 percent for seedlings of Oregon white oak, 28.5 percent for California bay, and 87.9 percent for Douglas-fir (*table 1*). In the 1995 re-survey of the 10 transects, the number of oak seedlings increased by 9.2 percent to an average of 52.3 seedlings per acre as a result of new seedlings established after the fire. California bay seedling populations increased 19.9 percent to 52.3 per acre, while the number of Douglas-fir seedlings decreased 50 percent to 8.7 per acre.

Table 1*—Seedling populations and fire-caused mortality occurring in the 1994 prescribed burn compartments at Annadel State Park*

Species	Number of seedlings before prescribed fire	Number of seedlings killed by prescribed fire	Fire-caused mortality	Number of seedlings alive in 1994 after fire	Number of seedlings alive in 1995
	no./acre	*no./acre*	*pct*	*no./acre*	*no./acre (pct)*
Quercus garryana	78.4	30.5	38.9	47.9	52.3
Umbellularia californica	61.0	17.4	28.5	43.6	52.3
Pseudotsuga menziesii	143.7	126.3	87.9	17.4	8.7

As is generally the case in understory burning, both the 1994 and 1995 prescribed fires burned in a mosaic of lesser and more severe fire intensities, because of uneven distribution of surface fuels. Oak leaf litter and Douglas-fir needles produce poor surface fuels to carry a fire on the forest floor under the live tree canopy. In contrast, native California fescue (*Festuca californica*) produces high volumes of flammable grass fuel. Those locations occupied by California fescue burned with high intensity. Where surface fuels allowed fire to spread, Douglas-fir seedling mortality was near 100 percent. Approximately 2 percent of the area along the transects through the 1994 prescribed burn area did not burn because of sparse surface fuels. Nearly all of the Douglas-fir seedlings that survived the prescribed fire were observed in these unburned areas.

Discussion and Conclusions

The general resource management strategy for the park is to dovetail prescribed burning with volunteer or funded hand labor projects. Manual removal of Douglas-fir seedlings and saplings must be accomplished in portions of the oak woodland that are not affected by burning. Girdling of larger Douglas-fir will be required where trees survive burning. Our experience since 1994 shows that relatively small numbers of volunteers, with proper training, can be effective over time. Prescribed fire is very reliable in reducing Douglas-fir invasion in fuels dominated by California fescue, but is less reliable in sparse fuels such as oak leaf litter and Douglas-fir needles.

The prescribed burning prescriptions used at Annadel were developed after many years of field experience in burning the fuel types represented within the park, coupled with advanced fire behavior calculations training. The BEHAVE family of fire behavior prediction models (Burgen and Rothermel 1984) was used to quantify predicted fire behavior during burning. The nature of surface fuels within the park is extremely variable, and site-specific burning prescriptions are always necessary to ensure that prescribed burning is conducted in a safe manner, while satisfying burn objectives. The weather recorded during the 1994 and 1995 burns represented warm, yet moderate, burning conditions for Annadel.

Burning at this location can still be safely conducted with temperatures as high as 89 °F until the relative humidity drops to 25 percent. Burning when the relative humidity falls below 25 percent makes controlling and containing a prescribed fire at Annadel much more difficult and provides a more limited margin of safety. Wind measurements are also crucial for developing a burning prescription. Surface winds in excess of 10 miles per hour make it difficult to contain fire spread and intensity.

Prescribed burning experience at Annadel has demonstrated that fall burning at this location is not entirely appropriate. After the fall rains, the composition of surface fuels precludes adequate fire spread. The relatively non-flammable oak leaf litter and Douglas-fir needles will sustain surface fire only under the driest conditions. Burns can be conducted in the fall, just before the first rains, because live and dead fuel have reached critical moisture levels. Burning in early or midsummer can be most effective and can also provide 2 to 3 months of fire protection for the homes in the urban interface around park boundaries.

References

Amme, David. 1987. Revised by M.S. Hastings. 1992. **Annadel State Park Unit Prescribed Fire Management Plan.** 137 p.

Barnhart, S.J.; . McBride, J.R.; Cicero, C.; DaSilva, P.; Warner, P. 1987. **Vegetation dynamics of the northern oak woodland.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12 - 14, 1986; San Luis Obisbo, CA. Gen. Tech. Rep. PSW - 100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 53 -58.

Barnhart, S.J.; McBride, J.R.; Warner, P. 1996. **Invasion of northern oak woodlands by *Pseudotsuga menziesii* (Mirb.) Franco in the Sonoma Mountains of California**. Madroño 43(1): 28-45.

Burgen, R.E.; Rothermel, R.C. 1984. **BEHAVE: Fire behavior prediction and fuel modeling system.** Gen. Tech. Rep. INT-167. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 84 p.

Finney, Mark A.; Martin, R.E. 1992. **Short-fire intervals recorded by redwoods at Annadel State Park**. Madroño 39(4): 152-262.

A California Black Oak Restoration Project in Yosemite Valley, Yosemite National Park, California[1]

Susan L. Fritzke[2]

Abstract: *In 1985, California black oak (*Quercus kelloggii*) stands in Yosemite Valley, Yosemite National Park, California, were identified as a sensitive plant community requiring protection and restoration. Changes in natural fire processes, encroachment by conifer trees, browsing by large populations of deer (*Odocoileus *spp.) and rodents, and impacts from construction projects and uncontrolled visitor use had caused a significant decline of black oak density and stand structure. Restoration work began in 1987, and after 8 years, the results have been positive. Low-profile fences have virtually eliminated problems of human trampling, and 172 of 500 transplanted oak seedlings have become established. The seedlings received a variety of treatments that potentially enhanced seedling survival, growth, and vigor. Seedling growth or survival were not affected by fertilizer, but there was a significant difference in oak seedling survival, growth, and vigor between tree shelters of open plastic mesh or solid double-layer plastic. This project has provided the park with valuable information about restoring native species and effectively managing visitors in a heavily used area.*

In 1985, the open, mature stands of California black oaks (*Quercus kelloggii*) in Yosemite Valley were identified as a sensitive plant community requiring protection and restoration (USDI 1985). In Yosemite Valley, this species forms pure open stands of large stately trees with an herbaceous understory, unlike other areas of California where it typically grows in mixed conifer stands or more open stands intermixed with shrubs and other tree species. This difference is primarily attributed to frequent low-intensity natural and Native American-caused fires.

The Southern Sierra Miwok Indians frequently lit surface fires in Yosemite Valley oak stands to maintain oak habitat, which would otherwise have been encroached by more shade-tolerant species. This frequent disturbance was also thought to enhance acorn production by reducing potential plant competition to mature oaks and recycling nutrients in the soil. Today, the black oak stands provide food, shelter, and habitat for at least 45 wildlife species and produce many products which were used by Native American groups in the area (Anderson 1993).

Pure California black oak stands currently cover about 60 ha of Yosemite Valley, a 90-percent reduction from the original 500-600 hectares that existed when the valley was first discovered by Euro-Americans in 1851 (Gibbens and Heady 1964). Furthermore, the remaining black oak stands have few trees less than 130 years old. This decline is visible in photographic comparisons and is most likely due to the suppression of frequent fires that have allowed invasion by conifer trees, primarily incense-cedar (*Calocedrus decurrens*) and California white fir (*Abies concolor* var. *lowiana*).

Oak establishment subsequently decreased because black oak saplings and trees are intolerant of dense shade. Increased browsing by rodents and deer (Odocoileus spp.), caused by a decrease in human and wildlife predators parkwide, also probably reduced the success of seedlings that did manage to become established after the 1850's. These factors, in conjunction with the effects of trampling and destruction of understory and seedling vegetation by visitors,

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subsequent soil compaction, and construction projects, served to further endanger the sustainability of the remaining oaks in Yosemite Valley (Angress 1985). The potential loss of this plant community led to a restoration project proposal in 1987.

In October 1988, a pilot restoration project began at the "schoolyard oak woodland" (so named because of its location adjacent to the Yosemite Valley elementary school) with an initial donation of $50,000 from The Yosemite Fund. In 1990 an additional $200,000 was received through The Yosemite Fund to continue oak restoration in other areas of Yosemite Valley. This paper focuses on the restoration methods used and results obtained at the schoolyard site.

The general goal of this restoration project was to re-establish the open California black oak community. The plan consisted of revegetating the understory with native herbaceous species, and improving soil characteristics to promote natural oak seedling establishment over time. In addition, before natural oak seedling establishment, nursery-grown oak seedlings were planted to create an early age class under the mature oaks.

Methods

Site Description and Original Condition

The schoolyard oak stand grows at an elevation of 1,200 m at the end of colluvial and alluvial fans with gravelly to sandy soils. This stand, with about 50 mature black oak trees forming an open overstory with no other overstory species, serves as an ecotone between the low-lying montane meadows adjacent to the Merced River and the higher, drier mixed-conifer and live oak forests growing on the alluvial fans and talus slopes (Acree 1994). The site is 0.5 km west of the Yosemite Valley Visitor Center, between the village mall and Yosemite Lodge.

Before 1988, the site received heavy foot traffic and was criss-crossed with 14 social trails ranging from 0.5 to 3 m in width. In summer 1988, a 2- to 4-m wide trench was dug by heavy equipment through the middle of the stand to install new underground electrical cables. This resulted in a 15-m wide swath of bare ground. The entire area was trampled to varying degrees. The most highly impacted sites consisted of highly compacted (cement-like) bare ground with less than 10 percent vegetation cover of mostly exotic plant species resistant to trampling such as puncture vine (*Tribulus terrestris*), pigweed (*Chenopodium album*), and Jerusalem-oak (*C. botrys*). Moderately disturbed sites had less deeply compacted soils dominated by early-successional native species including sierra lessingia (*Lessingia leptoclada*), diffuse gayophytum (*Gayophytum diffusum*), horseweed (*Conyza canadensis*), and kelloggia (*Kelloggia galioides*). Undisturbed or minimally trampled sites consisted of a dense mixed herbaceous layer of bracken fern (*Pteridium aquilinum* ssp. *pubescens*), dragon sagewort (*Artemesia dracunculus*), occasional showy milkweed (*Asclepias speciosa*), and several native and exotic grasses.

Restoration Work

Vegetation Documentation

In 1987, before restoration work, the condition of the site's understory vegetation was documented by the establishment of permanent photo points. These were set up to illustrate changes in understory species composition and cover following each major step in the restoration process, and to show planted and natural oak seedling development. The photo points were re-taken at the same phenological period each year from established locations around the site. Although they did not provide a quantitative means of assessing understory changes, they did allow park staff to subjectively evaluate the general goal of re-establishing the open California black oak community.

Site Preparation

In 1988, the area was blocked off to foot traffic with a low (0.6-meter) post-and-rope fence. Invasive exotic plant species were removed by hand to promote the establishment of a native species understory over time. No attempt was made to remove naturalized exotic grasses, however, since these species are found throughout Yosemite Valley and would simply recolonize the site or allow colonization by other more undesirable exotic species if they were removed.

Soils were scarified to a depth of 25 cm in bare areas by a small tractor equipped with digging tines. In vegetated or sensitive areas, hand-held digging forks and spade shovels were used to loosen soils to a depth of 10 cm. All bare areas were watered heavily before soils were loosened. Locally gathered native seeds of dragon sagewort, showy milkweed, deer grass (*Muhlenbergia rigens*), and California goldenrod (*Solidago californica*) were then scattered over the site. Direct transplanting of adjacent native species was also done, following natural vegetation patterns (Alexander 1988). During the spring and summer of 1989, invasive exotic plants, including bull thistle (*Cirsium vulgare*) and woolly mullein (*Verbascum thapsus*), were weeded by hand in the project area, and additional native seeds were scattered.

Oak Seedlings Planted

In fall 1989, 500 2-year-old black oak seedlings were planted that had been grown at a local nursery from acorns collected from the site in fall 1987. The acorns had been planted in tubes and were later transplanted into D-pots (10- by 10- by 30-centimeters) to promote the development of deep root systems. Seedlings were distributed in groups of three to five trees, randomly spaced throughout the site where wooden stakes thrown into the air had landed.

Once seedling locations had been marked, planting holes were drilled to a depth of 0.6 m using a power auger and posthole digger. The auger was critical for efficiently digging holes, and the posthole digger was used when the soil became too rocky or compacted for the auger. The holes were lined with unstapled bottomless cylinders of 0.6-cm galvanized steel mesh to prevent root damage by numerous area rodents. The holes were then watered thoroughly and backfilled with 30 cm of loosened soil to enable rapid root growth from the bottom of the root ball.

Each seedling was removed from its container with soil intact around the roots and placed into a hole. A time-release fertilizer tablet was dropped into the holes for 250 randomly chosen seedlings. The holes were filled in to ground level, and the soil around each seedling was tamped in using the handle-end of a shovel. The seedlings were then watered, surrounded in a 1-m diameter by locally gathered oak leaf mulch to a depth of 5-10 cm, and protected from browsing by a tree shelter of either solid double-layer plastic or open plastic mesh. Oak leaf mulch was then applied to the entire site to an overall depth of 10-15 cm to add organic matter to soils made barren by years of trampling and construction work. Finally, informational and "area closed" signs were installed along the fenceline.

Altogether, the seedlings received four different treatments: solid double-layer plastic tree shelter with fertilizer (n = 53), solid double-layer plastic tree shelter without fertilizer (n = 55), open plastic mesh tree shelter with fertilizer (n = 197), and open plastic mesh tree shelter without fertilizer (n = 195). Treatments were distributed randomly throughout the site to account for variations in moisture availability, shading, soil compaction, and other local variables.

Since 1989, work at the schoolyard site consisted of measuring oak seedling growth and mortality, re-photographing the site to document herbaceous understory re-establishment, weeding out exotic plant species, and eliminating all herbaceous plants within 0.5 m of each oak seedling. The rope in the fence was replaced with more durable, visible, and vandal-resistant plastic-coated cable. About 100 western raspberry (*Rubus leucodermis*) and 50 dragon sagewort plants were also planted in a few locations where visitors persisted in crossing the fence. The thorny western raspberry plants were especially effective in deterring visitors from walking through the restoration site, and the sagewort rapidly covered bare areas.

In 1995, new 1- to 2-m tall solid double-layer plastic tree shelters were installed over 166 of the remaining 172 oak seedlings planted in 1989 and secured to 2.5-m tall metal snow stakes. Six seedlings over 1 meter tall were enclosed in 0.5- by 2-m wire mesh cylinders, to allow the seedlings to sway and develop stronger trunks. More than 100 naturally established oak seedlings were also documented and measured. Their approximate ages were estimated on the basis of height and branching form, and the healthiest in appearance were protected from browsing by the installation of solid double-layer plastic tree shelters.

Experimental Design and Sampling

The California black oak seedlings planted in 1989 were monitored to assess the effect of the two types of tree shelters and the fertilizer treatment. The seedlings were marked with aluminum tags attached to the outside of each tree shelter which included the tree identification number, type of shelter, and whether or not they had received fertilizer. Unfortunately, the tags were highly visible and many tags were either vandalized or were chewed off by deer or other animals. As a result, only 109 seedlings comprised the sample in 1995, although 172 seedlings had survived.

Seedling heights were first measured immediately following planting in 1989. Surveys of seedling survival and growth were then conducted in 1991, 1992, 1993, and 1995 after leaf-out (May to June, depending on the year). Measurements were taken from ground level to the top of the woody stem. Some seedlings had double- or triple-shoots, and only the tallest shoot height was recorded. Seedlings in poor health (insect damage, fungus, late leaf-out) were noted on the data sheet. Dead individuals were also noted, and the tree shelters and tags were removed from the site.

Statistical Analysis

Descriptive statistics were calculated for each surviving seedling for each year surveyed, separated into the four treatments (*table 1*). A Levene statistic determined that the variances of seedlings within the two tree shelter types were significantly different. Therefore, a Kruskal-Wallis (nonparametric) one-way ANOVA was used to compare overall height differences of 1995 seedlings for the two tree shelter types.

Results

Understory Vegetation

Native plant understory establishment was evaluated subjectively on the basis of photographs. The appearance of the site showed an increase in overall plant cover. Exotic plant species had declined in both number and distribution over the site, based on notes taken during weeding.[3] There was a much greater cover of bracken

[3]Fritzke, Susan L. 1995. Journal records, on file at Resources Management Office, Yosemite National Park.

fern and California goldenrod in wetter areas, and drier sites were dominated by dragon sagewort, showy milkweed, kelloggia, and other native plants.

Planted Oak Seedlings

Seedling mortality was greatest between 1989 and 1991, probably from a combination of drought conditions prevalent at that time, planting shock, and loss of tree shelters due to wildlife, weather (wind and snow), and people. Forty seedlings died in 1991, eleven in 1992, five in 1993, and seven between 1994 and 1995. The remaining losses were from unknown causes.

In 1995, 109 marked and 63 unmarked planted seedlings remained in the restoration site, or 34 percent overall survival. Thirty-nine percent of the seedlings in solid double-layer plastic tree shelters survived the first 6 years, as opposed to only 17 percent of those seedlings in open plastic mesh shelters (*fig. 1*).

The seedlings within solid double-layer plastic exhibited the greatest range of variability in 1995 height (from 0.08 to 1.59 m) and the greatest average height (0.69 m). The seedlings in solid double-layer plastic shelters were significantly taller ($P = 0.0097$) than those in open plastic mesh shelters, with single-stemmed growth and minimal lateral branching. This should enable these seedlings to grow above browse height (estimated at 2 m) more quickly.

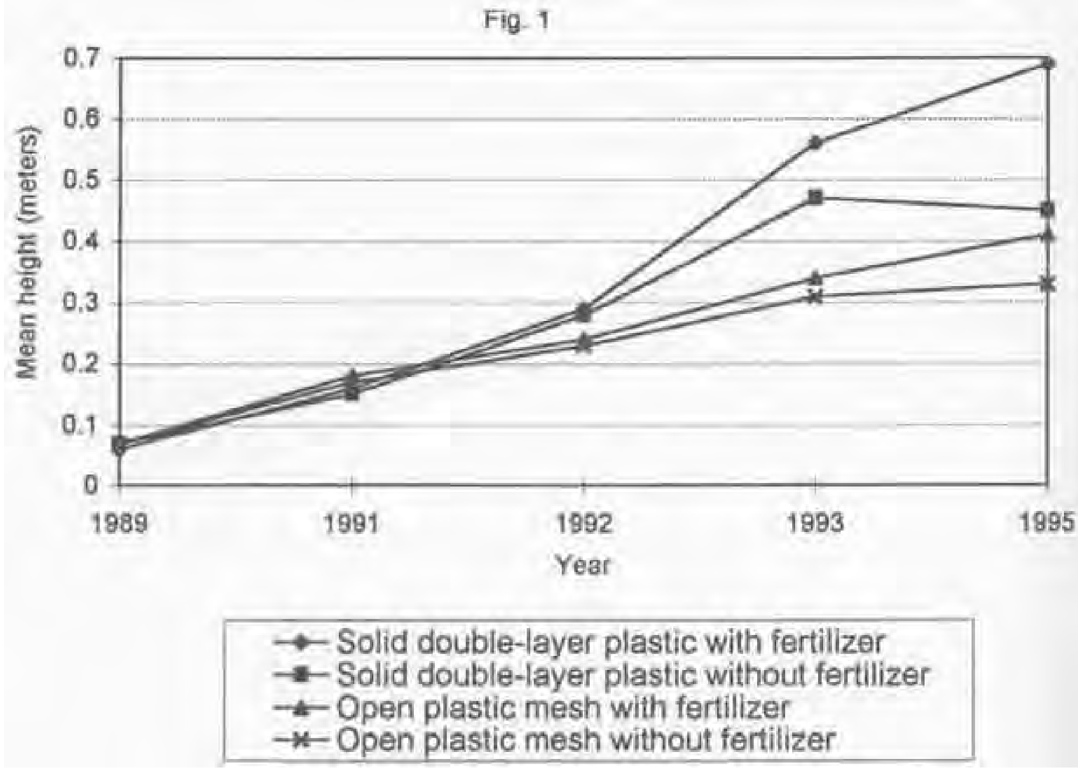
The average height of fertilized seedlings in both types of shelters was somewhat greater than unfertilized seedlings, but these differences were not significant. There was no significant difference in the survivorship of fertilized

Table 1—Summary of oak seedling surveys, 1989-1995

Year	Solid double-layer plastic with fertilizer $n = 53$	Solid double-layer plastic without fertilizer $n = 55$	Open plastic mesh with fertilizer $n = 197$	Open plastic mesh without fertilizer $n = 195$	Total $n = 500$
1989	Mean height: 0.06 m (2.4 in.) (s = 0.03 m)	Mean height: 0.07 m (2.8 in.) (s = 0.04 m)	Mean height: 0.07 m (2.8 in.) (s = 0.05 m)	Mean height: 0.07 m (2.8 in.) (s = 0.04 m)	500 (year planted)
1991	45 survive (85 pct) Mean height: 0.16 m (6.3 in.) (s = 0.08 m)	42 survive (76 pct) Mean height: 0.15 m (5.9 in.) (s = 0.06 m)	106 survive (54 pct) Mean height: 0.18 m (7.1 in.) (s = 0.11 m)	106 survive (54 pct) Mean height: 0.17 m (6.7 in.) (s = 0.06 m)	299 survive (60 pct of original plantings)
1992	33 survive (62 pct) Mean height: 0.29 m (11.4 in.) (s = 0.17 m)	32 survive (58 pct) Mean height: 0.28 m (11 in.) (s = 0.16 m)	53 survive (27 pct) Mean height: 0.24 m (9.4 in.) (s = 0.09 m)	55 survive (28 pct) Mean height: 0.23 m (9.1 in.) (s = 0.11 m)	173 survive (36 pct of original plantings)
1993	26 survive (48 pct) Mean height: 0.56 m (22 in.) (s = 0.37 m)	26 survive (47 pct) Mean height: 0.47 m (18.5 in.) (s = 0.34 m)	46 survive (23 pct) Mean height: 0.34 m (13.4 in.) (s = 0.21 m)	44 survive (23 pct) Mean height: 0.31 m (12.2 in.) (s = 0.17 m)	141 survive (28 pct of original plantings)
1995	21 survive (39 pct) Mean height: 0.69 m (27.1 in.) (s = 0.45 m)	21 survive (38 pct) Mean height: 0.45 m (17.7 in.) (s = 0.30 m)	34 survive (17 pct) Mean height: 0.41 m (16.1 in.) (s = 0.25 m)	33 survive (17 pct) Mean height: 0.33 m (13.0 in.) (s = 0.18 m)	109 survive (22 pct of original plantings)

***n* = number, *s* = standard deviation**

Figure 1—Average height of surviving oak seedlings, 1989-1995.



seedlings in either solid double-layer plastic or open plastic mesh shelters (*table 1*). The apparent loss in height in 1995 of non-fertilized seedlings in solid double-layer plastic tree shelters was attributed to dead or browsed shoots. The re-sprouts, measured in 1995, were considerably shorter and therefore brought down the average.

Discussion and Conclusions

Overall Condition of the Restoration Site

The condition of the schoolyard oak site has improved since restoration began in 1988. It now has a thriving native plant understory, and more than 100 naturally established 1- to 3-year-old black oak seedlings are scattered throughout the site. Six overstory oak trees within the restoration site have died since 1988, making natural oak seedling establishment even more important for maintaining the black oak community at this site.

The previously cement-like soils have been further loosened by ground squirrels (*Spermophilus beecheyi*), pocket gophers (*Thomomys bottae*), and other biotic and abiotic forces, allowing the natural establishment of black oaks and other native plants. Fencing has successfully eliminated 90-95 percent of the foot traffic that originally went through the area. These short fences are visually unobtrusive, but are surprisingly effective at confining use to delineated pathways around restoration areas.

Planted Oak Seedlings

One hundred seventy-two 10-year-old planted black oak seedlings are now growing within the restoration site. The greatest survival rates were seen in seedlings protected by double-layer solid plastic tree shelters. This can be attributed to a number of factors. First, the bamboo poles supporting the open plastic mesh rotted within a year, making it easy for humans and deer to dislodge the mesh tree shelters, as opposed to the more sturdy 3-cm^2 square wooden stakes holding the solid double-layer plastic in place. The open mesh shelters also broke down more quickly than the solid tree shelters, and seedlings in open mesh were therefore more frequently exposed to browsing. The solid double-layer plastic tree shelters not only protected the seedlings from outside forces, but probably created a more favorable microclimate which promoted greater survival (Costello and others 1996).

The 0.6-cm galvanized steel mesh screens installed in each seedling hole before planting appear to have been effective at reducing the number of seedlings lost to root predation. As the seedlings continue to grow, these unstapled screens can expand to allow normal root growth. In addition, naturally established oak seedling mortality from root browsing is expected to decrease as root browse pressure is taken off these seedlings by the establishment of more herbaceous and shrubby vegetation. Eventually, ground-screens should not be necessary at this site.

Future Management Directions

Park staff have begun evaluating the possibility of prescribed burning the site, which would add nutrients to the soil and discourage mistletoe and insect infestations on mature black oak trees. Burning could also benefit the oak seedlings by reducing competition from other plants, including a number of ponderosa pine and incense-cedar seedlings that have become established since restoration work began. However, a burn could also kill the above-ground portions of the oak seedlings, so all aspects are being weighed.

In the future, California black oak restoration efforts in Yosemite will be streamlined to eliminate unnecessary steps. Appropriate levels of site preparation, such as eliminating trampling, loosening soils, and reducing the number of exotic plants under overstory oaks will be prescribed on the basis of particular site characteristics.

For example, in areas where oak seedlings will be planted, rodent-proof screens will not be used if the soil is rocky. Fertilizer will not be used on oak seedlings, as it does not appear to either stimulate more rapid growth or assure seedling survival. The effectiveness of solid double-layer plastic tree shelters supported by snow stakes will reduce the need to plant oak seedlings in such high densities, as long as each planted seedling is monitored over a long period of time to reduce mortality from vandalism and wildlife. The snow stakes the park currently uses have a spade on the bottom and are sunk into the ground 0.5 m which makes them very difficult to pull out.

Finally, visitor education through the use of informational signs and articles will continue to play an important role in ensuring understanding and compliance to closed-off areas and fences.

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References

Acree, L.N. 1994. **The plant communities of Yosemite Valley—a map and descriptive key.** Technical Report NPS/WRUC/NRTR-94-01. U.C. Davis, CA. 32 p.

Alexander, B. 1988. **Schoolyard oak woodland restoration final report.** Yosemite National Park in-house report. 30 p.

Anderson, K. 1993. **Indian fire-based management in the sequoia-mixed conifer forests of the central and southern Sierra Nevada.** Final report submitted to the Yosemite Research Center, Yosemite National Park. 426 p.

Angress, E.E. 1985. **The decline of Quercus kelloggii in Yosemite Valley: an evaluation of fire and moisture regimes.** San Francisco, CA: San Francisco State University; 54 p. M.S. thesis.

Costello, L.R.; Peters, A.; Guisti, G.A. 1996. **An evaluation of treeshelter effects on plant survival and growth in a mediterranean climate.** Journal of Arboriculture 22(1): 1-9.

Gibbens, R.P.; Heady, H.F. 1964. **The influence of modern man on the vegetation of Yosemite Valley.** Berkeley: University of California Press; 44 p.

U.S. Department of the Interior. 1985. **Natural resources management plan and environmental assessment: Yosemite National Park, California.** National Park Service; 147 p.

Evaluation of Techniques and Costs for Valley Oak Riparian Forest Restoration on the Sacramento River[1]

F. Thomas Griggs Daryl R. Peterson[2]

***Abstract**: In 1989 The Nature Conservancy, in conjunction with both state and federal agencies and private landowners, initiated a riparian forest restoration program along the 161-km section of the Sacramento River between Red Bluff and Colusa. By 1995, valley oak (*Quercus *lobata*) had been planted at six different restoration units. Survival and growth varied among the units because of different maintenance regimes and different site conditions. Seed germination and survival through the first year was highly variable, ranging from 35 to 90 percent. Mean height ranged from 20 to 45 cm. Seven years into this project we will report costs associated with different restoration techniques and our recommendations for site selection, maintenance (irrigation, weed control, herbivore control), and performance standards for establishing valley oaks in large (>80 ha) retired agricultural fields.*

Riparian forests support more species of wildlife than any other forest type in California (Williams and Kilburn 1984). Two important factors may be their proximity to water and the complex structure of their vegetation, which allows many species of wildlife to find habitat space.

Valley oak (*Quercus lobata* Nee) grows on deep alluvial soils in the floodplains of the rivers and streams of the Great Central Valley and the Coast Ranges of California. It is the dominant species in a distinctive and threatened riparian forest community (Holland 1986). Valley oak riparian forest of the Great Central Valley is best developed on finer-textured soils (clay- and silt-loams of the Columbia soil series) at sites which are flooded only infrequently. It was formerly abundant on the high terraces of the Sacramento River floodplain. These comprise some of the best agricultural soils in the state, and most were cleared and converted to agriculture in the nineteenth century. With the completion of Shasta Dam in 1945, most of the remaining valley oak riparian forest in mid-terrace, flood-prone areas near the river was converted to agriculture. In the past decade remnant individuals and groves have been severely affected by urban development in the Great Central Valley.

In 1989, the Sacramento River National Wildlife Refuge was created by the U.S. Congress, to protect riparian forest habitat. The Refuge was to be established only on parcels of land contiguous to the river, prone to flooding, and available for purchase from a willing seller.

Two of the problems confronting the creation of this new wildlife refuge along a highly developed section of the river, with its hydrology altered by a dam, were that land purchases often included sub-optimal valley oak habitat and that optimal lands had mostly been converted to agriculture. The first step to deal with these problems was a program to test the feasibility of restoring relatively large areas of riparian forest and to evaluate different techniques for restoring sites having a range of soils and hydrology.

This program was entrusted to The Nature Conservancy (TNC). In cooperation with several agencies (U.S. Fish and Wildlife Service, California Department of Fish and Game, California Department of Water Resources) and private landowners (Parrott Investment Co.), TNC began implementing riparian forest restoration projects along the 161-km section between Red Bluff and

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Colusa. The immediate goal was to develop the technology to implement large (40+ ha) restoration plantings. The ultimate goal of the project was to double the existing extent (ca. 8,100 ha) of riparian forest by means of revegetation on ecologically appropriate sites; that is, sites which still flood today. One highly desirable outcome would be to improve the ecological health of wildlife populations in the Great Central Valley.

Since 1989, nine units (8 to 50 ha) have been planted at five different locations, totaling 223 ha. Valley oak was planted on all units, in differing densities, depending on local site conditions. For example, more valley oak was planted on the higher terraces and finer soils, while cottonwoods were planted on terraces with more varied soil strata.

In 1989, little was known of the biological and technical requirements for large-scale riparian forest restoration in general. Few previous efforts to restore valley oak riparian forest were available to guide the program (Reiner and Griggs 1989, Griggs 1990, Pavlik and others 1991). As the program developed and implemented successive, larger plantings, TNC's staff carefully monitored survival and growth of the individuals planted. This paper reports the results of monitoring the survivorship and growth of valley oak seedlings and saplings in the riparian forest restoration plantings along the Sacramento River for four years. Six different units (plantings) dating from 1992 are included.

Methods

Restoration Units

Table 1 compares important characteristics of each restoration unit. Site conditions which varied between units include area, patterns of soil texture, and depth to water table. Planting design and methods were tailored to each unit's site conditions and the existing farming infrastructure (primarily, the existing irrigation system). For example, River Vista II is adjacent to the river and soil textures are highly variable across the unit, while at Sam Slough, one mile from the river, soil is is mostly silty loam. River Vista II was irrigated by a solid-set sprinkler system already on site, while at Sam Slough, a drip system was installed. At each unit a mixture of species were planted. This conservative approach was based upon the recognition of the dynamic complexity of riparian ecology, and was designed to ensure that at least some species would establish. The relative proportion of valley oak in the planting mix was based upon site conditions: valley oak was planted at higher densities on finer texture soils that were more than 4 m from the water table.

Collection and Planting

To minimize disturbance of natural genetic population structures and to increase the probability that individuals would survive under local conditions, acorns were collected as near to each planting unit as possible. In all cases, collections were from the mainstem of the Sacramento River, and from trees growing on the Columbia Soil Series. The planting density for the acorns varied from about 250 to 1500 acorns per ha, depending upon the number of other species to be planted at a unit. In particular, on units where a mixture of tree and shrub species was planted, valley oak acorns were planted at lower densities.

Acorns were collected when ripe in October or November, stored in a refrigerator between 1 and 5 °C, and planted into the unit before mid-December. Acorns were planted across the unit in rows to facilitate weed control and irrigation.

Table 1–Characteristics of the restoration planting units

Planting units Soil types (ha)	Year planted	Depth to water table	Irrigation system	Valley oak density	Overall plant density
		meters		*acorns/ha*	*seedlings/ha*
Sam Slough					
Silty Loam (26)					
Sandy Loam (3)	1991	5	Drip	1580	1830
Princeton Ferry					
Loam (12)					
Clay Loam (1)					
Sand (5)	1992	3-5	Drip	740	1450
River Vista I					
Sandy Loam (7)					
Sand (2)	1992	5	Solid set sprinkler	395	650
River Vista II					
Loam (8)					
Sand (16)					
Gravel (8)	1993	5	Solid set sprinkler	285	650
River Vista III					
Loam (9)					
Sandy Loam (25)					
Sand (17)	1994	5	Solid set sprinkler	390	740
Lohman					
Loam (6					
Sand (2)	1994	3	Flood	100	1000

Weed Control Strategy

Each planting unit was tilled just before planting to control germinating weed seedlings. Mowing of the aisles between rows and spraying glyphosate around the trees controlled weeds during the first growing season. During the second and third seasons, only mowing of the aisles between the trees rows was needed. Another very important reason to control weeds is to destroy vegetative cover for rodents. Pocket gophers and meadow voles can consume a large number of planted acorns and seedlings in a few months. Mowing several times during the growing season is sufficient to control voles.

Irrigation Strategy

During the first year, irrigation was applied to maintain a moist root zone from the soil surface down to the top of the ground water table (usually 3.6-6 m). The application schedule was about every 10 days to 2 weeks. During the second and third years, long-duration irrigations that moistened the deeper soil strata were employed to promote deep root growth. The time between irrigations was also increased to about once every 6 weeks in the second year, and only two times during the third year.

At several locations over the unit, commercially available gypsum blocks were placed at different depths to monitor the relative moisture status of the layers of soil and to track the downward movement of irrigation water through the soil.

Monitoring Methods

At the end of each growing season, usually in October, each revegetation unit was sampled at permanent 0.04-ha plots. Plots were established in a stratified random design covering between 5 and 10 percent of the total area of the unit. Saplings were counted and measured for height. Implementation success is reported as percent survival of the number of acorns planted, and height, in cm.

Results and Discussion

Survival

Variation in valley oak survival (*figure 1*) among the units reflects ecological differences among units, including patterns of soil texture, flooding regime, abundance of rodents, and weather patterns. For example, the Sam Slough Unit is composed of uniform soils (91 percent is silt-loam). It was planted with a very high density of acorns (1580 per ha), and nearly half failed to survive the first season. Nevertheless, after four growing seasons, there are more than 370 healthy saplings surviving per ha. Comparison of first-year survival at the three River Vista subunits shows a dramatic increase for River Vista III, apparently caused by the elimination of the rodent population by the floods of early 1995.

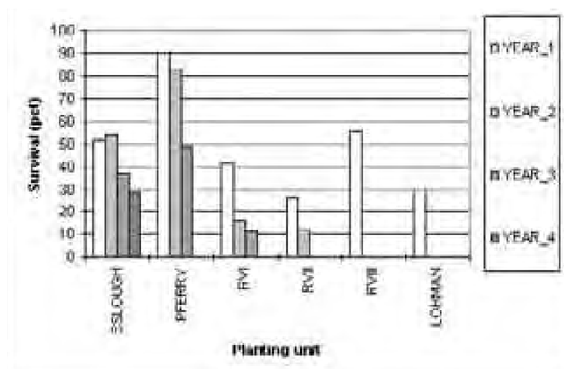

Figure 1—Percent survival of valley oak seedlings and saplings at six riparian forest restoration units. Planting units are: SSLOUGH = Sam Slough, PFERRY = Princeton Ferry, RVI = River Vista I, RVII = River Vista II, RVIII = River Vista III.

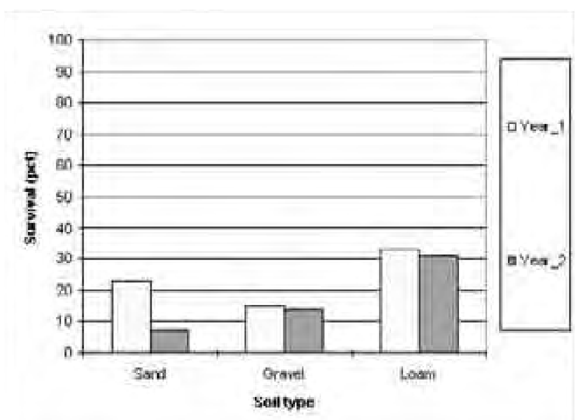

Figure 2—Percent survival of valley oak seedlings on three soil textures at River Vista II unit.

To further demonstrate ecological variability between, and within units, *figure 2* compares survival on different soil textures at the River Vista II unit during two seasons. The valley oaks planted into each soil texture class were all planted on the same day, at the same density, and were given identical irrigation and weed control management.

Growth

Variation in valley oak height growth among the units is a reflection of the variation in soil conditions. *Figure 3* compares age-specific height of oak seedlings. As with survival, there are differences in annual height growth among the units: The relatively finer soil texture at Sam Slough probably caused the superior height achieved by its saplings.

Figure 4 compares height growth in the first two seasons on three soil textures at the River Vista II unit. Coarse soil texture resulted in less growth compared to finer texture soil.

The message here is that one should have some idea of the variety and pattern of soil textures across a restoration unit before developing a planting design and expect differences in growth based upon differences in soil texture. Ecologically, this is a positive outcome. Spatial patchiness in height growth results in more structural diversity across the unit, which, in turn, will support a greater diversity of wildlife.

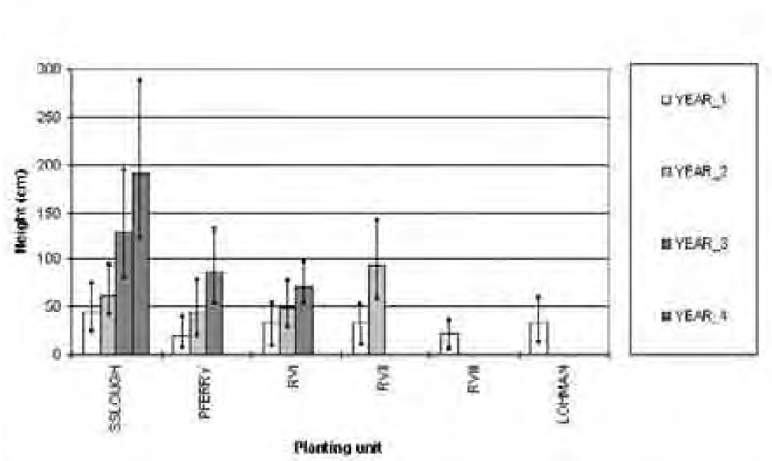

Figure 3—Mean and standard deviation for age-specific height of valley oak seedlings and saplings at six riparian forest restoration units. Planting units are: SSLOUGH = Sam Slough, PFERRY = Princeton Ferry, RVI = River Vista I, RVII = River Vista II, RVIII = River Vista III.

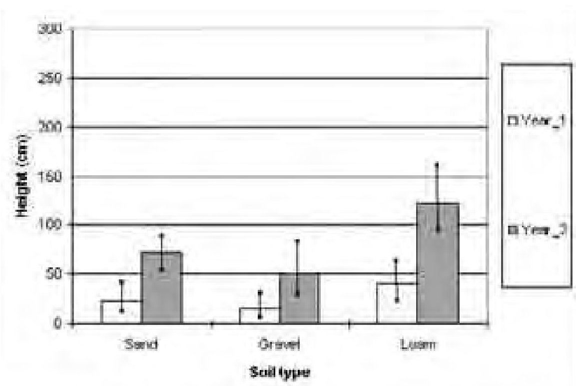

Figure 4—Mean and standard deviation of height of valley oak seedlings on three soil textures.

Plant Performance

Figure 5 shows the average end-of-season-height by age class across all units, soil textures, and planting dates. The resulting curve over 4 years gives us a "standardized growth curve" for valley oak on riparian restoration units along the Sacramento River. The standard growth curve can be used to predict valley oak seedling and sapling growth on future restoration units. Further refinement could include developing standard growth curves for plants growing on each soil texture class.

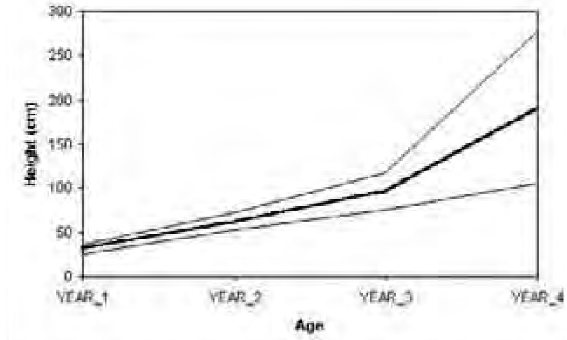

Figure 5—Standard growth curve: mean height (dark line) and standard deviation by age class across all six restoration units and soil textures.

We should remember that this growth curve reflects implementation success, not restoration success. Restoration implies much more —namely ecologically healthy natural processes (Jackson and others 1995). Ecological success is the primary goal of TNC's restoration projects. Ecological success may go beyond the boundaries of each unit and become evident when ecological processes have been restored and native plant communities and wildlife populations demonstrate improved vigor.

Implementation Costs

Each restoration unit represented a unique challenge for implementation because of the differences in soils, topography, characteristics of flooding (erosion and deposition), and existing road and irrigation system infrastructure. Implementation cost is influenced by many variables. Site preparation can be minimal if the unit has been farmed recently. If the unit has been abandoned for several years, or a flood event has rearranged the topography, then time and labor must be expended on removing flood-debris and weeds, and land-planing of the unit to allow access for equipment. Costs for planting and weed control are similar for all units. Irrigation costs, however, are highly variable among units and can amount to the single most expensive component of the implementation, up to 70 percent of total cost. For example, at Princeton Ferry we needed to drill a well, purchase a pump and pipes, and install a mainline and drip system.

Our current cost estimate for a new unit is less than $12,350 per ha, much less (by half) if an irrigation system is present. Also, ever larger units result in an economy of scale as fixed costs, such as planning, wells, equipment hauling, etc., are amortized over a larger area.

Recommendations

1. Plant large numbers of acorns per hectare (over-plant). Acorns are inexpensive compared to nursery stock, so the dollar cost to plant more acorns is trivial. With our methods, the cost of irrigation and weed control per hectare is essentially the same regardless of planting density. A high-density planting will develop habitat structure earlier — more stems per hectare — than a low-density planting because more individuals per hectare will survive. Thus, a high-density planting is not only cost effective, it is also ecologically effective. Stated differently, a higher-density planting will provide higher-quality "interim habitat" until the structure of the forest develops over future decades.
2. Weed control on these restoration units was minimal, by orchard standards, yet the best height growth occurred on the Sam Slough

unit where weed control was given the least amount of effort. The message here is to know the ecological impacts of the weeds on the unit: do they create dense shade or light? What season are they most competitive? What soil conditions does each species of weed indicate? Do they provide cover for rodents, or do they hide seedlings from deer?

3. Irrigation method is not as important as management of the irrigation. Manage the irrigation with the objective of maintaining soil moisture that is adequate for root growth in the deeper soil strata. This translates into low-frequency, long-duration irrigation events.

An alternative method for managing soil moisture that has been used successfully at the Parrott Ranch is to bank the soil moisture each spring by cultivating (disking) the unit before the spring weeds have fully developed. This method conserves soil moisture in the entire soil profile by sealing it under a "cultivated-soil mulch." This method has worked well on silt loam soils, allowing first-year valley oak seedlings to establish without applying any irrigation water.

Conclusion

These results show that (1) Over all the restoration units, a percentage of the oak seedlings survived and grew to saplings, demonstrating that the implementation of valley oak riparian forest restoration is feasible. (2) Growth and survival were better on fine-textured soils. This dictates the need for a comprehensive soil survey before planning a restoration project. (3) Simple methods of weed control and irrigation are cost-effective and result in adequate survival and growth of valley oak.

References

Griggs, Tom. 1990. **Valley oaks: can they be saved?** Fremontia 18(3): 48-51.

Holland, R.F. 1986. **Preliminary descriptions of the terrestrial natural communities of California**. Unpublished report. State of California, The Resources Agency, Dept. of Fish and Game, Heritage Division, Sacramento, Calif.

Jackson, L.L.; Lopoukhine, N.; Hillyard, D. 1995. **Ecological restoration: a definition and comments**. Restoration Ecology 3(2): 71-75.

Pavlik, B.; Muick, P.C.; Johnson, S.; Popper, M. 1991. **Oaks of California**. Los Olivos, CA: Cachuma Press; 184 p.

Reiner, R.; Griggs, T. 1989. **Nature Conservancy undertakes riparian restoration projects in California**. Restoration and Management Notes 7(1): 3-8.

Williams, D.F.; Kilburn, K.S. 1984. **Sensitive, threatened, and endangered mammals of riparian and other wetland communities in California**. In: Warner, R.E. and Hendrix, K.M., eds. California riparian systems: ecology, conservation, and productive management. Berkeley, CA: University of California Press; 950-956.

RANGE AND LIVESTOCK RELATIONS

III

Section Overview

Range and Livestock Relations[1]

William E. Frost[2]

Tracing the evolution of research on range and livestock relations on oak (*Quercus* spp.) woodlands from the inaugural oak symposium held in Claremont, California, in 1979 shows a trend that reflects the direction of rangeland research in general. The presentations at the 1979 symposium were fairly narrow and focused on livestock utilization of oak woodlands and the impact of overstory on forage production and quality. By the 1986 symposium in San Luis Obispo, California, the focus had been broadened somewhat. Presentations were made on the effects of overstory on forage production and quality, and on the impacts of vegetation conversion on beef production. Information on the relationship between blue oak age structure and livestock grazing history and the long-term changes in vegetation with and without grazing was also presented.

By the 1990 Davis, California, symposium, information was forthcoming on the impacts of livestock grazing on blue oak seedlings, both from artificial plantings and a study examining the effects of two different grazing seasons and combinations of grazing pressure. There was a continuation of work regarding the effect of oak canopy on forage production and quality.

In this Symposium, we saw a vast broadening of the areas of research in the category of range and livestock relations. Studies have been conducted examining the effect of livestock grazing on both development and viability of seedlings and saplings. Research has also expanded to look at watershed-level effects, with two ongoing studies examining grazing and water quality relationships. A corollary study showed the ability of a simple supplemental feeding strategy to reduce cattle use of riparian areas. There was also the first information correlating livestock grazing to wildlife activity—in this case, ground squirrels. Work on the relationship of overstory canopy cover to forage production continues.

What is interesting from this look back is what we have learned and what questions still are not being asked. We now know that the relationship of oak canopy cover to forage production is not a universal relationship. It is related to various attributes including annual precipitation, number and size of trees, tree species, and other factors. We have been able to draw some broad conclusions which can guide land managers. Research has shown the impact of grazing on seedling survival and identified multiple factors that also contribute to seedling failure. Long-term exclusion of livestock has not been shown to enhance natural regeneration in central California, but protection from livestock has been beneficial is some areas. At this Symposium information was presented that indicates that a successful regeneration strategy may be to protect individual trees from livestock while maintaining grazing in the area, thus reducing competition from the herbaceous plants.

Many questions still have not been asked or answered. It is generally acknowledged that large areas of functioning hardwood rangeland exist today because landowners can manage these lands for a profit through livestock production. This has kept areas intact, rather than becoming fragmented

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developments or ranchettes. If we accept that premise, renewed research efforts in more efficient, while still environmentally sound, livestock production may be needed.

There have also been no long-term investigations into grazing management strategies which may enhance oak recruitment, even though it is clear that livestock grazing will continue and that, at least in some areas, oak regeneration is a concern. We do know that livestock will consume some seedlings, results of their effect on saplings are mixed, and that oak regeneration is occurring on many grazed areas. How and why successful recruitment is occurring under grazing is not well understood.

Even with long-term investigation of the relationships between canopy cover, and forage production and quality, there is not much breadth to our current knowledge. For example, we do not know the successional relationships among canopy species, the mechanisms for canopy influence (although there has been much conjecture), nor the effects of grazing on understory vegetation.

Range and livestock-relations research is broadening its scope by looking at watershed- or ecosystem-level questions, while continuing to investigate site-specific relationships. By continuing to incorporate multiple perspectives and integrating future efforts in efficient resource management for livestock producers, this area of research can contribute significantly to the sustainability of viable hardwood rangeland throughout California.

Effects of Cultural Inputs on Survival and Growth of Direct Seeded and Naturally Occurring Valley Oak Seedlings on Hardwood Rangeland[1]

Elizabeth A. Bernhardt[2] Tedmund J. Swiecki[2]

Abstract: *In 1989, acorns were planted at three locations in northern California as part of a project to demonstrate methods for restocking valley oak on hardwood rangeland using site-specific cultural inputs. Inputs used included protective caging, cattle exclusion, mulching, tillage, and first-year irrigation. In 1995, survival ranged from more than 80 percent in the best treatment/site combination to zero in the worst, and maximum seedling height was 288 cm. Protection from cattle was essential for seedling growth and survival in grazed fields. Seedling survival and growth in caged sites was greater in grazed fields than in adjacent nongrazed fields. Landscape fabric and wood chip mulches applied at planting favored seedling growth and/or survival.*

Valley oak, *Quercus lobata* Nee, is frequently included in oak planting projects. This species is relatively easy to propagate, particularly with intensive cultural inputs during the establishment phase. However, intensive inputs may be prohibitively expensive for large-scale plantings intended to restock formerly wooded rangelands. Furthermore, intensive inputs may not be necessary to restock valley oaks in some areas. If large areas of valley oak woodlands are to be restored, land managers will need to identify the set of cultural inputs that will permit them to restock target areas at a minimum of cost.

In 1989, we reviewed the literature and evaluated previous plantings to identify factors that affect the establishment of valley oak seedlings (Swiecki and Bernhardt 1991). Using this information, we designed demonstration projects for three locations in northern California. For each project site, we determined what factors were most likely to limit seedling establishment and growth. We then selected restocking methods for each project which represented varying levels of cultural inputs, starting from the minimum deemed necessary to establish seedlings. The combinations of inputs tested in each planting differ because of the different conditions that existed at each location.

We previously reported on survival and growth at these projects 9 months (Bernhardt and Swiecki 1991) and 18 months after planting (Swiecki and Bernhardt 1991). In this paper, we report on results from these projects after 6 growing seasons. A fourth demonstration project site, at The Nature Conservancy's Cosumnes River Preserve, was included in the original study (Bernhardt and Swiecki 1991, Swiecki and Bernhardt 1991). We do not include follow-up data on the Cosumnes project in this paper, because it differs in many respects from the projects at the other three locations.

Methods

The demonstration plantings are at three sites: the California Academy of Science's Pepperwood Ranch Natural Preserve in the North Coast Ranges of Sonoma County; the Napa County Land Trust's Wantrup Wildlife Sanctuary in

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Pope Valley; and the City of Vacaville's Hidden Valley Open Space reserve in Solano County. All three locations have been used for livestock grazing for a number of years. Elevations of the three locations are 76 m for Vacaville, 200 m for Wantrup, and 305 m for Pepperwood. Historical average annual rainfall is 64 cm for Vacaville, 76 to 89 cm for Wantrup, and an estimated 102 cm for Pepperwood. A drought reduced rainfall during the first 2 years after planting by 30 to 50 percent, depending on the location. The areas selected for restocking were open, grassy fields that, historically, had supported valley oaks. All fields had at least some scattered valley oaks at their edges or nearby. There was no significant shrub cover within any of the fields. Harding grass (*Phalaris tuberosa* L. var. *stenoptera* [Hack.] Hitchc.) was prevalent at the Pepperwood and Wantrup sites. We have previously reported detailed descriptions of the study sites (Bernhardt and Swiecki 1991, Swiecki and Bernhardt 1991).

At all locations, volunteers planted locally collected acorns in late October or early November 1989. For most treatments, planting sites were prepared by using a shovel to turn over and break up the soil. At each site, four intact acorns were planted on their sides at a depth of about 5 cm, spaced 15 cm apart in a square pattern. At Wantrup, soil was not turned over before planting, and acorns were inserted into cracks in the soil opened up with a shovel.

In grazed fields, we used cages constructed of welded, 5- by 10-cm mesh galvanized 12-gauge wire fencing to protect seedlings from browsing by both cattle and deer (Vaca cages). Each Vaca cage was secured on one side by a steel T-post and on the opposite side by a 86-cm length of 9.5-mm diameter steel reinforcing bar (rebar), which was driven into the soil at least 30 cm. In nongrazed areas, we used cages constructed of lightweight 2.5-cm diameter wire mesh (poultry netting) to prevent deer browsing (deer cages). Deer cages were secured by a 150-cm length of rebar or a T-post on one side and a 60-cm length of rebar on the opposite side. Both Vaca and deer cages were 122 cm tall and about 45 cm in diameter.

We used 90-cm squares of nonwoven polypropylene landscape fabric (Typar®, Reemay, Inc.) as a mulch in some treatments. We cut two slits about 30 cm long in an "X" pattern in the center of each fabric square to permit emergence of oak seedlings and fastened the fabric to the ground with a 10-cm long steel staple in each corner. Because Typar® fabric breaks down when exposed to sunlight, we covered it with a 5- to 7-cm thick layer of waste wood chip mulch, following the manufacturer's recommendations. Other materials used for mulch included a 5- to 7-cm thick layer of waste wood chips and a 7- to 10-cm thick layer of old, moldy oat hay.

We collected data on seedling survival and height several times during the first two growing seasons and annually or less frequently between 1992 and 1995. Survival percentages we report are based on the total number of planting sites in which seedlings emerged during the first year. The overall percentage of sites with emerged seedlings was 81 percent at Pepperwood, 82 percent at Wantrup and 97 percent at Vacaville (Swiecki and Bernhardt 1991). Average heights reported are those of the tallest live seedling at each planting site, and height analyses exclude sites without live seedlings. We used contingency table analysis and logistic regression to analyze the effects of treatments on seedling survival, and analysis of variance to analyze the effects of treatments on seedling heights. Differences and effects reported as significant are significant at $P \leq 0.05$, unless otherwise noted.

Vacaville

The Vacaville project site is an urban open-space buffer between housing developments within the City of Vacaville and consists of two adjacent south-facing hillsides of about 2.8 ha each. Both hillsides are grazed by cattle at variable stocking rates that average about 2.5 animals/ha. Grazing periods have varied as follows:

	Grazing season	
Year	*West hill*	*East hill*
1990	April – mid-May	Late March – late-April
1991	May – mid-July	Mid-March – late-April
1992	December 1991 – late-June	December 1991 – late-June
1993	Mid-March – late-April	No grazing
1994	Early January – late-June	Early April – late-June
1995	December 1994 – late-July	December 1994 – late-June

We anticipated that damage by cattle, moisture stress due to weed competition, soil depth and compaction, and vandalism would be the most likely factors to limit restocking success at this site. To protect seedlings from cattle, we installed Vaca cages on all but a single treatment. We marked noncaged sites with metal tags pinned to the soil with 110-cm nails and used a metal detector and distance and azimuth readings from known reference points to relocate the sites.

We used landscape fabric mulch in two treatments, and the remaining treatments received a thin mulch of dry grass. For one treatment, we used a two-person power soil auger with a 10-cm diameter bit to loosen the soil to a depth of 45 to 60 cm. For two other treatments, we probed the soil at potential planting sites with a 6-mm diameter steel rod in an attempt to differentiate between shallow/compacted sites and deep/noncompacted sites. We combined these cultural inputs to construct the following five planting treatments and planted 30 planting sites per treatment on each hillside:

Treatment	*Cultural inputs*
V1	No cage, grass mulch, probe to depth of 45-60 cm
V2	Vaca cage, grass mulch, probe to depth of 45-60 cm
V3	Vaca cage, grass mulch, probe to depth of 30 cm
V4	Vaca cage, landscape fabric, wood chip mulch
V5	Vaca cage, landscape fabric, wood chip mulch, auger to depth of 45-60 cm

Pepperwood

The planting locations at Pepperwood are two adjacent hillside fields, one currently grazed by cattle and the other nongrazed. For the first several years after planting, cattle had access to the grazed field from late October to mid-May, and there was little residual herbaceous cover at the end of this period. Since 1992, the grazed field has been stocked at 2.5 animals/ha, and grazed for 1 to 3 weeks in late spring or early summer.

We anticipated that browsing by cattle and deer and water stress due to shallow soils and weed competition would be the major factors limiting restocking. We protected all sites with cages, using deer cages in the nongrazed field and Vaca cages in the grazed field.

To cope with the limitation of soil depth and make the best use of available soil moisture, we avoided areas with extremely shallow soil and concentrated our planting sites near seeps and seasonal creeks present in the fields. We planted 40 to 41 sites per treatment in the grazed field, and 24 to 33 sites per treatment in the nongrazed field. The treatments were:

Treatment	*Cultural inputs*
P1	No mulch (both fields)
P2	Wood chip mulch only (both fields)
P3	Landscape fabric mulch (both fields)
P4	Landscape fabric mulch, first summer irrigation (nongrazed field only)

Sites in the irrigated treatment received approximately 40 L of water per irrigation through 4-L/h drip emitters once a month, beginning 1 June 1990 and ending 1 September 1990.

Wantrup

The Wantrup Wildlife Sanctuary planting sites are located in three adjacent fields on the nearly level floor of Pope Valley. Field 1 is a 40.5-ha pasture that has been grazed for many years, and since 1989, it has been stocked with about 15 cow-calf pairs from December through June. There is little residual herbaceous cover after seasonal grazing, except for patches of yellow star thistle (*Centaurea solstitialis* L.). Field 2 is an area adjacent to a seasonal creek which was fenced to exclude cattle in about 1984. Field 3 had been grazed less heavily than field 1 for several years before planting, and grazing was discontinued after planting. Field 3 was tilled in summer 1995, and eight planting sites that had live seedlings in October 1994 were destroyed.

We expected that browsing by deer and/or cattle, moisture stress due to weed competition, damage by ground squirrels in the grazed field, and gophers in field 3 would limit restocking at this location. We used Vaca cages in the grazed field and deer cages in the remaining fields to protect seedlings from browsing. We avoided areas of high rodent activity for most plantings, but some planting sites in field 1 were intentionally located near an active ground squirrel colony for comparative purposes.

We tested several cultural inputs to reduce weed competition and conserve soil moisture. In each field, a strip about 4 m wide was tilled with a disc in September 1989 to remove weeds. We planted sites in both the tilled areas and in adjacent nontilled areas in each field. Every other site was mulched with hay at the time of planting.

In the nontilled portion of field 3, we also tested hay-mulched and nonmulched drip irrigation treatments. During 1990 only, irrigated sites received 20 L of water once weekly, starting 13 May and ending September 17.

We also tested herbicide application as a weed-control treatment in the nontilled portion of field 2. Glyphosate was applied at full label rate in a 150-cm radius around each planting site 1 month before planting and again about 1.5 months after planting. The post-planting application occurred several months before oak seedling emergence. No mulch was used in the herbicide treatment.

We used a 3 by 2 by 2 factorial design for the bulk of the planting: three fields with nontilled/tilled and nonmulched/mulched treatments in each. Irrigated (mulched and nonmulched) and herbicide treatments were treated as three separate treatments in addition to the 12 factorial treatment combinations. We planted 20 sites for each treatment.

At Wantrup, we also set up a separate study in field 1 involving existing natural valley oak seedlings and saplings, all of which were heavily browsed. Initial heights of these oaks ranged from 10 to 52 cm and averaged 35 cm. On 6 June 1989, we set up several types of protective cages around 22 juvenile oaks in the grazed portion of the field and four within a 0.5-ha barbed wire exclosure that excludes cattle but not deer. The cages were originally of varying heights, but all were eventually upgraded to a height of at least 120 cm. Using distance and azimuth measurements to known reference points, we charted the positions of 20 additional oaks in the grazed area and six in the exclosure. These noncaged oaks were located among and were similar in height and condition to the caged oaks. We measured the heights of the caged and noncaged oaks on 6 June 1989 and periodically thereafter.

Results

Seedling Survival

By July 1995, survival at Vacaville was significantly affected only by the use of Vaca cages (*fig. 1*). Survival of noncaged seedlings was significantly lower than that of caged seedlings. The largest single-year decline in survival of noncaged seedlings occurred between the 1991 and 1992 growing seasons. Noncaged sites had few live seedlings after the extended 1992 grazing season. However, some of the browsed-off seedlings resprouted and were observed in 1993, during which one field was grazed lightly and the other was not grazed. Mortality includes four caged sites that have been lost due to vandalism.

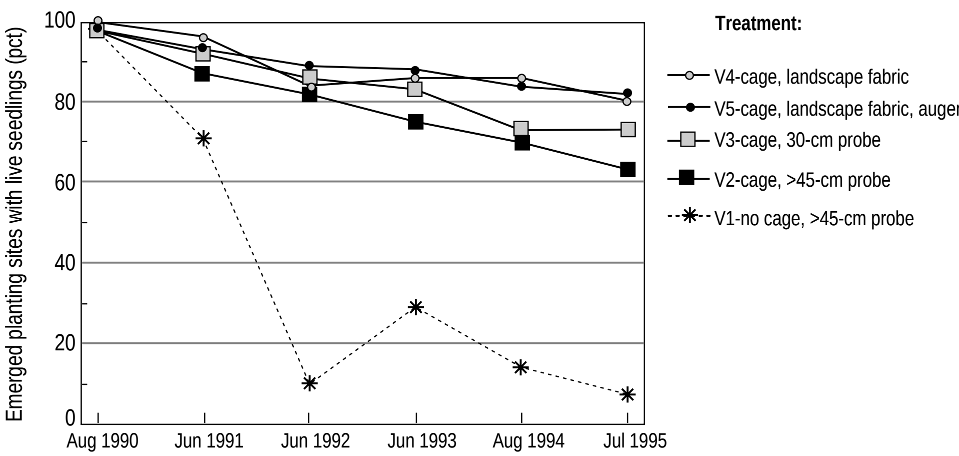

Figure 1—Survival by treatment of planting sites at Vacaville.

At Pepperwood, survival through 1995 (*fig. 2*) was significantly affected by both field and treatment, but the logistic regression analysis showed no significant interaction between these variables. Most treatments showed a sharp drop in survival between June 1991 and June 1992. In 1995, the overall survival rate of caged seedlings in the grazed field (70 percent) was significantly greater than in the nongrazed field (45 percent). Seedling damage attributed mainly to voles has been common in the nongrazed field, which is covered with a very dense and tall (100-180 cm) stand of Harding grass. In the grazed field, cattle have kept growth of Harding grass and other herbaceous weeds in check, and there has been little rodent damage.

Within each field, seedling survival was significantly greater in mulched treatments than in nonmulched treatments (*fig. 2*). First-year irrigation, tested only within the nongrazed field, did not affect seedling survival.

At Wantrup, survival differed significantly between fields (*fig. 3*), but was not affected by mulch, tillage, herbicide, or irrigation treatments. As at the other locations, the greatest increase in seedling mortality occurred between June 1991 and June 1992.

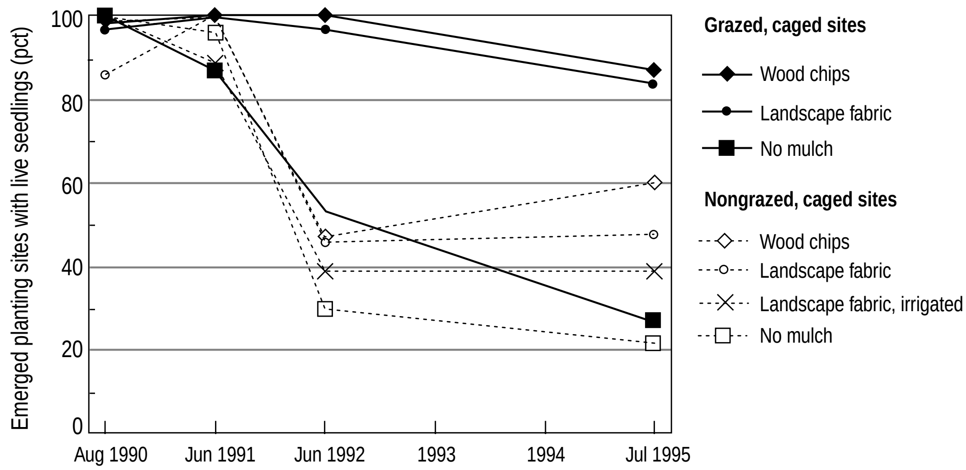

Figure 2—Survival by treatment and planting sites at Pepperwood.

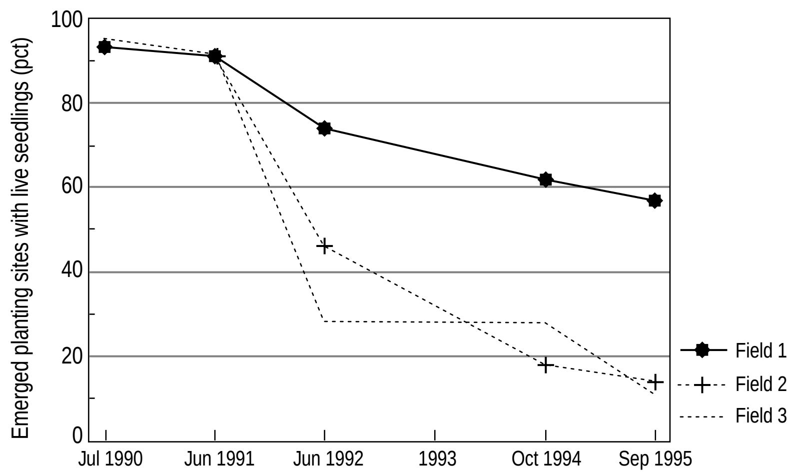

Figure 3—Survival by field of planting sites at Wantrup, where Field 1 = caged, grazed; Field 2 = caged, ungrazed; and Field 3 = caged, ungrazed.

Survival of seedlings in the caged sites in the grazed field (field 1) was greater than that in the nongrazed fields (*fig. 3*) as early as 1992, and this difference was highly significant in 1994 and 1995. By 1995, both nongrazed fields had dense stands of Harding grass, although the Harding grass density in field 3 had been much lower at the start of the project. Seedling damage attributed to voles was common in the nongrazed fields, but rare in the grazed field.

Within the grazed field, seedling survival was significantly lower among sites located within 10 to 15 m of an active ground squirrel colony than among sites located farther away from the colony. By September 1995, 31 percent of the sites near the ground squirrel colony had live seedlings, compared to 65 percent survival for sites away from the colony.

Seedling Growth

In the two-way analysis of variance of 1995 seedling heights for Vacaville, the effects of hillside and treatment were significant, but the interaction between these factors was nonsignificant. Seedlings on the east hillside were significantly taller than those on the west hillside (*fig. 4*). Much of this difference is due to rapid growth in planting sites on the east hillside which are located on an alluvial fan. Valley oaks located in this area were much taller than seedlings on other parts of the hillside and ranged up to 288 cm tall in 1995. In addition, some of the seedlings on the west hillside were defoliated by grasshoppers in mid- to late summer of 1994 and 1995, but such damage has not occurred on the east hillside.

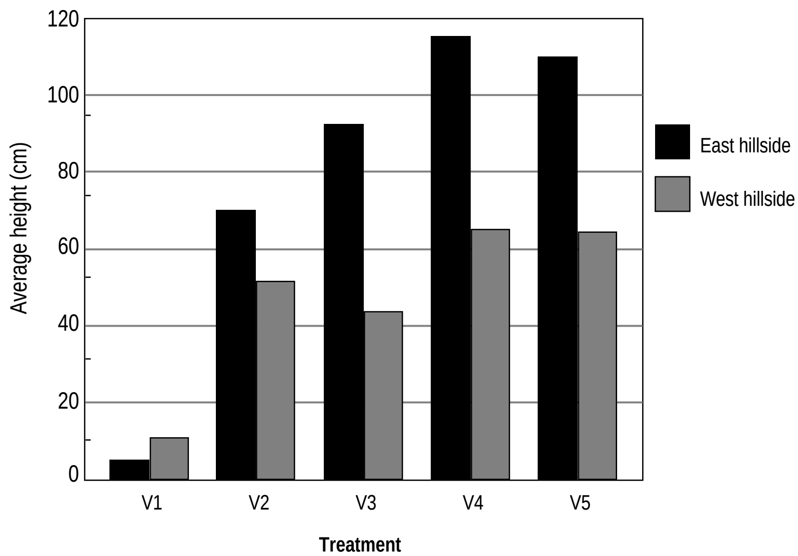

Figure 4—Average height of the tallest surviving seedling per site in July 1995 by treatment and hillside at Vacaville. See text for treatment descriptions.

The few surviving noncaged seedlings were significantly shorter than the seedlings in Vaca cages (*fig. 4*). The average seeding height in the caged sites has increased steadily, whereas the average height of the noncaged seedlings has fallen from 10 cm in 1990 to 6.5 cm in 1995. Based on orthogonal contrasts, seedlings in caged, mulched treatments (V4 and V5) were significantly taller than those in caged, nonmulched treatments (V2 and V3). All of these same factors and comparisons have been significant since the first height evaluation in August 1990.

Since the seedlings were not thinned after planting, surviving planting sites have one to four seedlings. Average seedling height in 1995 was somewhat greater in sites with more than one seedling than in sites with a single seedling. However, the effect of seedling count per site was not significant in the analysis of seedling heights.

At Pepperwood, the average height of caged seedlings was significantly greater in the grazed field (76 cm) than in the nongrazed field (54 cm) in August 1995. This was true whether or not the irrigated treatment (P4), which was present only in the nongrazed field, was included in the two-way analysis of variance by treatment and field. The effect of treatment was not significant in either the two-way analysis or in one-way analysis of variance tests for each field. The lack of significance is due in part to the low numbers of surviving seedlings in several treatments.

At Wantrup, only the effect of field was significant in a three-way analysis of variance comparing the effects of fields, tillage, and mulch on 1994 and 1995 seedling heights. We omitted irrigated and herbicide treatments from these three-way analyses. Surviving seedlings in the grazed field were significantly taller than those in the nongrazed fields:

	Average height of tallest seedlings per site (cm)[1]
Field 1 (grazed)	85 a[2]
Field 2 (nongrazed)	39 b
Field 3 (nongrazed)	31 b

[1]All planting sites protected from deer or cattle by cages.

[2]Means followed by the same letter are not significantly different at $P < 0.05$.

We also examined the effects of the herbicide and irrigation treatments on seedling height using one-way analysis of variance tests on data from individual fields. None of the within-field analyses showed any significant effects of treatment on seedling height. However, the number of surviving seedlings in most of these treatments was very small, so the power of these tests to detect differences was low.

Protected Natural Juvenile Oaks (Wantrup)

Three natural juvenile oaks in this study died; all of these were noncaged. One noncaged oak within the cattle exclosure died, apparently because of girdling by gophers. Two of the 20 noncaged juvenile oaks in the grazed area died over the study period, apparently because of browsing and trampling by cattle.

The average growth of caged and noncaged natural juvenile oaks between June 1989 and September 1995 is shown below:

	Average increase in height (cm)	
	Caged seedlings	*Noncaged seedlings*
Cattle-grazed area	112	0
Cattle exclosure	74	71

Within the grazed field, caged juvenile oaks grew significantly more than noncaged controls. All caged oaks within the grazed area gained height, with increases ranging from 22 to 272 cm. In contrast, seven of the 18 surviving noncaged oaks in the grazed area were shorter in 1995 than they were in 1989, and none of these oaks grew more than 24 cm. Within the cattle exclosure, growth of caged and noncaged juvenile oaks did not differ significantly, even though this exclosure is frequented by deer.

Cage Performance

Vaca cages used at each of the sites have required periodic maintenance, because some of the cages are seriously bent or dislodged by cattle each year. In areas that receive especially heavy use by cattle, we have had to reinforce the cages by adding an additional T-post and/or longer rebar stakes. At Vacaville, several cages are typically removed by vandals each year, but are usually relocated and replaced. Deer cages were effective at Wantrup and Pepperwood and did not require any maintenance.

Discussion

The demonstration projects clearly show that in rangeland seasonally stocked with moderate cattle densities, planting sites must be protected from cattle browsing and trampling in order to successfully restock valley oak. Although first-year emergence did not differ significantly among treatments at Vacaville (Bernhardt and Swiecki 1991), after 6 years, survival and growth is practically nil in the planting sites left unprotected from cattle. Over seven growing seasons at Wantrup, established natural seedlings and saplings grew substantially only if they were protected from cattle. Half of the cattle-exposed oaks in the natural juvenile oak study either lost height or died over this interval.

In grazed areas where sufficient numbers of existing seedlings or saplings can be located, protective caging may be the only input required for restocking. On the basis of the strong results of the demonstration projects, land managers at both Pepperwood and Wantrup have begun to protect individual natural seedlings from browsing to help restock degraded stands. The Vaca cage (Swiecki and Bernhardt 1991) has been fairly successful as a cattle-excluding structure. Vaca cages currently require about $8.00 to $10.00 worth of materials (if purchased new) and are fairly easy to construct, but do require periodic inspection and maintenance. Caging individual seedlings or planting sites is therefore somewhat intensive in terms of materials and labor, but this input is critical for restocking valley oak in cattle-grazed fields.

Cattle can inhibit natural or artificial regeneration by damaging or killing oak seedlings and saplings. However, by controlling the growth of herbaceous vegetation, grazing can indirectly favor growth and survival of caged oak seedlings. At Pepperwood and Wantrup, where all planting sites were individually protected from browsing, survival and growth of seedlings were significantly greater in grazed fields than in adjacent nongrazed fields. At both of these locations, the nongrazed fields are densely populated with Harding grass, which competes with oak seedlings for soil moisture. Various researchers have shown that competing herbaceous vegetation can reduce survival and growth of oak seedlings (Adams and others 1991, Griffin 1971, Knudsen 1987).

Furthermore, the dense Harding grass in the nongrazed fields at Pepperwood and Wantrup also provides habitat for voles and other rodents. Repeated clipping of seedling shoots and leaves by voles (Tecklin 1995), and possibly other small rodents, has apparently contributed to seedling mortality in the nongrazed fields. Moisture stress due to Harding grass competition may further exacerbate damage caused by voles or other agents. Slow-growing, water-stressed seedlings remain susceptible to small herbivores for an extended period and have smaller carbohydrate reserves to draw upon for recovery after being damaged.

Mulch applied at planting is a relatively inexpensive, one-time input that can suppress weed growth and conserve soil moisture around planting sites. At Vacaville and Pepperwood, landscape fabric and/or wood chip mulches were beneficial in promoting seedling growth and survival (*figs. 1, 2,* and *4*). The moldy hay mulch used at Wantrup did not provide any growth or survival benefit and was somewhat inhibitory to seedling emergence (Swiecki and Bernhardt 1991). The hay mulch was originally quite compacted and did not break down well because of low rainfall in the first winter. Within the nongrazed fields, the hay was also used by voles for nesting. Therefore, while mulch can be a beneficial input, improper materials or poor application may negate any potential benefits.

By 6 years after planting, none of the other cultural inputs we used at planting significantly affected either survival or growth, although they did entail additional cost and effort. Irrigation during the first summer, which was an expensive input, did not significantly increase survival or growth of seedlings growing in nongrazed fields at Pepperwood and Wantrup. Based on field observations, these seedlings generally sustained greater damage from small herbivores than did nonirrigated seedlings. Damaging animals may be attracted to irrigated sites by the moist soil or increased succulence of oak tissues.

As expected, seedlings close to the ground squirrel colony at Wantrup had much lower survival rates than seedlings farther from the colony, but gophers have not caused substantial amounts of mortality to date. Our strategy of locating planting sites away from active rodent burrows has been successful in minimizing damage caused by gophers and ground squirrels. This simple step may be sufficient to eliminate the need for more expensive inputs, such as additional caging or shelters, if gopher and ground squirrel populations are not excessive.

At all locations, treatments with less than 60 percent survival by 1995 showed the largest drop in survival between the 1991 and 1992 growing seasons, or 2 years after planting (figs. 1-3). This may represent the point at which carbohydrate reserves derived from the acorn are exhausted in seedlings that die back to the ground early during the first two growing seasons. We previously reported that natural blue oak seedlings that died back to the ground in 2 successive years had higher mortality rates than seedlings that maintained above-ground shoots in one or both years (Swiecki and others 1990).

Although some of the trees in the Vacaville planting have grown well above browse line in 6 years, it will clearly be many years before most of the valley oaks in the demonstration projects are recruited to the tree stage. Overall growth rates for the plantings are fairly low, averaging between about 5 and 15 cm/year for caged seedlings. Even though the plantings were established during a prolonged drought, such low growth rates are probably not atypical for nonirrigated plantings growing under rangeland conditions.

Although some of the trends we observed in the first two growing seasons have persisted into the 6th season, other trends have changed substantially. For example, although the difference in growth between grazed and nongrazed fields was noticeable at Pepperwood the first year after planting, at Wantrup, seedlings in the grazed field were initially shorter than those in field 3 (Swiecki and Bernhardt 1991). The difference in survival now evident between grazed and nongrazed fields at Wantrup and Pepperwood did not develop within the first two seasons. Long-term monitoring of oak planting projects is necessary to determine which cultural inputs are the most worthwhile.

Acknowledgments

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References

Adams, Theodore E., Jr.; Sands, Peter B.; Weitkamp, William H.; McDougald, Neil K. 1991. **Blue and valley oak seedling establishment on California's hardwood rangelands**. In: Standiford, Richard B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 41-47.

Bernhardt, Elizabeth A.; Swiecki, Tedmund J. 1991. **Minimum input techniques for valley oak restocking**. In: Standiford, Richard B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 2-8.

Griffin, James R. 1971. **Oak regeneration in the upper Carmel Valley, California**. Ecology 52: 862-868.

Knudsen, Monty D. 1987. **Life history aspects of *Quercus lobata* in a riparian community, Sacramento Valley, California**. In: Plumb, Timothy R.; Pillsbury, Norman H. , tech. coords. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 38-46.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A. 1991. **Minimum input techniques for restoring valley oaks on hardwood rangeland**. Sacramento, CA: Forest and Rangeland Resources Assessment Program, California Department of Forestry and Fire Protection; 79 p.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1990. **Impacts of diseases and arthropods on California's rangeland oaks**. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA. 94 p. plus appendix.

Tecklin, Jerry. 1995. **Oaks 'n' voles**. Oaks 'n' Folks 10 (1):2. Newsletter of the Integrated Hardwood Range Management Program, Department of Environmental Science, Policy, and Management, University of California, Berkeley, CA.

Effects of Livestock Grazing on Blue Oak Saplings[1]

Henricus C. Jansen[2] Richard R. Snow[2] Gregory A. Treber[2] Fremont L. Bell[3]

Abstract: *Effects of two systems of livestock grazing and no grazing on the growth of blue oak (*Quercus douglasii *H. & A.) saplings were examined over a 4-year period in western Colusa County, California. In grazed plots, base and height growth and moisture stress of saplings were less, while soil bulk density was mostly higher. Residual dry matter increased in non-grazed plots but not in grazed plots. Effects of the two grazing systems on sapling and plot variables did not differ significantly except for browse utilization which was significantly higher under high-intensity, short-duration grazing than under traditional, moderate grazing in 3 out of 4 years.*

The dynamics and management of California's hardwood rangelands, and in particular of the blue oak (*Quercus douglasii* H. & A.) dominated foothill woodlands, are of considerable interest to researchers, private landowners, and public resource management agencies (Muick and Bartolome 1986). Several studies have reported on the poor regeneration and recruitment of blue oak in various parts of its natural range (Bolsinger 1988, Mayer and others 1986, Mensing 1992, Muick and Bartolome 1986).

Predation on acorns and seedlings by wildlife and livestock, altered fire frequency and intensity, and altered competitive relationships with herbaceous vegetation have been suggested as possible causes of poor regeneration and recruitment in oaks. Hall and others (1992) reported on the effects of cattle grazing on 1-year-old blue oak seedlings. They found that spring and summer grazing resulted in the most seedling damage and lowest seedling survival. They also found that seedling damage (but not survival) increased with livestock density for both spring and summer grazing.

In this study the effects of two systems of livestock grazing and no livestock grazing on the growth of well-established blue oak saplings were examined over a 4-year period.

Study Area

The study was conducted on Walnut Valley Ranch, located in western Colusa County near Lodoga, California, in the foothills of the northern Coast Range (Lat. 39° 17'N, Long. 122° 28'W). The study area supports a mosaic of blue oak woodland and chamise chaparral and occurs at elevations from 400 to 540 m. It receives an average of 50 cm of annual rainfall between mid-October and late April. Preliminary soil survey data (Southard 1993) classify the soils as Contra Costa loamy clay (clayey-skeletal, mixed, thermic Typic Palexeralf). Aspect is easterly (65°), slopes range from 15 to 20 percent, and elevation is 475 m.

Ownership of the land has changed several times over the past hundred years, but land use at the study site has always been livestock grazing. In the late 1950's or early 1960's, when blue oak removal in California was widespread and recommended to increase grazing, the trees on the site were chained and burned (Bell 1984) and the area seeded with Harding grass (*Phalaris aquatica* L.). Under current ownership, grazing is light to moderate and occurs from late winter through late spring.

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Methods

In spring 1991, nine rectangular 0.1-ha plots were established at the study site. Three treatments (no grazing; traditional moderate grazing; and high-intensity, short-duration grazing) were randomly assigned to these plots (*table 1*). The non-grazed control plots were fenced to exclude livestock, while the high-intensity, short-duration grazed plots were fenced to include and confine livestock for a single, 10-hour grazing period each year. All plots were accessible to deer (*Odocoileus hemionus columbianus*). Treatment replication was limited because of the relatively small size of the area containing an adequate number of blue oak saplings.

Table 1—Grazing treatments during the 4-year study.

Year	Grazing period	Days of grazing	Cow-calf pairs	Stocking rate (AUD[1] ha^{-1})	
				T.M.[2]	H.I.S.D.[3]
1991	3 - 13 May	9.7	33	18	220
1992	16 May -9 June	22.8	32	46	182
1993	19 Mar - 3 Apr	14.2	31	27	177
1994	16 Mar -1 Apr	16	35	34	—
	21 Apr - 7 May	15.8	37	34	87

[1]Animal unit days
[2]Traditional, moderate grazing
[3]High-intensity, short-duration grazing

Blue oak saplings in the plots were mapped and measured for height and basal diameter. In each plot, eight saplings measuring between 45 and 175 cm in height were randomly selected from those present for detailed study of treatment effects. On each of these selected saplings, three branches on the outside perimeter within reach of livestock were randomly selected and tagged in order to measure browse utilization and branch diameter growth. While we took measurements on the same saplings throughout the study period, we could not always use the same tagged branches. Some branches died, some grew unevenly in diameter, and others produced too many or too few leaves and twigs for reliable estimation of browse utilization. In addition, some tagged branches were broken off by livestock as was clearly evident from hair and rubbing marks.

Sapling basal diameter was measured within 10 cm of the soil surface and the exact location of measurement recorded and later marked with a semi-permanent pin. Sapling height represents total height from soil surface to highest living branch or bud. It was measured within 50 cm of, and level with, the sapling base. This location was recorded and later marked with a semi-permanent spike. A caliper and a surveying rod were used for diameter and height measurements, respectively.

Browse utilization by deer and livestock on the tagged branches was measured twice a year: in mid-March just before bud break and livestock grazing began in the pasture (except in the first year of the study when it was measured in mid-April) and again shortly after livestock removal from the pasture, which varied from mid-April to mid-June. Browse utilization was measured by counting all grazed twigs and the total number of twigs on tagged branches and expressing the ratio as a percentage. Twigs were considered grazed if leaves and/or stem were partially or completely removed. Twigs less than 2.5 cm in length were considered to be spurs and were not used in the utilization counts.

As noted, sapling branch diameter, basal diameter, and height were measured at the beginning of the study and in November of each year to determine annual growth in diameter and height.

Sapling moisture stress was determined with a portable pressure chamber (Cleary and Zaerr 1984). Measurements were taken between the hours of 10 p.m. and 5 a.m., and used leafy twigs produced during the current season. Sampling occurred in late-June and mid-August each year.

Three soil bulk density determinations were made in each of the nine plots, using the compliant cavity method (Grossman 1983). Soil cavities measured 12.5 cm in diameter and 7.5 cm in depth. Plot sampling was restricted in its randomness, so that each sample contained an observation from the lower, middle, and upper portions of the plot. Samples were collected in late June every year.

In mid- to late October, a sample of six observations on residual dry matter was taken in each of the nine plots by clipping and removing all above-ground dry matter from 1-ft^2 circular quadrats. Sampling for residual dry matter was also restricted in its randomness so that each sample contained two observations from the lower, middle, and upper portions of the plot.

The 24.5-ha pasture containing the study plots was grazed every year with cow-calf pairs with an average weight of 727 kg. While in the pasture, the livestock grazed the unfenced plots (traditional, moderate grazing) and were rotated through the fenced plots for high-intensity, short-duration grazing (*table 1*).

Livestock spent approximately 10 hours in each of the high-intensity, short-duration grazed plots. During the last year of the study, animal stress, possibly brought on by consumption of goldenbush (*Haplopappus* sp.) and aggravated by confinement and lack of water in the fenced plots, led us to reduce both animal density and amount of time spent in these plots.

Treatment effects on blue oak saplings and plot variables were analyzed for each year of the study with a completely randomized design using analysis of variance. Cumulative treatment effects on sapling dimensions and growth were also analyzed with this design as well as with a completely randomized design with a split. The split treatment is initial sapling height. Oak saplings taller and shorter than 122 cm are the two levels of this treatment. Means were compared with the Duncan Multiple Range (DMR) test where significant treatment effects were detected.

Results

The 1991 Grazing Season

Grazing treatments were applied during the first 2 weeks of May (*table 1*). Mean browse utilization levels and mean branch diameter growth differed significantly at $P < 0.001$ and $P < 0.05$. Other sapling and plot characteristics did not differ significantly (*table 2*).

At the time of grazing, all oak saplings had completed leaf and twig growth. In June, more than 90 percent of the saplings in the high-intensity, short-duration grazed plots had resprouted compared to approximately 50 percent in the traditional, moderately grazed plots. Only about 5 percent of the saplings in the non-grazed plots resprouted.

The 1992 Grazing Season

Grazing occurred during the last 2 weeks of May and the first week of June (*table 1*). The longer and later grazing season resulted in mean browse utilization levels of 72.6 percent in the traditional, moderately grazed plots and 91.9 percent in the

Table 2—Annual browse utilization, growth, and moisture stress for blue oak saplings; and soil bulk density (B.D.) and residual dry matter (R.D.M.) in plots receiving three grazing treatments over 4 years.

Treatment	Browse util'n	Sapling growth Branch	Sapling growth Base	Sapling growth Height	Moisture stress Spring	Moisture stress Summer	Soil B.D.	R.D.M.
	pct	*mm*	*mm*	*cm*	*bars*	*bars*	*g cm*$^{-3}$	*g ft*$^{-2}$
				1991				
No grazing	0.5c	1.3a	2.9	7.8	11.4	29.0	1.35	25.2
T.M.[1]	28.2b	0.8b	1.5	6.4	10.1	26.8	1.42	22.2
H.I.S.D.[2]	78.8a	1.4a	1.9	3.2	9.0	23.0	1.46	26.3
CV[3] (pct)	18.1	11.8	53.1	49.3	15.7	17.1	7.9	19.1
DMR[4] test(*P*)	0.001	0.05	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
				1992				
No grazing	0.9c	1.5	1.5	8.1ab	18.1	40.8	1.21	34.6a
T.M.	72.6b	1.3	0.9	4.4b	17.4	35.7	1.23	32.7a
H.I.S.D.	91.9a	1.4	1.5	8.7a	17.0	35.1	1.25	26.6b
CV (pct)	6.0	18.7	50.4	27.1	13.8	10.0	4.3	8.7
DMR test (*P*)	0.001	N.S.	N.S.	0.05	N.S.	N.S.	N.S.	0.05
				1993				
No grazing	0.7	1.5	3.6a	9.0a	13.7	16.9	1.36	36.0a
T.M.	21.6	1.3	2.6b	2.2b	14.8	20.7	1.31	22.4b
H.I.S.D.	44.0	1.5	2.7b	5.0ab	12.8	16.4	1.42	22.3b
CV (pct)	115.9	23.7	17.0	68.7	10.0	18.0	11.7	16.2
DMR test (*P*)	N.S.	N.S.	0.10	0.10	N.S.	N.S.	N.S.	0.01
				1994				
No grazing	2.5b	0.8	2.3	7.4	24.0a	48.2a	1.25b	43.0a
T.M.	61.4a	0.7	1.5	4.4	21.6ab	47.2ab	1.48a	19.1b
H.I.S.D.	74.2a	0.6	1.6	4.8	15.8b	45.0b	1.37ab	20.6b
CV (pct)	25.4	34.7	33.0	58.7	14.8	3.5	7.5	16.6
DMR test (*P*)	0.001	N.S.	N.S.	N.S.	0.05	0.10	0.05	0.01

[1]Traditional, moderate grazing
[2]High-intensity, short-duration grazing
[3]Coefficient of variation
[4]Duncan Multiple Range: Means in the same column followed by the same letter are not significantly (N.S.) different at the indicated level of probability.

high-intensity, short-duration grazed plots. Mean browse utilization levels differed significantly among all treatments at the $P < 0.001$ level. Mean sapling height growth and mean residual dry matter levels differed significantly among grazed treatments at the $P < 0.05$ level. Other sapling and plot variables showed no significant differences among treatments (*table 2*).

Resprouting following livestock grazing occurred on 70 percent of the saplings in the high-intensity, short-duration grazed plots, on 40 percent of the saplings in the traditional, moderately grazed plots, and on less than 5 percent of the saplings in the non-grazed plots. As was the case in 1991, summer (mid-August) moisture stress levels in the oak saplings in the grazed plots were considerably lower than in the saplings in the ungrazed plots; however, these differences were not significant.

The 1993 Grazing Season

Grazing occurred during the second half of March and first few days of April (*table 1*) and, thus, much earlier in the season than during the previous 2 years. Although mean browse utilization levels of the saplings differed considerably among treatments, these differences were not significant. In grazed versus non-grazed plots, mean growth in basal diameter and height differed significantly ($P < 0.10$), as did the mean residual dry matter levels ($P < 0.01$). Other sapling and plot variables showed no significant treatment effects (*table 2*).

The stocking rate in the high-intensity, short-duration grazed plots was about the same as in 1992; however, browse utilization was only half as much. Stocking rate in the traditional, moderately grazed plots was intermediate between 1991 and 1992 levels, but browse utilization was lower. Browse utilization was highly variable in all grazed plots and resulted in a coefficient of variation (CV) with the unusually high value of 115.9 percent.

The low and highly variable browse utilization levels in 1993 may be related to the early grazing period. Saplings were still in the early stages of leafing out, while forage plants were green and highly palatable.

The 1994 Grazing Season

There were two grazing periods of about equal length in 1994 (*table 1*). During the first grazing period, the saplings were still in bud, and no browsing by livestock was observed. During the second grazing period the saplings were fully leafed out and were browsed.

Grazing treatments resulted in significantly different browse utilization levels ($P < 0.001$) between grazed and nongrazed plots but not between the traditional, moderate and high-intensity, short-duration grazed plots. Mean growth in branch and basal diameter, and height of saplings did not differ significantly among treatments. Both spring (end-June) and summer (mid-August) moisture stress levels in saplings differed significantly at the $P < 0.05$ and $P < 0.10$ levels, respectively. Mean soil bulk density (B.D.) and residual dry matter (R.D.M.) of plots also differed significantly at $P < 0.05$ and $P < 0.01$ levels, respectively. As was the case in 1993, all significant treatment differences were between grazed and non-grazed plots (*table 2*).

Cumulative Treatment Effects over Study Period

Initial and final dimensions, and total growth in mean basal diameter and height of short (initial height less than 4 feet), tall (initial height more than 4 feet), and combined (short and tall) saplings are shown in *table 3*. Total diameter growth of the short and tall saplings differed significantly ($P < 0.10$) in the nongrazed plots, while total height growth of short and tall saplings differed significantly ($P < 0.10$) in the high-intensity, short-duration grazed plots. Differences among short and tall saplings in other plots were not significant.

Table 3—Blue oak sapling dimensions and growth under three grazing treatments and for two sapling height classes from April 1991 to November 1994.

Treatment	Height class[1]	Initial dimensions Base	Initial dimensions Height	Final dimensions Base	Final dimensions Height	Total growth Base	Total growth Height
		mm	*cm*	*mm*	*cm*	*mm*	*cm*
No grazing	1	31.2ab	87.8b	40.3bc	119.7b	9.1b	31.8ab
	2	39.1a	139.8a	51.9a	170.1a	12.8a	30.3ab
	combined	35.1	108.7	45.3	139.2	10.2	30.5
T.M.[2]	1	25.3b	76.0b	31.8c	97.7b	6.5bc	16.6ab
	2	41.4a	143.0a	47.2ab	167.2a	5.8c	24.2ab
	combined	27.4	84.4	33.8	102.0	6.4	17.6
H.I.S.D.[3]	1	30.3ab	90.7b	37.7bc	103.9b	7.5bc	13.2b
	2	37.2a	137.4a	45.4ab	172.4a	8.2bc	35.0a
	combined	33.3	105.2	40.9	128.1	7.7	22.9
CV[4] (pct)		15.5	10.5	12.7	8.0	22.1	48.8
DMR[5] test (*P*)		0.05	0.01	0.05	0.01	0.10	0.10

[1]Class 1 = shorter than 122 cm; class 2 = taller than 122 cm
[2]Traditional, moderate grazing
[3]High-intensity, short-duration grazing
[4]Coefficient of variation
[5]Duncan Multiple Range: Means in the same column followed by the same letter are not significantly different at the indicated level of probability.

When short and tall saplings in plots were considered as a single response group, combined saplings in traditional, moderately grazed plots increased less in basal diameter and height than saplings in non-grazed plots (differences in growth were significant at $P < 0.05$ and $P < 0.10$, respectively, but could not be shown in *table 3*). However, because the initial dimensions of the saplings in the traditional, moderately grazed plots are considerably less than those of saplings in the other plots, it is entirely possible that the effect of the grazing treatment on growth is confounded with the possible effect of initial sapling size on growth.

Discussion

When livestock grazing occurred during a single, early grazing period (second half of March 1993) and saplings were in the early stages of leafing out while forage plants were green and succulent, browse utilization levels were highly variable (CV = 115.9 percent) and low (21.6 and 44 percent, respectively) under regimes of traditional, moderate grazing (27 animal unit days (AUD) ha^{-1}) and high-intensity, short-duration grazing (177 AUD ha^{-1}) (*tables 1* and *2*).

When livestock grazing occurred late (May and early June 1992), after saplings had completed shoot growth and when forage plants were dry or drying, browse utilization levels were very uniform (CV = 6 percent) and high (72.6 and 91.9 percent, respectively) under regimes of traditional, moderate grazing (46 AUD ha^{-1}) and high-intensity, short-duration grazing (182 AUD ha^{-1}). It is probable that the high variability and rather low levels of browsing during early grazing are the result of low livestock preference for oak browse at this time. The reverse situation may also be true.

Small branch diameter growth was generally unaffected by timing or intensity of livestock grazing, while basal diameter growth was mostly too variable to allow for detection of possible treatment effect. Total cumulative diameter growth of saplings was less in grazed than in nongrazed plots, but these differences are significant only when comparisons were made with the saplings in the traditional, moderately grazed plots. Differences in initial sapling dimensions are also possible causal factors (*table 3*).

The variability in annual height growth of saplings was even greater than the variability in annual diameter growth (*table 2*). This higher variability may be partly due to different initial sapling heights, and partly to different degrees of height reduction by grazing. Differences in annual height growth between no grazing and traditional, moderate grazing were significant in 2 out of 4 years. Total cumulative sapling height growth in traditional, moderately grazed plots was 43 percent less than in nongrazed plots. The effect of high-intensity, short-duration grazing on sapling height growth was difficult to determine. Annual height growth of saplings under this grazing treatment was usually greater than for saplings with moderate, traditional grazing, and less than for saplings with no grazing. Total cumulative height growth of saplings in high-intensity, short-duration grazed plots was 25 percent less than in non-grazed plots. To understand why the saplings with the high-intensity, short-duration grazing did at least as well as those with the traditional, moderate grazing treatment, grazing effects on short and tall saplings were analyzed separately (*table 3*). Short saplings grew somewhat less than tall saplings in traditional, moderately grazed plots, and significantly less ($P < 0.10$) in the high-intensity, short-duration grazed plots. Short and tall saplings in the non-grazed plots grew by approximately the same amount. Variability in height growth among plots with the same treatment was highest for the two grazing treatments and lowest for the nongrazing treatment. In 3 out of 4 years, two plots with high-intensity, short-duration grazing contained the sapling with the most height growth observed for all plots.

Sapling moisture stress was usually less (but not significantly so) in grazed than in nongrazed plots, and was lowest for the plots with high-intensity, short-duration grazing. An exception occurred in 1993 when grazing was early and browse utilization in the traditional, moderately grazed plots was light (*table 2*). Significant differences in sapling moisture stress occurred only once (1994), and then between nongrazed and high-intensity, short-duration grazed plots. Grazing during the growing season decreases leaf surface areas of grasses which in turn decreases the depletion rate of soil water (Miller and others 1990). It is not clear from this study whether the browsing of the saplings or the grazing of the forage plants contributed more to the lowering of moisture stress in the oak saplings.

Differences in soil bulk density among treatments were not significant in 3 out of the 4 years of the study. Soil bulk density was mostly higher in grazed than in nongrazed plots, except in 1993 when it was lowest in the traditional, moderately grazed plots. The following year it was highest in these plots (*table 2*). This rather large, year-to-year variation in soil bulk density may have been due to the small sample size for soil cores (three cores per plot) and the abundance of gopher mounts.

Residual dry matter increased gradually and consistently in the nongrazed plots, whereas it changed little in the grazed plots over the course of the study. As a result, the residual dry matter in the nongrazed plots was more than double that of the grazed plots by the fourth and final year of the study. In 3 out of 4 years, residual dry matter in the traditional, moderate and high-intensity, short-duration grazed plots did not differ significantly (*table 2*). Thus, the high stocking rates of high-intensity, short-duration grazing did not result in lower levels of residual dry matter. There are two possible reasons for this: (1) the livestock did not graze much during their 10-hour confinement to the plots; (2) the observations on residual dry matter consisted of plants and animal excretions, and an abundance of the latter material made up for a scarcity of the former.

Conclusions

Timing of spring grazing (March versus May and June) had a major effect on browse utilization levels of saplings. Early spring grazing resulted in less browsing than late spring grazing. Both grazing systems caused reductions in total diameter and height growth, and seasonal moisture stress of saplings. With the exception of browse utilization, sapling height growth, and residual dry matter, the annual effects of treatments on sapling and plot variables did not differ significantly in 3 out of 4 years. When saplings were split into two height classes, the effects of high-intensity, short-duration grazing on the total height growth of saplings were uneven, resulting in very little growth for small saplings and excellent growth for tall saplings.

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References

Bell, Monte. University of California Farm Advisor Emeritus at Orland, Calif. [Telephone conversation with Henricus Jansen]. April 1984.

Bolsinger, C.L. 1988. **The hardwoods of California timberlands, woodlands, and savannas**. Resour. Bulletin PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Cleary, Brian; Zaerr, Joe. 1984. **Guidelines for measuring plant moisture stress with a pressure chamber**. Corvallis, OR: PMS Instrument Co.; 17 p.

Grossman, R.B. 1983. **Bulk density by the excavation procedure using compliant cavities**. Unpublished draft circulated by author.

Hall, Lillian M.; George, Melvin R.; McCreary, Douglas D.; Adams, Theodore E. 1992. **Effects of cattle grazing on blue oak seedling damage and survival**. Journal of Range Management 45(5): 503-506.

Mayer, K.E.; Passof P.C.; Bolsinger C.; Grenfell W.E.; Slack H. 1986. **Status of the hardwood resource of California: a report to the Board of Forestry**. Cal. Dept. of For. and Fire Prot., Sacramento, CA.

Mensing, Scott A. 1992. **The impact of European settlement on blue oak (*Quercus douglasii*) regeneration and recruitment in the Tehachapi Mountains, California**. Madroño 39(1): 36-46.

Miller, R.F.; Haferkamp, M.R.; Angell, R.F. 1990. **Clipping date effects on soil water and regrowth in crested wheatgrass**. Journal of Range Management 43: 253-257.

Muick, P.C.; Bartolome, J. 1986. **Oak regeneration on California hardwood rangelands**. Transactions, Western Section of the Wildlife Society 22: 121-125.

Southard, Susan B. 1993. **California site #4**. In: Kimble, J.M., ed. Proceedings of the eighth international soil management workshop. Utilization of soil survey information for sustainable land use. Oregon, California, Nevada; July 11-24, 1992. Washington, DC: U.S. Department of Agriculture, Soil Conservation Service, National Soil Survey Center; 61-95.

Effects of Blue Oak Canopy on Annual Forage Production[1]

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Abstract: *Production of annual forage was compared at four sites under four blue oak (*Quercus douglasii*) canopy levels (0, 25, 50, and 75 percent), over 5 years, at the University of California Sierra Foothill Research and Extension Center in Yuba County, California. Long-term annual precipitation averages 28.5 inches. Significant differences in herbaceous forage production occurred among years, with the highest rainfall season being the most productive and the drier years generally being less productive. There was a significant (approximately 100 percent) difference in production among sites. The effects of canopy cover varied from year to year; canopy significantly depressed forage yield in 2 of the 5 years. High rainfall years appeared to favor herbaceous plant growth under the higher canopy levels.*

Clearing of blue oaks (*Quercus douglasii*) from northern California hardwood rangelands has been shown to increase the production of forage for livestock (Jansen 1987; Johnson and others 1959; Kay 1987; Murphy and Crampton 1964). However, forage enhancement due to clearing is not consistent throughout the state, and at other California locations, higher herbage levels have been found under oak canopy (Duncan and Clawson 1980; Duncan and Reppert 1960; Frost and McDougald 1989; Holland 1973, 1980). Bartolome and others (1994) found no difference in forage yield due to oak canopy.

Duncan and Clawson (1980), Kay (1987), and Menke (1987) discussed reasons for the variable effects of oak canopy on forage growth throughout the state. These include tree density, climate, and soil factors. McClaran and Bartolome (1989) identified mean annual precipitation as a factor influencing the relationship between forage yield and oak canopy; they reported reductions in forage production due to oak canopy only where mean annual precipitation is greater than 20 inches.

Kay (1987) demonstrated that increased forage yield due to blue oak clearing continued only for a limited time (15 years). He also showed that naturally open grasslands produced more forage than areas with trees, suggesting that cleared areas will return to a forage production level that is higher than that under canopies.

Oak woodlands are valuable for wildlife habitat and protection of soil and water quality. Because oak management practices have long-term implications, and because canopy effects vary widely, it is important to determine the long-term results of oak clearing under specific conditions. The objective of this study was to compare herbaceous forage production under a range of blue oak canopy levels, across a number of sites, in the northern Sierra Nevada foothills.

Methods

The study was located in the northern Sierra Nevada foothills at the University of California Sierra Foothill Research and Extension Center in Yuba County, California. The study area supports a mosaic of small open grasslands, savannas, and dense oak woodlands. Woody species are mostly blue oak, interior live oak (*Quercus wislizenii*), and foothill pine (*Pinus sabiniana*). Common grasses include *Bromus hordeaceus*, *B. madritensis*, *B. diandrus*, *Lolium multiflorum*, *Avena barbata*,

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Elymus caput-medusae, and *Cynosurus echinatus*. Important forb species are filaree (*Erodium* spp.), *Trifolium hirtum*, and *Geranium molle*. Jansen (1987) further describes the common species.

Four study sites were selected; each provided areas of open grassland (0 percent canopy) and blue oak canopy of approximately 25 percent, 50 percent, and 75 percent in reasonable proximity (*table 1*).

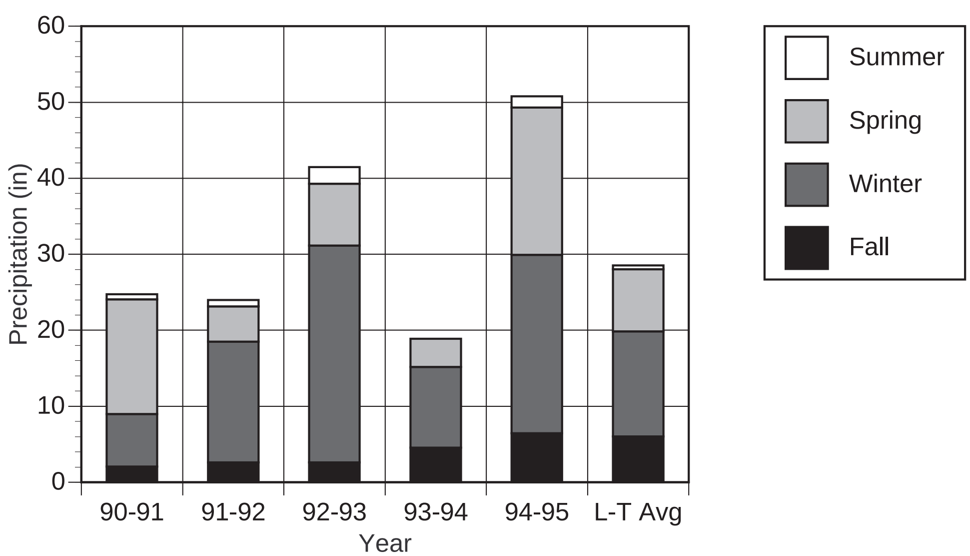
Table 1—Study site description

Site	Elev.	Slope	Slope aspect	Soils[1]	Stems[2]	Basal area	Avg. DBH[3]
	ft	*pct*			*per acre*	*ft²/acre*	*in.*
1 – Lewis	700	25	West	Sobrante-Las Posas very rocky loams	25-306	37-139	14
2 – Scott	1,350	18	South	Auburn-Las Posas-Argonaut rocky loams	32-64	27-72	14
3 – Koch	1,150	20	NW	Auburn-Sobrante very rocky loams	57-209	45-110	12
4 – Schubert	600	40	South	Sobrante-Auburn very rocky loams	40-139	32-47	10

[1]Herbert, F.W. and Begg, E.L. (1969)
[2]Low end of the range represents 25 percent canopies, high end = 75 percent canopies.
[3]Average stem diameter at breast height

Almost 4 miles separate the most distant sites. Precipitation was recorded at 600 feet elevation at a location central to the four study sites. Annual and seasonal precipitation during the 5 years of the study are presented in *figure 1*. Long-term (1962 to 1995) mean annual precipitation is 28.5 inches.

Figure 1–Annual and seasonal precipitation for the years 1990-91 to 1994-95 and the long- term average (L-T Avg).



In fall 1990, before leaf fall of blue oak, four plots at each study site were selected to represent canopy levels of 0, 25, 50, and 75 percent. Canopy levels were estimated by measuring the shaded area within the plot at midday and by use of a spherical densiometer. Canopies were almost exclusively blue oak; interior live oak and foothill pine were rarely encountered. The 16 plots averaged 0.24 acre with a range of 0.1 to 0.4 acre.

Each fall, for the years 1990 through 1994, twelve wire cages to prevent grazing were placed in each plot. Cages were made from woven wire field fencing and were 3 feet by 5 feet by 2 feet high. Each was held in place with four 3/8-inch steel reinforcing bars. These subplots were located by following a stratified random procedure. In the 25 percent canopy plots, 25 percent of the cages were placed under canopy; in 50 percent canopy plots, 50 percent of the cages were under canopy; and in the 75 percent canopy plots, 75 percent of the cages were under canopy. Areas of 0.5 m were hand clipped from within each subplot at peak standing crop each year. The clipped material was air dried and weighed to estimate herbaceous forage production. Cages were removed after clipping in the spring, to allow grazing by cattle, and were relocated to different subplots the following fall using this same procedure. Data were analyzed by analysis of variance as a split plot in time. The 12 subplots in each plot were pooled for analysis. This analysis allows examination of interaction effects for site by year and canopy by year. It does not allow investigation of site by canopy interaction or the three-way effects, site by canopy by year. Where statistical significance for main effects was indicated ($P < 0.05$), mean separation was tested at the 5 percent confidence level using Tukey's procedure.

Results and Discussion

Sites

Forage yield differed significantly ($P < .01$) among the four sites (*table 2*). The most productive site, with an average yield of 2052 pounds per acre, provided twice the yield of the least productive site. Sites intermediate in productivity differed significantly from either of the extremes, but not from each other. The large difference among four sites located within 4 miles of each other demonstrates the large variability in forage production in oak woodlands. Yield differences were consistent over years and do not appear to be related to the obvious physical factors: elevation, slope, or slope aspect. Soil differences based on the mapped descriptions also do not explain the variation in yield among sites. Soils in the study area are variable and are made up of associations of several soils series. Variations within mapped associations can be considerable and may be partially responsible for the differences among sites (Herbert and Begg 1969).

Table 2—Forage yield by site

Site	Elevation	Average forage yield
	feet	*pounds/acre*
2 – Scott	1,350	2,052 a
1 – Lewis	700	1,644 ab
4 – Schubert	600	1,225 bc
3 – Koch	1,150	1,020 c

[1]Values in the same column followed by different letters are significantly different ($P < 0.05$)

Years

Forage yield varied significantly ($P < 0.01$) from year to year (*table 3*). Much of the difference in yield appeared to be related to differences in yearly precipitation totals. The year-by-canopy level interaction was also significant ($P < 0.01$), but this interaction had little effect on the forage yield rank among years. The 1994-95 growing season had the highest precipitation observed during the study period (50.7 inches, 178 percent of normal) and produced the most forage over all canopy levels (average 1975 pounds per acre). The 1990-91 and 1993-94 growing seasons, years with generally the lowest rainfall (87 and 66 percent of normal, respectively), ranked either lowest or next to lowest in forage yields over all canopy levels. These two seasons had the lowest forage yield, approximately 1100 pounds per acre. The 1991-92 growing season was unusual in that it produced relatively high forage yields in spite of annual precipitation of only 24.0 inches (84 percent of normal). That season was intermediate in ranking over all canopy levels and was statistically similar in forage yield to the 1992-93 season which received 145 percent of normal rainfall. The 1991-92 season may demonstrate the importance of even distribution of moisture throughout the growing season. Substantial rainfall was received during each 2-week period from the middle of October to the end of April. Rainfall exceeded 1 inch during most of these 2-week periods, and it exceeded 0.6 inch during every 2-week period but one. Pitt and Heady (1978) included rainfall pattern as important in determining forage yield. George and others (1988) recognized rainfall pattern as a factor in forage growth, but credited temperature, described by degree days, as being of more importance.

Table 3—Forage yield by year

Year	Normal precipitaion	Average forage yield[1]
	pct	*pounds/acre*
1990-91	87	1,100 c
1991-92	84	1,694 b
1992-93	145	1,522 b
1993-94	66	1,136 c
1994-95	178	1,975 a

[1]Values in the same column followed by different letters are significantly different ($P < 0.05$)

Canopy Level

The effect of blue oak canopy on forage yield varied among years as indicated by the significant interaction between year and canopy level. An apparent increase in yield over all years for open grassland compared to canopy was not consistent among years or statistically significant *(table 4)*. Yield significantly decreased with increasing canopy during the 1990-91 rainy season, and open grassland was more productive than tree-covered plots in 1992-93. No significant differences due to canopy were found during the other 3 years of the study. Results of previous research suggest that a negative effect of blue oak canopy on yield would be expected in the northern California foothills (Jansen 1987; Johnson and others 1959; Kay 1987) and in locations with more than 20 inches mean annual precipitation (McClaran and Bartolome 1989). The results of the current study agree with Jansen (1987) who found yield at peak standing crop to be significantly

Table 4—Forage yield by canopy level and year

Year	Normal precipitation	Canopy level 0 pct	25 pct	50 pct	75 pct
	pct	*pounds/acre*			
1990-91	87	1,557 a	1,178 b	816 c	848 c
1991-92	84	1,651 a	1,872 a	1,702 a	1,551 a
1992-93	145	1,704 a	1,316 c	1,467 bc	1,599 ab
1993-94	66	1,255 a	1,147 a	1,061 a	1,082 a
1994-95	178	1,989 a	1,877 a	1,993 a	2,041 a
Average		1631 a	1478 a	1408a	1424 a

[1]Values in the same row followed by different letters are significantly different (P <0 .05)

higher in open grassland than under blue oak canopy in half of the 6 years reported in his study. We could not consistently match the finding of Kay (1987) who reported 26 percent more production in open grassland than in tree-covered (about 75 percent tree canopy) areas. The significant differences in forage yield that occurred in 2 of the 5 years of this study do not allow us to report a consistent effect of canopy level on forage yield. This supports the contention of Passof and others (1985) that canopy levels up to 40 to 60 percent do not depress forage production.

Kay (1987) suggested that the improved forage yield he found when blue oak trees were cleared from a site was greatest in dry years. Jansen (1987) did not report the same finding, and the current study does not clarify the question of whether canopy effects are greatest in dry years. The 1994-95 season, the year of highest precipitation, resulted in relatively high levels of forage under canopy compared to open grassland. On the other hand, the 2 years with significant differences in forage yield between open grassland and tree-covered areas (1990-91 and 1992-93) included both a relatively dry year (87 percent of normal precipitation) and a wet year (145 percent of normal).

Forage production varied less among years at the low canopy levels. The difference in forage yield between the most and least productive years was more than 1175 pounds per acre for the 50 percent and 75 percent canopy levels compared to only 730 pounds for the 25 percent canopy and the open grassland. Kay (1987) reported even larger differences in the yearly variation between open grassland and tree-covered areas. He noted that this difference in yield is an important factor to the livestock producer. Not only is stable forage production valuable, but forage produced in low forage years is relatively more valuable, per pound, than that produced in a high production year.

Conclusion

In this study, the effect of blue oak canopy on forage yield varied among sites and years. We did not find a consistent effect of oak canopy levels, up to 75 percent canopy, on herbaceous forage production. The presence of canopy appeared to increase variability of forage production among years, which is of considerable importance to livestock producers. Forage yield varied among years and was apparently related to annual precipitation. Yield varied greatly among sites located in relative proximity (approximately 4 miles apart), demonstrating the large variability of forage response in oak woodlands.

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References

Bartolome, J.W.; Allen-Diaz, B.H.; Tietje, W.D. 1994. **The effect of *Quercus douglasii* removal on understory yield and composition.** Journal of Range Management 47(2): 151-154.

Duncan, D.A.; Clawson, W.J. 1980. **Livestock utilization of California's oak woodlands.** In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on ecology, management and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 306-313.

Duncan, D.A.; Reppert, J.N. 1960. **A record drought in the foothills.** Misc. Paper 46. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 6 p.

Frost, W.E.; McDougald, N.K. 1989. **Tree canopy effect on herbaceous production of annual rangeland during drought.** Journal of Range Management 42(4): 281-283.

George, M.R.; Raguse, C.A.; Clawson, W.J.; Wilson, C.B.; Willoughby, R.L.; McDougald, N.K.; Duncan, D.A.; Murphy, A.H. 1988. **Correlation of degree-days with annual herbage yields and livestock gains.** Journal of Range Management 41(3): 193-197.

Herbert, F.W., Jr.; Begg, E.L. 1969. **Soils of the Yuba area, California.** Davis: Department of Soils and Plant Nutrition, University of California; 170 p.

Holland, V.L. 1973. **A study of vegetation and soils under blue oak compared to adjacent to open grassland.** Berkeley: University of California; 369 p. Ph.D. dissertation.

Holland, V.L. 1980. **Effect of blue oak on rangeland forage production in central California.** In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on ecology, management and utilization of California oaks; 1979 June 26-28. Claremont, CA: Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 314-318.

Jansen, H.C. 1987. **The effect of blue oak removal on herbaceous production on a foothill site in the northern Sierra Nevada.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 343-350.

Johnson, W.; McKell, C.M.; Evans, R.A.; Berry, L.J. 1959. **Yield and quality of range forage following 2,4-D application on blue oak trees.** Journal of Range Management 12: 18- 20.

Kay, B.L. 1987. **Long-term effects of blue oak removal on forage production, forage quality, soil and oak regeneration.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 351-357.

McClaran, M.P.; Bartolome, J.W. 1989. **Effect of *Quercus douglasii* on herbaceous understory along a rainfall gradient.** Madrono 36(3): 141-153.

Menke, J.W. 1987. **Hardwood range management.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinator. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 342.

Murphy, A.H.; Crampton, B. 1964. **Quality and yield of forage as affected by chemical removal of blue oak.** Journal of Range Management 17: 142-144.

Passof, Peter C.; Clawson, W. James; Fitzhugh, E. Lee. 1985. **Preliminary guidelines for managing California's hardwood rangelands.** Oakland: Division of Agriculture and Natural Resources, University of California; 92 p. Available from Cooperative Extension, University of California; Oakland, CA: publication 21413.

Pitt, M.D.; Heady, H.F. 1978. **Responses of annual vegetation to temperature and rainfall patterns in northern California.** Ecology 58: 336-350.

The Influence of Cattle Grazing on California Ground Squirrels in a Blue Oak Savanna[1]

James W. Bartolome[2]

Abstract: *This experiment compared California ground squirrel (*Spermophilus beecheyi*) activity on replicated grazed and ungrazed pastures in a blue oak (*Quercus douglasii*) savanna. During the 4-year study, squirrel activity, measured as the number of active burrows, generally declined in grazed and ungrazed pastures without oak canopy. Squirrel activity declined least in grazed pastures with blue oak canopy, and by the end of the experiment those pastures had significantly highest squirrel activity. Livestock management has only moderate potential for influencing squirrel abundance on grazed blue oak rangeland.*

The California ground squirrel (*Spermophilus beecheyi*) is a native rodent common on rangelands (Lidicker 1989). As an agricultural pest on annual-dominated range, it damages structures, eats crops, serves as a disease vector, and competes with livestock for forage. As an indigenous component of rangeland ecosystems, ground squirrels are an important prey species and help support a diversity of predators.

Studies at the San Joaquin Experimental Range near Fresno suggested that squirrels compete with livestock for forage, and that livestock grazing increases squirrel populations (Howard and others 1959, Fitch and Bentley 1949). Heavy livestock grazing was proposed to reduce litter and favor the germination of broadleaved plants more desirable to squirrels (Howard 1953). Linsdale (1947) observed, at the Hastings Reservation in Carmel Valley, that both light and heavy grazing favored squirrels, presumably through changes in species composition and litter, and that removal of grazing leads to disappearance of squirrels.

I compared moderate cattle grazing and grazing removal on replicated pastures in oak savanna and annual grassland at Del Valle Park in southern Alameda County to determine the effects on ground squirrel abundance.

Methods

Del Valle Park is normally moderately grazed year-round by cattle but had not been grazed for 3 years before the study because of an extended drought. Livestock grazing was reintroduced to the park in early 1991.

California ground squirrels are abundant on the annual grasslands and oak (*Quercus* spp.) savannas that characterize the park's vegetation. I selected three locations (blocks) within the southeastern portion of the park according to the following criteria: (1) vegetation annual grassland or blue oak dominated savanna with about 50 percent tree canopy coverage, (2) at least nine active squirrel colonies within a contiguous 4 ha (the minimum block size) of either annual grassland or oak savanna, (3) slope less than 40 percent, and (4) an area with likely moderate livestock use. Each location was divided into randomly assigned grazed and ungrazed treatments with fencing constructed in fall 1991. Each location included four experimental units, a paired grazed and ungrazed grassland and a paired grazed and ungrazed oak savanna.

Within each experimental unit three active squirrel colonies were located and marked with steel rebar at the center of colony activity. All burrow openings

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19 - 22, 1996, San Luis Obispo, Calif.

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within a 10-m radius of the colony center were mapped and rated for activity from fall 1991 through 1994. To determine colony activity, I rated each hole with scores of "0" (no evidence of a previously mapped hole), "1" (hole filled with dirt, vegetation growing on filled surface, paths to other holes not evident), "2" (hole filled in or partially filled, no evidence of recent use but vegetation not yet reestablished on fill), "3" (hole open but no evidence of recent use, sticks or cobwebs in the hole, no recent soil disturbance, paths may be present to other holes), and "4" (hole open, evidence of recent use, soil disturbance, active use of paths to other holes).

A wire cage with 5- by 10-cm mesh (squirrels easily travelled under and through the cages) was randomly located near the colony center and 1/16-m^2 plots clipped outside and inside in spring to determine forage production and cattle utilization. Results were analyzed by ANOVA and mean separation with differences judged significant if $P < 0.05$.

Results and Discussion

Forage productivity was considerably higher in the grassland than in the oak savanna (*table 1*). Production and apparent livestock utilization varied significantly among years in the grassland, and 1993 was the only year with satisfactory utilization near 50 percent. In the oak savanna, apparent utilization was close to the desired 50 percent, and production varied little among years. Although livestock ranged throughout the study area, they preferred areas within the tree canopy, especially in spring.

Table 1—Weight (grams/m^2) of standing biomass as measured in spring inside and outside of cages excluding livestock grazing (n=9 clipped quadrats per data point).

Year	1992	1993	1994
		g/m^2	
Grassland (grazed, outside cage)	402	230	303
Grassland (ungrazed, inside cage)	387	392	247
Savanna (Grazed, outside cage)	121	95	166
Savanna (ungrazed, inside cage)	212	201	210

In grassland, ungrazed biomass in 1993 differs significantly ($P < 0.05$) from grazed biomass and ungrazed biomass was significantly higher in 1992 and 1993 than in 1994. In oak understory, grazed biomass was significantly lower than ungrazed biomass in 1992 and 1993.

The overall density of active squirrel holes (ratings of 3 or 4) generally declined over the course of the study (*table 2* and *fig. 1*). Three years of cattle grazing had little effect on changes in squirrel activity in grassland. This result is not surprising given the lack of grazing pressure and relatively high amounts of standing biomass with and without grazing on those sites.

In the oak savanna, squirrel activity increased significantly during the study in one grazed block and averaged significantly higher for grazed savanna than the other treatments (*fig. 1*). Interpretation of the reasons for this result is difficult because the significant effect results primarily from a treatment × block

Table 2—Density of active ground squirrel holes (holes/m²) in fall (n=9 *colonies/plots per data point).*

	1991	1992	1993	1994
	holes/m²			
Ungrazed grassland	0.026	0.023	0.019	0.014
Grazed grassland	0.032	0.018	0.013	0.012
Ungrazed savanna	0.024	0.025	0.012	0.014
Grazed savanna	0.055	0.056	0.031	0.034

Differences between 1991 and 1994 are significant at $P < 0.05$ for all treatments. Within 1994, the grazed savanna differs significantly from the other treatments.

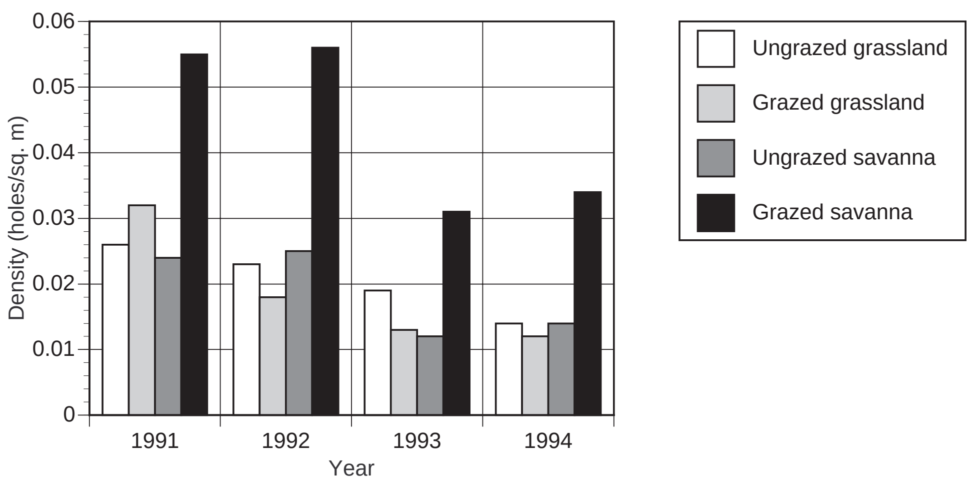

Figure 1—Density of active squirrel holes (ratings of 3 or higher, see text for explanation) in fall. Within 1994, the grazed savanna differs significantly ($P < 0.05$) from other treatments.

"interaction" (squirrel activity in two of the three savanna blocks did not change significantly). Production and utilization appeared similar among blocks, and there were no obvious differences in forage species. The major reasons proposed for squirrel reactions to grazing, amount of litter and changes in plant species composition, did not appear important. Grazed or not, savanna areas had only about half the forage productivity and standing biomass of grasslands.

Ground squirrels, despite 3 years of modest decrease in activity, are still very abundant on the study site. Grazing at the moderate levels used in this study did not affect squirrel activity in open grassland and had a variable effect in oak savanna. Proposals to change grazing, based on the presumed impact on squirrels, need to consider two points. If grazing affects squirrel numbers at all, it is likely to be at high grazing intensity, and any effects on the squirrels will differ considerably among and within sites.

Acknowledgments

Funding was provided by the East Bay Regional Park District. I thank Nancy Brownfield, Jeff Fehmi, and the many "squirrel hole mappers" at the University of California at Berkeley for their help on this project. Guy McPherson and Jeff Fehmi reviewed and commented on a draft manuscript.

References

Fitch, H.S.; Bentley, J.R. 1949. **Use of California annual-plant forage by range rodents.** Ecology 30: 306-321.

Howard, W.E. 1953. **Rodent control on California ranges.** Journal of Range Management 6: 423-434.

Howard W.E.; Wagnon, K.A.; Bentley, J.R. 1959. **Competition between ground squirrels and cattle for range forage.** Journal of Range Management 12: 110-115.

Lidicker, W.Z., Jr. 1989. **Impacts of non-domesticated vertebrates on California grasslands.** In: Huenneke, L.F.; Mooney, H., editors. Grassland structure and function: California annual grassland. Dordrecht: Kluwer Academic Publishers; 135-150.

Linsdale, J.M. 1947. **The California ground squirrel: a record of observations made on the Hastings Natural History Reservation.** Berkeley: University of California Press.

Preliminary Results from the Evaluation of Different Seasons and Intensities of Grazing on the Erosion of Intermittent Streams at the San Joaquin Experimental Range[1]

Royce E. Larsen[2] Melvin R. George[3] Neil K. McDougald[4] Kenneth W. Tate[3] Kenneth O. Fulgham[5]

Abstract: *A study was initiated during summer 1994 to evaluate the effect of season and intensity of grazing on erosion along intermittent streams at the San Joaquin Experimental Range. Five treatments (no grazing, dry season moderate, dry season heavy, wet season moderate, and wet season heavy) were applied on three different streams. Change in channel cross-sectional area, following one season of treatments, was determined and evaluated. There was no significant difference* (P = *0.236) between treatments. Erosion and deposition resulting from heavy rainfall and streamflow may have masked treatment effects. Treatments will continue to be applied annually for an additional 4 years.*

Grazing-derived sediment impacts on the beneficial uses of water are a continual concern among conservation groups and regulatory agencies, such as the Regional Water Quality Control Board (George 1992, 1993). While crucial salmonid water bodies receive a great deal of attention, little attention is given to sediment delivery from low-elevation intermittent streams in California's Central Sierra Nevada foothills. Field observations suggest that sediment delivery from these streams can be high during runoff periods. Sediment from grazed watersheds can come from several sources including inadequate vegetative cover, cattle trails, and roads. In addition, miscellaneous surface disturbances in the uplands or streambank erosion and stream degradation in the intermittent stream channels can contribute to the sediment load.

The objective of this study was to demonstrate and evaluate the impact of different seasons and intensities of grazing on streambank and channel erosion along intermittent stream channels. In addition, monitoring of runoff and sediment load relationships for a small watershed was begun.

Site Description

The 4380-acre San Joaquin Experimental Range (SJER) has been a USDA Forest Service research facility since the 1930's. The station lies in the lower central Sierra Nevada foothills in the oak (*Quercus* spp.) savanna vegetation type (*fig. 1*).

Currently SJER is managed by California State University Fresno (CSUF), for research and education purposes under a long-term agreement with the USDA Forest Service, Pacific Southwest Research Station. A herd of 210 beef cattle is maintained at the station by CSUF.

The station has a Mediterranean climate with annual precipitation ranging from 10 to 32 inches with a mean of 19 inches, mostly coming between October and March. Mean monthly air temperatures range from 42˚F in January to 80˚F in July.

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19 - 22, 1996, San Luis Obispo, Calif.

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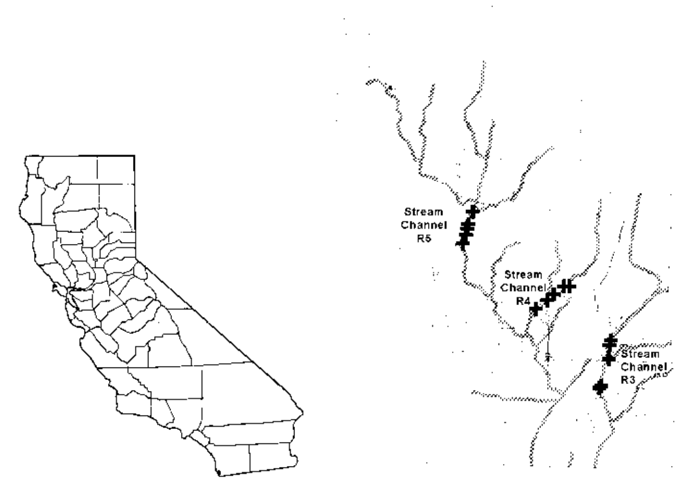

Figure 1—Location of five treatments on three intermittent stream channels at the San Joaquin Experimental Range in Madera County, California.

Elevation ranges from 700 to 1700 feet. Soils are coarse sandy loam derived from granitic rocks, and most are less than 2.5 feet deep. The Ahwahnee series (Mollic Haplustalf) are common, covering about 96 percent of SJER. The Visalia series soils (Cumulic Haploxeroll) are found on alluvial or swale sites.

The station is dissected by first-, second-, and third-order intermittent stream channels. Stream flow occurs during the rainy season and for a few weeks into the dry season. While granitic rocks, oak trees, and other woody vegetation provide some stability, the majority of the stream banks are vegetated by shallow-rooted annual grasses and forbs. The stream bottoms are predominantly sand with some granitic rock and boulders. The channels are 2 to 10 feet wide and 1-3 feet deep. The study reaches are low gradient with less than 2 percent slope.

The oak woodlands of SJER are dominated by blue oak (*Quercus douglasii*) and interior live oak (*Quercus wislezenii*). The understory vegetation is dominated by annual grasses and forbs. Wedgeleaf ceanothus (*Ceanothus cuneatus*) is a common understory shrub.

Methods

Five grazing treatments were replicated on three different first-, second-, and third-order intermittent streams that are tributaries to Cottonwood Creek. Cottonwood Creek is a fourth-order stream that drains into the San Joaquin River just below Friant Dam. The three stream channels designated R3, R4, and R5 are 1 to 2 miles apart and at an elevation of 900 to 1350 feet (*fig. 1*).

The five treatments consisted of no grazing (NG) (control), dry season moderate (DSM), dry season heavy (DSH), wet season moderate (WSM), and wet season heavy (WSH). Wet Season grazing treatments were applied in December or January and maintained through the remainder of the rainy season by reapplication to remove regrowth to maintain the treatment target. Dry Season grazing treatments were applied once in late summer before the rainy season. Because this is the dormant period, reapplication of dry-season treatments was not necessary.

Each of the treatments were applied to a 200- by 200-foot area centered over the stream channel (*fig. 2*). Each treatment was applied to a randomly selected location (experimental unit) within the stream reach (*fig. 2*). These treatments were replicated on the three different stream channels as a randomized complete block design.

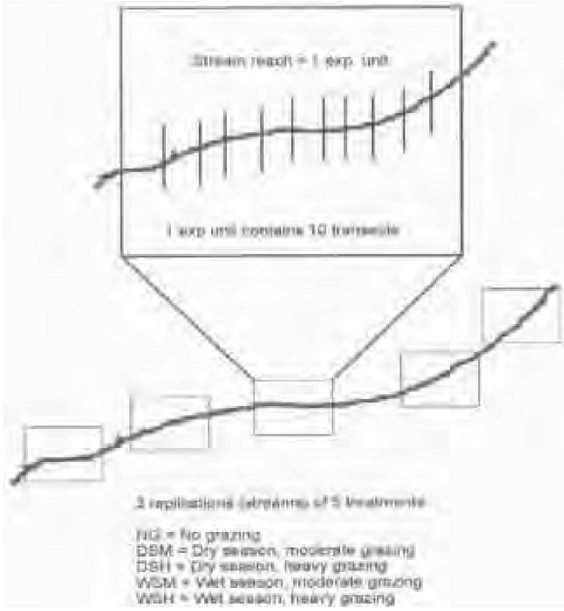

Figure 2—Stream channel treatment layout.

Permanent fences were built to exclude grazing from the no-grazing treatment. Temporary electric fences were used as needed during periods following application of moderate or heavy grazing. Residual dry matter (RDM) targets of 700-1000 pounds/acre and <600 pounds/acre were used to define moderate and heavy grazing, respectively. The RDM levels were estimated visually following methods described in Clawson and others (1982). Supplemental feeding adjacent to treatment sites was used to achieve desired intensity when ambient grazing intensities were inadequate.

Stream Channel Measurements

Channel cross-sections were measured using methods outlined by Bauer and Burton (1993). For each stream reach 10 permanent cross-section transects, 20 to 30 feet long, were placed perpendicular to the stream channel, a distance of 1 to 1.5 times the channel width apart (*fig. 2*). The transects were marked with permanent stakes that were referenced to a permanent benchmark, generally a large boulder nearby, at each stream reach. Stream elevation was determined every 6 inches along the transect. The elevational readings were used to calculate the cross-sectional area of each transect. The cross-sectional area was subtracted from the baseline values to obtain the change in cross-sectional area. The averages for each experimental unit (10 transects) were used to evaluate the grazing effects. A one-way analysis of variance was used to analyze the data.

Runoff and Sediment Monitoring

Stream reach R4, which drains a 342-acre watershed (*fig. 1*), was gauged with a 3-foot H flume. Stream flow was calculated from stage height. A tipping bucket rain gauge was installed near the flume. Stage height and rainfall values were recorded hourly using a data logger.

Suspended sediment load was estimated from taking water samples near the flume. The samples were filtered, dried, and weighed, and suspended sediment concentration was calculated. Water samples were collected several times a day during rainstorms and subsequent high runoff periods. Samples during low flows were collected only once every 1-2 weeks.

The maximum peak flow for the year was estimated using the cross-sectional area of the farthest downstream set of cross-section treatments and Mannings equation (Branson and others 1981). The *n* value for Mannings equation was estimated by measuring velocity and calculating n during high flows when we were present. The high water marks were then used to estimate the maximum peak flow for the year.

Three sets of paired runoff plots were established within the watershed. Each set of runoff plots was on different slope classes of 10 percent, 20 percent, and 30 percent. These plots were 6 feet wide and 70 feet long. Surface water runoff and sediment were collected for each storm event.

Results and Discussion

Above-average rainfall promoted the evaluation of stream bank and channel erosion following one year of grazing treatment. Total rainfall recorded at the study site (R4) was 30.93 inches (163 percent of normal) for September 1994 - August 1995. The majority of the rainfall at SJER came during January (9.4 inches) and March (9.1 inches). The largest single storm event was 4.85 inches occurring in a 48-hour period during March 9-11, 1995 (*fig. 3*).

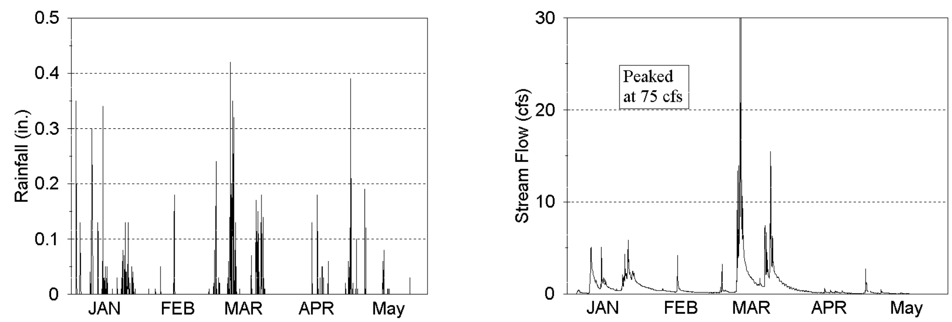

Figure 3—Hourly rainfall and stream flow (cubic feet per second) for watershed R4 at the San Joaquin Experimental Range during winter 1995.

This large storm event occurred on saturated soil conditions and produced a large estimated peak flow on each of the three study stream reaches. Stream reach R3 had an estimated peak flow of 136 cubic feet per second. The flume on stream reach R4 was exceeded by an estimated peak flow of 76 cubic feet per second. Stream reach R5 had the largest peak flow which was estimated at 366 cubic feet per second.

Stream Bank and Channel Erosion

The mean differences in cross-sectional area between baseline and first-year treatment are shown in *table 1*. There were no significant differences ($P = 0.236$) between grazing treatments. However, some small differences were detected. The greatest erosion occurred in the NG treatment. In contrast, the DSH treatment had the highest deposition rate. The average changes following one year were as follows; NG = -2.9 percent, WSH = -1.4 percent, DSM = -0.3 percent, WSM = 1.1 percent, and DSH = 2.1 percent. The greatest change for any treatment site was -6.1 percent for the NG treatment on stream reach R3. Interestingly, soil erosion and deposition was not correlated with any treatment effect. Erosion and deposition resulting from heavy rainfall and streamflow may have masked treatment effects.

Unfortunately, very few studies have compared season, intensity, or frequency of grazing treatments to assess grazing impacts or to test grazing management practices. Studies of grazing impacts on riparian zones and fishery

Table 1—Cross-sectional area differences between baseline and first season grazing treatments[1] at the San Joaquin Experimental Range.

Treatment[2]	Area difference	
	Mean	Percent
	ft^2	
Dry season heavy	0.65	2.1
Wet season moderate	0.48	1.1
Dry season moderate	-0.11	-0.3
Wet season heavy	-0.54	-1.4
No grazing	-0.85	-2.9

[1]Positive values = deposition; negative values = erosion

[2]Replicated on three different stream reaches. There was no significant difference among grazing treatments (P = 0.236).

habitat commonly focus on adjacent comparisons of grazed and ungrazed reaches on the same stream. Many of these studies were recently reviewed by George (1994).

Buckhouse and others (1981) reported differences in streambank erosion between several grazing treatments including no grazing. Siekert and others (1985) reported that spring grazing had no significant effect on channel cross-sectional area, with degree of these impacts varying with climatic differences. Marlow and Pogacnic (1985) reported that the greatest amount of bank alteration in an ephemeral stream in Montana occurred when soil moisture exceeded 10 percent.

Observations of Sediment Movement in Watershed R4

The watersheds at SJER are flashy in nature, as shown by the hydrograph of stream R4 in *figure 3*. During saturated conditions, peak flows occur rapidly following rainfall initiation, then recede quickly following storm cessation. This condition allows for high peak flows. High peak flows can be responsible for movement (erosion and deposition) of sediments within a stream channel.

Runoff from watershed R4 began January 4, 1995 and ended on May 17, 1995 (*fig. 3*). Monthly totals for rainfall, runoff, and suspended sediment load are shown in *figure 4*. There were 30.9 inches of rainfall with 8.6 inches of runoff for the season on watershed R4. There was an estimated 24.2 tons of suspended sediment for the whole runoff season. This is an average of 0.07 tons/acre for the whole watershed. There was movement of sediments (erosion and sedimentation) throughout the entire stream. However, the actual amount of sediment transported out of the watershed was small.

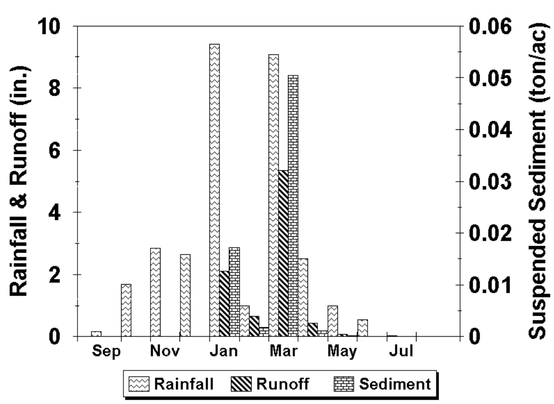

Figure 4—Monthly rainfall, runoff, and suspended sediment from watershed R4, water year 1994-1995.

The seasonal surface runoff from the paired plots was highest at the 10 percent slope (>9 inches), least for the 20 percent slope (3.6 inches), and moderate for the 30 percent slope (5.4 inches). The value for the 10 percent slope was estimated. It is believed that subsurface water from upslope was transported through rodent burrows within the paired plots. Water from these plots flowed approximately 3 days following the major storm event in March. However, sediment loss from these plots was very low. The greatest amount of sediment loss was from the 30 percent slope (0.022 ton/acre), moderate from the 20 percent slope (0.012 ton/acre), and the least from the 10 percent slope (0.008 ton/acre). These small amounts of soil erosion would suggest that most of the suspended sediment load in the stream came from the stream channel itself, and not from surface erosion from the uplands.

Plans

The grazing treatments will continue to be applied annually for another 4 years to increase the chances of finding a significant treatment effect. Hand sampling of suspended sediment load has been replaced by an automatic water sampler. An additional set of paired plots was installed on a 10 percent slope in a permanent exclosure. The paired plots will continue to be monitored for another 2 years. One plot from each of the pairs will then be fenced to evaluate grazing impacts on upland surface erosion by differing slope classes.

Acknowledgments

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References

Bauer, Stephen B.; Burton, Timothy A. 1993. **Monitoring protocols to evaluate water quality effects of grazing management on western rangeland streams.** Washington, DC: U.S. Environmental Protection Agency; 179 p.

Branson, Farrel A.; Gifford, Gerald F.; Renard, Kenneth G.; Hadley, Richard F. 1981. **Rangeland hydrology.** Dubuque, IA: Kendall Hunt Publishing Company.

Buckhouse, J.C.; Skovlin, J.M.; Knight, R.W. 1981. **Streambank erosion and ungulate grazing relationships.** Journal of Range Management 34: 339-340.

Clawson, James W.; McDougald, Neil K.; Duncan, Don A. 1982. **Guidelines for residue management on annual range.** Leaflet 21327. Davis, CA: Cooperative Extension, Divison of Agricultural Sciences, University of California; 3 p.

George, Melvin R. 1992. **Nonpoint sources of pollution on rangelands.** Rangeland Watershed Program Fact Sheet No. 3. Davis, CA: Department of Agronomy and Range Science, University of California; 3 p.

George, Melvin R. 1993. **Grazing effects on riparian areas.** Rangeland Watershed Program Fact Sheet No. 14. Davis, CA: Department of Agronomy and Range Science, University of California; 3 p.

George, Melvin R., ed. 1994. **Evaluation of the effectiveness of livestock and range management practices in grazed watersheds.** Davis, CA: Department of Agronomy and Range Science, University of California; 42 p.

Marlow, C.B.; Pogacinic, T.M. 1985. **Time of grazing and cattle induced damage to streambanks.** In: Johnson, R.R., and others, technical coordinators. Riparian ecosystems and their management: reconciling conflicting uses; First North American Riparian Conference; 16-18 April 1985; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 279-284.

Siekert, R.E.; Skinner, Q.D.; Smith, M.A.; Dodd, J.L.; Rodgers, J.D. 1985. **Channel response of an ephemeral stream in Wyoming to selected grazing treatments.** In: Johnson, R.R., and others, technical coordinators. Riparian ecosystems and their management: reconciling conflicting uses; First North American Riparian Conference; 16-18 April 1985; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 276-278.

Livestock Grazing and Riparian Habitat Water Quality: An Examination of Oak Woodland Springs in the Sierra Foothills of California[1]

Chris G. Campbell[2] **Barbara Allen-Diaz**[2]

Abstract: *Studies throughout the western United States have shown that livestock can degrade riparian vegetation and stream channels and produce sediment, pathogen, and nutrient loading. This study at the Sierra Foothill Research and Extension Center is the first to focus on effects of livestock grazing on hardwood rangeland springs and associated riparian resources. Cattle grazing treatments at three intensities were applied in 1- to 2.5-ha pastures, which included a spring and ephemeral creek. Over a 5-year period we monitored nitrate, orthophosphate, dissolved oxygen, temperature, and pH. Results show no significant differences in measured parameters among treatments. Sites were the source of some significant differences. This study indicates that moderate livestock grazing intensities do not detrimentally affect water quality at springs or ephemeral creeks in the oak woodlands of California.*

Riparian systems, including springs, seasonal and perennial streams, and shoreline vegetation, comprise an important and unique component in oak (Quercus spp.) woodland habitat and are crucial considerations in land management (Ewing and others 1988, Platts and others 1987). California's Mediterranean climate, with a summer drought period of 5-8 months, results in hardwood rangelands dominated by introduced annual grasses, varying amounts of native perennial grasses, and native oak species. Hardwood rangelands provide 75 percent of the forage used by the State's range livestock industry, in addition to furnishing many species with a source of water and habitat (Ewing and others 1988). Thus riparian patches provide critical sources of water for humans, wildlife, and livestock, and unique habitat and diversity of plant and animal species.

Western riparian zones in general are suggested to be the most productive habitats in North America (Johnson and others 1977). However, development of these fertile environments, such as in the Central Valley of California, has resulted in massive conversion or degradation of these systems (Franzreb 1987). Spring systems have historically been developed to provide water for domestic uses.

It has been suggested that livestock grazing is a major cause of riparian habitat disturbance (Fleischner 1994, Kauffman and Krueger 1984). Cattle seek riparian habitat for shade, cool temperatures, water, and abundant forage supplies. Livestock may directly affect the physical condition of riparian areas as well as directly or indirectly degrade water quality. Physical disturbance parameters include streamside vegetation, channel morphology, and the soil structure (Kauffman and Krueger 1984, Platts 1981, Platts and Nelson 1989). Water quality degradation includes chemical changes such as nutrient loading and physical changes such as increased flow and turbidity (Stednick 1991). At the watershed level, nonpoint source pollution may be observed as diffuse changes in the water quality and runoff quantity.

Livestock may compact soil, decreasing infiltration and increasing overland flow which may result in erosion and sedimentation. Wood and others (1989) found that mean infiltration rates were significantly greater on treatments excluded from livestock grazing. Wood also found infiltration rates and quality

[1]An abbreviated form of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Issues, March 19-22, San Luis Obispo, Calif.

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of runoff water decreased, in an insignificant trend, from grazed treatments as the seasons progressed from late spring to fall. Sediment production from livestock grazing treatments was significantly greater than that from treatments with no livestock (Wood and others 1989).

The EPA recognizes sediment, pathogens, nitrogen and phosphorus, biochemical oxygen demand, and turbidity as possible nonpoint source pollutants originating from cattle (Mulkey 1977). Water quality changes from heavy metals, temperature changes, pesticides, and other potential pollutants that might stem from grazing are not considered significant by the agency. However, other sources indicate that temperature changes (such as those resulting from vegetation removal) may be important, particularly in allowing the environment to become more conducive to pathogen growth (Hall and Amy 1990). Temperature may also affect fish habitat (Clark 1992).

Nutrients are particularly important as they increase the biological oxygen demand in the stream waters. Nitrogen and phosphorus are two nutrients which commonly limit growth of microorganisms (Fedkiw 1991). Their increased loading may result in blooms of algae and microorganisms. This may lead to eutrophication of the waters when the population dies out and their degradation uses up the available oxygen in the system (Clark 1992).

Moderate livestock grazing does not appear to produce a significantly higher nutrient loading (Larsen and George 1995). The authors concluded that nitrogen and phosphorus loading associated with moderate grazing was very low and was typical of natural streams. In fact, many studies have not been able to demonstrate any significant degradation in quality of runnoff water (Johnson and others 1977, Coltharp and Darling 1973). However, Wood and others (1989) did find that total nitrogen concentrations were greater from the grazed treatments than from treatments without grazing. The study also found concentrations of total phosphorus similar in all treatments.

Many pathogens in cattle, such as *Cryptosporidium parvum* and *Giardia duodenalis*, may be transferred into municipal water supplies. These pathogens cause gastrointestinal problems in humans (Atwill 1995). Studies concerning contamination of water supplies have not been able to pinpoint the exact sources (Atwill 1995). Johnson and others (1977) found that bacterial counts increased in grazed pastures; however, they dropped to levels similar to those in the ungrazed pasture a few weeks or months after cattle were removed.

This idea of short pulses of pathogens in runoff was supported by Hall and Amy (1990). Their study revealed that bacterial levels increase with precipitation events, particularly in the presence of cattle. The influx of nutrients necessary for growth of microorganisms into the stream system may be dependent on overland water flow. Thus the influence of cattle could be seen months after they had been removed from pastures, when precipitation mobilized an influx of bacteria, nitrogen and phosphorus into the runoff (Hall and Amy 1990).

In their review, Larsen and George (1995) concluded that a large increase in bacteria was observed only where the cattle were concentrated and that very little bacterial contamination was associated with dispersed livestock herds. Another study by Buckhouse and Gifford (1976) demonstrated no significant differences in the average fecal indicator bacteria existed between grazed and ungrazed treatments. Such differences are likely to be related to variability of individual study sites and the scientist's definition of grazing intensities, as well as the inability of fecal indicators to account for all pathogen species (Buckhouse and Gifford 1976).

This study tested cattle grazing effects on spring and creek water quality. Different grazing intensities were applied and pH, temperature, conductivity, total dissolved solids, nitrate, orthophosphate, and turbidity were sampled at springs and the associated creek in the hardwood rangeland system. The results reported here are part of a larger study to evaluate grazing effects on hardwood rangeland wetland ecosystems.

Site Description

Nine study sites each containing an undeveloped spring and ephemeral creek were selected at the University of California Sierra Foothill Research and Extension Center in three different watersheds. The Center is located on the eastern side of the Sierra Foothills near Browns Valley, California, in Yuba County, covers 2300 ha, and varies between 90 and 600 m in elevation. The watersheds are dominated by blue oak/foothill pine savannas with an understory of introduced annuals. The Center has been owned and operated by the University of California for almost 30 years (Raguse and others 1990).

The 1- to 2.5-ha sites were selected on the basis of (1) the presence of an undeveloped spring and associated creek (2) similar livestock grazing history, and (3) practicality of fencing.

Methods

Beginning in 1992 three grazing treatments were applied randomly to sites within the three watersheds: (1) no grazing; (2) light-intensity grazing, leaving a target value of 1000–1200 kg/ha of residual dry matter (RDM); and (3) moderate/heavy-intensity grazing, leaving 600–750 kg/ha of RDM.

The water sampling methods used the Hach™ DREL2000 Water Testing Kit to measure temperature, pH, conductivity, dissolved oxygen, total hardness, calcium hardness, alkalinity, total dissolved solids, nitrates, orthophosphates, potassium, iron, sulfates, silica, chlorides, and recently (1994) turbidity. In the fourth year, 1995, we sampled temperature, pH, conductivity, total dissolved solids, dissolved oxygen, nitrates, and orthophosphates.

The pastures were grazed for short periods, based upon the seasonal growth of annual grasslands in California, to produced desired RDM. Water samples were taken within a few days after cattle removal for each grazing period. The grazing treatments were applied approximately every 3 months.

These parameters were statistically examined using repeated measures analysis of variance (Norusis 1993). The parameters of interest, nutrients, dissolved oxygen, conductivity, pH, and so on were first tested for significance by treatment, site, and sampling date. Because we were most interested in identifying treatment effects, two-way interactions of site-date, treatment-date, and treatment-site were analyzed to determined the sources of the observed differences. Mean comparison models at $P < 0.05$ were used to determine significance (Norusis 1993).

Rhizon Soil Moisture Samplers (Meijboom and van Noordwijk 1992) were used to take ground water samples at the spring heads. Conductivity, pH, total dissolved solids, temperature, and nitrate were recorded for all water samples. These results were compared to those recorded for the samples taken from the springs in order to determine the origin of our samples. The differences of the means of the sample measurements were tested against the hypothesis that the difference was zero. A *t*-test was used to determine significant differences between ground water and surface water for each site using the STATA statistical package (Daniel 1995).

Results and Discussion

This 5-year study is now on its 4th year; results are preliminary but very consistent. The means over the 4 years by treatment are displayed in *table 1*. The first year of the study (1992) was a baseline year, and a means comparison test revealed significant differences in water quality parameters among sites before treatments were applied. These differences in conductivity, total dissolved solids, total hardness, calcium hardness, and alkalinity simply continued regardless of treatment. Thus the significant results from this study are related to site differences. The graph of the conductivity (*fig. 1*) has a similar shape to those of total dissolved solids, total hardness, calcium hardness, and alkalinity.

Table 1—Summary of 5-year means by grazing treatment

	Heavy	SD[1]	Light	SD[1]	No graze	SD[1]
Spring						
Nitrate[2]	1.17	1.02	1.78	1.15	1.92	1.08
Phosphate[2]	0.10	0.05	0.13	0.08	0.15	0.09
pH	6.85	0.64	6.81	0.57	6.79	0.56
Conductivity[3]	0.52	0.22	0.50	0.22	0.30	0.05
Dissolved oxygen[2]	4.85	1.62	7.02	10.96	5.32	1.90
Temperature	17.42	4.29	17.62	3.75	17.77	3.43
Turbidity[4]	8.0	13.4	4.8	4.7	6.4	4.6
Creek						
Nitrate[2]	1.23	0.67	1.25	0.87	1.56	0.94
Phosphate[2]	0.12	0.14	0.12	0.07	0.11	0.09
pH	7.40	0.77	7.67	0.68	7.52	0.79
Conductivity[3]	0.53	0.18	0.50	0.22	0.30	0.05
Dissolved oxygen[2]	7.51	1.45	7.28	1.51	10.65	16.93
Temperature	17.62	5.16	17.24	5.46	16.66	4.74
Turbidity[4]	7.3	12.4	5.9	4.4	10.6	11.0

[1]S D = standard deviation
[2]NO_3-N, phosphate, and dissolved oxygen, measured in mg/l, $n = 27$
[3]Conductivity measured in mS/cm, $n = 27$
[4]Turbidity measured in NTU (Nephelometric Turbidity Unit), $n = 7$ *(started 4th year)

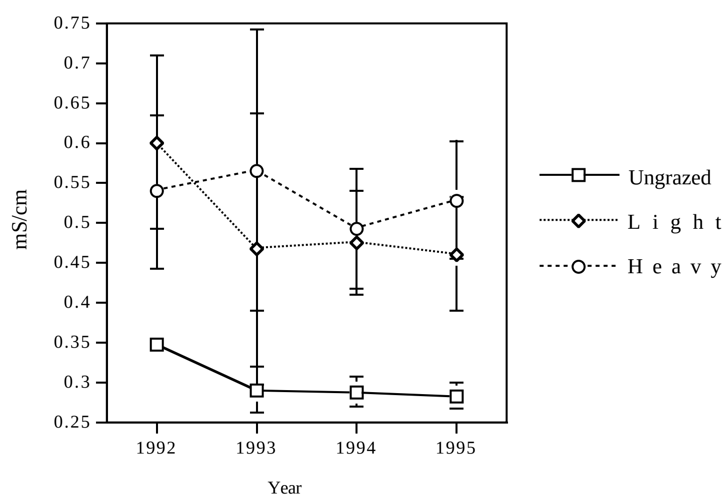

Figure 1—Data are yearly averages from three spring sites in each treatment. Ungrazed treatment sites had lower conductivity values even in the baseline year. Grazed treatments showed no significant differences in conductivity. Error bars represent ±1 standard error of the mean.

Over the 4 years there was a slight but insignificant increase in dissolved oxygen and orthophosphate at each site and a slight increase in nitrate at the ungrazed site. One contrary finding was on the heavily grazed Forbes watershed site. A significantly lower nitrate concentration was found for year 4. This site is the only one dominated by *Typhus* spp., and this may be one of many factors producing this result.

The graph of nitrate (*fig.* 2) shows the lack of differences between treatments by year. Phosphorus is also similar. It may be possible that the nutrients become more diluted with increased flows during storms, and because our sampling is point-in-time specific, this question will be examined in future studies where continuous concentration and flow data will be collected and loading calculated.

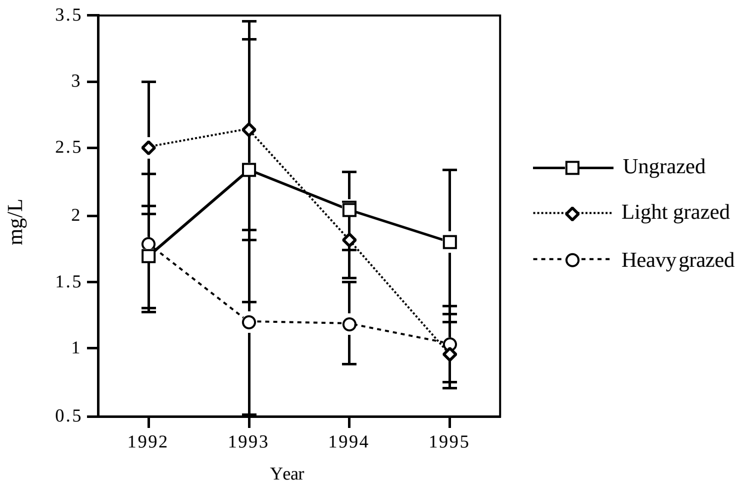

Figure 2—Data are yearly averages from three spring sites in each treatment. No significant differences in NO_3-N concentrations exist between treatments or over time ($P < 0.05$). Error bars represent ±1 standard error of the mean.

Turbidity measurements were added late in the study, but a smaller scale examination of conditions before, during, and after grazing on the Schubert and Forbes sites showed a slight increase in turbidity while cattle were on site and just after they were removed (*fig.* 3). Turbidity can be correlated to the amount of suspended sediment in the water column. However, this is a rough estimate of sediment which may be influenced by other water coloring factors, and the difference is not large enough to be significant. We intend to further examine this issue, by developing better methods to measure sediment load and better sampling practices.

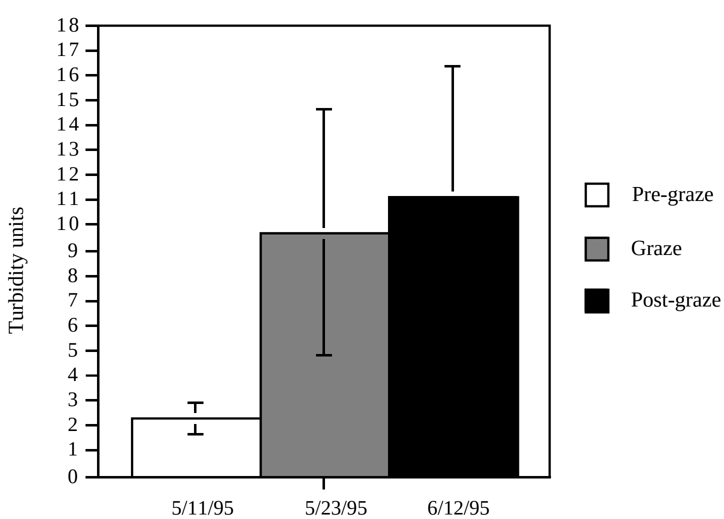

Figure 3—Turbidity results from two of three watersheds sampled before grazing, during a grazing period, and a week post-grazing (n = 6). Error bars represent ±1 standard error of the mean.

Temperature and pH are standard water quality parameters that influence most of the water quality measurements. Temperature and pH tell us about general conditions which can affect the biota of the waters. The ungrazed Forbes site had a lower average temperature than that of the other sites. This site has an overstory of blue oaks which may be responsible for the result. Other temperature measurements showed no obvious differences. The pH at the creek was consistently higher (more basic) than the spring. This could be a result of the flow of the water from a reduced environment in the soil to mixing with the atmosphere.

The Rhizon Soil Water Samplers were used to collect groundwater samples. The samples were taken from 10 cm below the ground surface at the origin of the spring. The results are summarized in *table 2*. The difference between the groundwater and spring samples is not statistically significant for conductivity, total dissolved solids, pH, and nitrate. Temperature was the only significant parameter; however, this is no surprise as the soil may have heterogeneous temperatures because of geothermal heating and different latent heat absorption and conductance properties, compared to the atmosphere.

Table 2—*t*-test values for Rhizon Soil Water Samplers.

Sample	Mean	SD[1]	*P*-value	Significant
Spring pH	7.30	0.33		
Rhizon pH	7.32	0.28	0.82	no
Spring nitrate[2]	1.31	2.31		
Rhizon nitrate[2]	1.15	4.63	0.45	no
Spring conductivity[3]	0.45	0.20		
Rhizon conductivity[3]	0.46	0.22	0.37	no
Spring temperature[4]	20.49	1.17		
Rhizon temperature[4]	23.29	1.07	0.00	yes

[1]Standard deviation
[2]Nitrate measured in mg/L
[3]Conductivity measured in mS/cm
[4]Temperature measured in °C

Conclusions

The study indicates that moderate livestock grazing intensities do not detrimentally affect water quality of springs, ephemeral creeks, or the localized ground water feeding the springs. Site characteristics have greater influence on water chemistry. The treatments applied had negligible effects on the water quality over time, and no cumulative differences were observed between the spring and creek at each site.

Creek samples had slightly higher, but not significant, pH, and dissolved oxygen values than the springs. This demonstrates a possibility of surface runoff containing nonpoint source pollution or organic acids present in the creek channel.

The observed water chemistry and the suggested origins of nonpoint source pollution agree with those of Mulder and others (1995), in their study of acid rain. Mulder worked to derive the origin of water flow in three water catchments in Norway to examine acid rain pollution. The conclusion was that low-flow water originated from ground water, while high-flow water originated from surface and subsurface flow. Only the high-flow conditions produced the nonpoint source pollution. Our findings demonstrate the lack of pollutants in the low-flow springs.

Thus surface and subsurface runoff after heavy rains is the likely source of nonpoint source pollution. In a system with low levels of erosion, such as at the Sierra Foothill Research and Extension Center, effects of cattle grazing do not become apparent in water quality of springs or ephemeral creeks. If nonpoint source pollution occurs in runoff, then it must collect in the downstream rivers. The greatest input of nonpoint source pollutants would theoretically occur as a flushing effect of the first rainstorms of the year.

Studies such as ours have obvious constraints of time, space, and money. Whole watersheds were not available for the study; thus small pastures were used. In order to simulate year-long grazing, a high-intensity short-duration management scheme was used to manage cattle to reach desired upland RDM levels. There may be some difficulty extrapolating to the larger watershed scales, however, the RDM levels were managed to simulate year-round grazing.

Despite these difficulties, our results are supported by the literature. The differences in nutrients (nitrate and orthophosphate) between treatments were not significant. Site characteristics are apparently a greater influence on water quality than our heavy grazing treatment. We are aware of cases in which grazing animals apparently caused environmental degradation and decreased water quality. However, our study did not show any detrimental effect on water quality. Unfortunately, we did not sample microorganisms in this study. However, the lack of changes in temperature, nutrients, and dissolved oxygen does support the idea that there were probably no major effects on microorganisms.

Finally, this study has produced many new ideas which need to be addressed in order to better understand the effects of grazing management on water quality at a watershed level. For example, high-flow streams are a more likely site of pollution than springs, so greater attention must be given to the surface and subsurface waters which flow into these streams. We plan to further evaluate the flow of nutrients, pathogens, and interill erosion from a boundary-layer perspective, as well as identify natural removal processes such as wetland biofiltration.

Greater attention must also be given to the spring sites as highly productive patches in a dryer oak woodland matrix. We would like to examine these patches as habitat and forage supply for birds and other wildlife. We would also like to use invertebrate bioassay techniques to study the general health of these systems.

On a watershed scale we have begun to develop paired watershed studies. Flow and pollutants can be monitored on a large scale, and management techniques and other utilization on the smaller scale may be related to the landscape observations.

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References

Atwill, R. 1995. ***Cryptosporidium parvum*** **and cattle: implication for public health and land use restrictions.** Davis, CA: University of California Medical Ecology and Environmental Animal Health.

Buckhouse, John C.; Gifford, Gerald F. 1976. **Water quality implications of cattle grazing on a semiarid watershed in southeastern Utah.** Journal of Range Management 29(2): 109-113.

Clark, R.B. 1992. **Marine pollution.** 3d ed. Oxford, England: Clarendon Press.

Coltharp, G.B., Darling, L.A. 1973. **Livestock grazing—a nonpoint source of water pollution in rural areas?** In: Jewell, V.H.; Swan, R., eds. Symposium proceedings. Rural Environmental Engineering. University of Vermont. Hanover, NH: University Press New England; 341-358.

Daniel, Wayne W. 1995. **Biostatistics: a foundation for analysis in the health sciences**. 6th ed. New York: John Wiley & Sons, Inc.

Ewing, Robert A.; Tosta, Nancy; Huntsinger, Lynn; Neilson, Ken; Tuazion, Raul; Marose, Robin; Monroni, Robert; Turan, Sarah. 1988. **California's forests and rangelands: growing conflict over changing uses**. Sacramento: California Department of Forestry and Fire Protection, FRRAP; 348 p.

Fedkiw, John. 1991. **Nitrate occurrence in U.S. waters**. Washington, DC: U.S. Department of Agriculture.

Fleischner, Thomas L. 1994. **Ecological costs of livestock grazing in western North America**. Conservation Biology 6(3): 629-644.

Franzreb, K.E. 1987. **Perspectives on managing riparian ecosystems for endangered bird species**. Western Birds 18: 3-9.

Hall, Deborah A.; Amy, Penny S. 1990. **Microbiology and water chemistry of two natural springs impacted by grazing in south central Nevada**. Great Basin Naturalist 50(3): 289-294.

Johnson, R.R; Haight, L.T.; Simpson, J.M. 1977. Endan**gered species vs. endangered habitats: a concept, importance, preservation, and management of riparian habitats: a symposium**. Gen. Tech. Rep. RM-43. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 68-79.

Kauffman, J.B.; Krueger, W.C. 1984. **Livestock impacts on riparian ecosystems and streamside management implications: a review**. Journal of Range Management 47: 430-437.

Larsen, Royce; George, Mel. 1995. **Risks of pathogen and nutrient transmission from grazing livestock to surface water sources based on existing literature**. University of California Extension. Browns Valley, CA: UC Sierra Foothill Research & Extension Center Beef & Range Field Day. Managing Hardwood Rangelands to Maintain and Enhance Water Quality; 5-9 p.

Meijboom, Frits; van Noordwijk, Meine. 1992. **Rhizon soil solution samplers as artificial roots, root ecology and its practical application**. Proceedings of the 3rd ISRR Symposium. Wein, Austria; 17-23 p.

Mulder, J.; Christophersen, N.; Kopperud, K.; Fjeldal, P.H. 1995. **Water flow paths and the spatial distribution of soils as a key to understanding differences in stream water chemistry between three catchments (Norway)**. Water, Air and Soil Pollution 81: 67-91.

Mulkey, Lee. 1977. **Non-point water quality modeling in wildland management**. Athens, Georgia: EPA-600/3-77-036.

Norusis, M.J. 1993. **SPSS for Windows**. Release 6.0. Chicago, IL: SPSS Inc.

Platts, William S. 1981. **Influence of forest and rangeland management on anadromous fish habitat in western North America**. 7. Effects of livestock grazing. Gen. Tech. Rep. PNW-124. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 25 p.

Platts, William S.; Armour, C.; Booth, G.; Bryant, M.; Bufford, J.; Cuplin, P.; Jensen, S.; Lienkaemper, G.; Minshall, G.; Monsen, S.; Nelson, R.; Sedell, J.; Tuhy, J. 1987. **Historic evaluation of riparian habitats.** In: Methods for evaluating riparian habitats with applications to management. Gen. Tech. Rep. INT-221. Ogden, UT: Intermountain Research Station, Forest Service, U.S. Department of Agriculture; 93-105.

Platts, W.S.; Nelson, R.L. 1989. **Characteristics of riparian plant communities and stream banks with response to grazing in northwestern Utah.** Practical approaches in riparian resource management. An educational workshop. Billings, MT: Bureau of Land Management; 3-81.

Raguse, Charles A.; Beall, Gary A.; Hull, John L.; McCreary, Douglas; Wilson, Charles B. 1990. **Thirty years of research: an overview**. University of California Sierra Foothill Range Field Station. California Agriculture 44(2): 1-3.

Stednick, John D. 1991. **Wildland water quality, sampling and analysis.** San Diego, CA: Academic Press; 217 p.

Wood, James C.; Blackburn, W.H.; Pearson, H.A.; Hunter, T.K. 1989. **Infiltration and runoff water quality response to silvicultural and grazing treatments on a long leaf pine forest**. Journal of Range Management 42(5): 378-381.

Influence of Supplemental Feeding Sites on Use of Hardwood Rangeland Riparian Areas by Cattle[1]

William E. Frost[2] Neil K. McDougald[3]

Abstract: *Over 3 years, typical cattle use on two range units left 50 percent of the riparian area with less than recommended amounts of residual dry matter (RDM). By relocating supplemental feeding sites away from these areas and into areas where high amounts of RDM were consistently left in the fall, the amount of cattle grazing in riparian areas was greatly reduced. In the 2 years of this study, use of traditional supplemental feeding locations resulted in 54 percent and 35 percent of the riparian areas being left with low amounts of RDM, contrasted to only 1 percent and 7 percent with low RDM in Range Units where new feeding locations were used.*

Hardwood rangelands are composed of several different land classes which vary in the amount of forage produced. The dispersal of livestock is best correlated with the average annual forage production per acre of each land class and not with the amount of area of each "site" present. Livestock spend much more time grazing the most productive sites, the riparian areas, than they do on the less productive slopes (when the relationship of acres available to time spent grazing is examined) (Green and others 1958; Wagnon 1963, 1968).

On these rangelands the greater use of riparian areas by cattle can result in lower amounts of residual dry matter (RDM) at the end of the grazing season (Frost and others 1988). Residual dry matter is the dry plant material left on the ground from the current year's forage growth. Moderate amounts of RDM provide a favorable microenvironment for early seedling growth, soil protection, adequate soil organic matter and a source of low quality fall forage (Clawson and others 1982). Moderate levels of RDM for riparian areas on the San Joaquin Experimental Range have been determined to be 400 to 800 pounds per acre. During a 3-year supplemental feeding trial under typical feeding practices, one half of the riparian area was consistently left with low amounts (less than 400 pounds per acre) of RDM while less productive areas were left with high amounts (more than 800 pounds per acre) (Dunbar and others 1988). The low amounts of RDM do not provide the best microenvironment for seedling growth nor the best soil protection. A means of redistributing cattle use into less productive and underutilized areas and away from riparian areas would provide more favorable conditions for forage production and soil protection than currently exists in this situation.

We report the results of a 2-year study to determine whether the use of riparian areas, expressed in terms of RDM remaining in the fall, could be affected by a low cost change in a livestock management practice. Past investigations found that relocation of salt blocks was ineffective in changing the distribution of cattle (Wagnon 1968). We examined the relocation of supplemental feeding locations into areas previously mapped as consistently having high amounts of RDM.

Study Area

The San Joaquin Experimental Range is located 28 miles northeast of Fresno, California, in Madera County, near the center of the state and in the heart of the granitic soil section of the Sierra Nevada foothills. It supports an annual plant/oak (*Quercus* spp.) woodland type vegetation and is characterized by grassy,

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rolling hills with a scattering of trees and occasional dense stands of brush. It is in the lower part of the woodland zone between the treeless valley floor and the higher brush and timber belts. Tree species include blue oak (*Quercus douglasii*), interior live oak (*Quercus wislizenii*) and foothill pine *(Pinus sabiniana*). Annual precipitation averages 19 inches, with extremes of nine and 37 inches.

Range Units 1 and 8 were used during this study. Both Units are approximately 450 acres of which more than 5 percent is considered riparian area. The Units have been classified into the following sites:

Site	*Range Unit 1*	*Range Unit 8*
Riparian	6 pct	7 pct
Rolling, open	21 pct	5 pct
Rolling, rocky , brushy	73 pct	63 pct
Steep, rocky, brushy	0 pct	25 pct
	100 pct	100 pct

The San Joaquin Experimental Range is dissected by first-, second-, and third-order intermittent stream channels. In general, stream flow occurs during the rainy season and for a few weeks into the dry season. The majority of streambanks are vegetated by annual grasses and forbs. Stream bottoms are predominantly sand with some granitic rock and boulders.

Methods

During a 3-year study (1982-85) of range cow supplementation, the amount of RDM remaining in the fall was measured and mapped for Range Units 1 and 8 (Dunbar and others 1988; Frost and others 1988). This 3-year period identified a pattern of use for riparian areas in those units. These patterns were used as the baseline to determine the effect of relocating supplemental feeding locations on the distribution of cattle use.

Supplemental feeding locations were relocated in 1986-87 in Range Unit 1 to areas which were identified as consistently having high amounts of RDM remaining in the fall. Traditional feeding locations were used in Range Unit 8. In 1987-88 these treatments were reversed, with feeding locations relocated to high RDM areas in Range Unit 8, with the feeding locations in Range Unit 1 reverting to the traditional places. Treatment reversal was conducted as a means of eliminating the effect of current year weather and forage production as the cause of a shift in the distribution of cattle use. Annual precipitation and forage production were lower in 1986-87 and 1987-88 than in the years involved in the supplemental feeding trial (1982-85), which established the cattle use distribution patterns (*table 1*). Use by cattle (expressed as animal unit months or AUM's) was similar for all years:

	Range Unit 1	*Range Unit 8*
	(use per year in AUM's)	
1982-85 average	449	469
1986-87	432	444
1987-88	440	451

In October of each year, RDM was measured and mapped using categories of high, moderate, and low (Clawson and others 1982).

Table 1—Average forage production and precipitation at the San Joaquin Experimental Range, California.

Year	Production	Date of germinating rain	Total precipitation
	lb/acre		*inches*
1982-83	3,630	Sept 26	37.4
1983-84	1,824	Oct 1	16.3
1984-85	1,690	Oct 17	13.6
1985-86	968	Sept 28	11.9
1986-87	807	Oct 29	12.1
60-year avg	2,266	Oct 28	19.1

Amounts of RDM were determined by the comparative yield method (Haydock and Shaw 1975) and visual estimation. The acreages within each RDM class were mapped, measured, and expressed as percentages of total riparian area. These percentages were examined to determine whether the change in supplemental feeding locations produced a change in the use of riparian areas.

Results and Discussion

Traditional supplemental feeding locations in Range Units 1 and 8 resulted in approximately 50 percent of the riparian areas being left with low amounts of RDM in early October during a 3-year supplemental feeding trial (Dunbar and others 1988). These feeding locations were generally located close to sources of livestock water, salting locations, or existing roads.

Supplemental feeding locations in Range Unit 1 were changed in 1986-87 on the basis of the residual dry matter maps from the previous 3 years. The locations were placed in areas where moderate or high amounts of RDM were consistently left in the fall. The relocating of feeding locations resulted in a dramatic change in RDM levels in the riparian areas. The percentage of total riparian area with low amounts of RDM was reduced from 48 percent in the 3-year baseline period to only 1 percent in 1986-87 (*table 2*). The percentage of area with moderate RDM levels was also reduced from 39 percent to 27 percent, while the percentage of riparian area with high RDM amounts was increased from 13 percent to 72 percent (*table 2*). Traditional sites were utilized in Range Unit 8 in this year. Residual dry matter amounts and patterns were similar to those in the 3-year baseline period (*table 2*).

Table 2—Percentage of riparian area within RDM classes in early October.

Year and Unit		Amount of residual dry matter		
		Low	Moderate	High
		pct	*pct*	*pct*
1982-85	Range Unit 1	48	39	13
	Range Unit 8	59	29	12
1986-87	Range Unit 1	1	27	72
	Range Unit 8	54	33	13
1987-88	Range Unit 1	35	59	6
	Range Unit 8	7	84	9

The following year, 1987-88, the Range Units were treated in the opposite manner. The supplemental feeding sites in Range Unit 8 were relocated into areas where moderate or high amounts of RDM were consistently left in the fall during the previous 4 years. This relocation resulted in a major change in the residual dry matter remaining in riparian areas. Less than 10 percent of the riparian area was left with low amounts of RDM, with more than 80 percent with moderate amounts. In Range Unit 1, where the feeding locations were placed back to the traditional sites, there was a greater percentage of riparian area with low RDM, more than 30 percent, with only 6 percent with high amounts of RDM.

These results, obtained in years of below-average forage production (*table 1*), indicate that cattle use can be manipulated through the location of supplemental feeding sites. On properly stocked rangeland, by moving supplemental feeding locations away from water sources and into areas where high amounts of RDM remain, the forage use in riparian areas of hardwood rangeland can be greatly reduced.

References

Clawson, W. James; McDougald, Neil K.; Duncan, Don A. 1982. **Guidelines for residue management on annual range.** Leaflet 21327. Oakland, CA: University of California Cooperative Extension, Division of Agricultural Sciences; 3 p.

Dunbar, John R.; McDougald, Neil K.; Jenkins, Audrey S.; Daley, Dave A.; Topping, Bart L.; Frost, William E. 1988. **Range cow supplementation**. California Agriculture. 42(5): 8-10.

Frost, William E.; McDougald, Neil K.; Clawson, W. James. 1988. **Residue mapping and pasture use records for monitoring California annual rangelands**. Davis, CA: Range Science Report No. 17. Davis: University of California Cooperative Extension; 9 p.

Green, L.R.; Wagnon, W.A.; Bentley, J.R. 1958. **Diet and grazing habits of steers on foothill range fertilized with sulfur.** Journal of Range Management 11(5): 221-227.

Haydock, K.P.; Shaw, N.H. 1975. **The comparative yield method for estimating dry matter yield of pasture.** Australian Journal of Experimental Agriculture and Animal Husbandry 15: 663-670.

Wagnon, Kenneth A. 1963. **Behavior of beef cows on a California range**. California Agricultural Experiment Station Bulletin 799. Davis, CA: Division of Agricultural Sciences, University of California; 1-58.

Wagnon, Kenneth A. 1968. **Use of different classes of range land by cattle**. California Agricultural Experiment Station Bulletin 838. Davis, CA: Division of Agricultural Sciences, University of California; 16 p.

WILDLIFE HABITAT RELATIONS AND HABITAT FRAGMENTATION

IV

Section Overview

Wildlife Habitat Relations and Habitat Fragmentation in California's Hardwood Rangelands[1]

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The nine papers in the following section on wildlife habitat relations and habitat fragmentation in hardwood rangelands from this symposium illustrate the wide diversity of these two research topics. With increasing human-induced changes to California's hardwood rangeland habitats, it is important that we understand how wildlife relate to these habitats and how wildlife are affected when habitat fragmentation occurs. This section provides some key sources of information in these areas.

Wildlife Habitat Relations

Three papers on bird communities (by Aigner and others, Tietje and others, Verner and others) and one paper on mammal communities (by Laudenslayer and Fargo) are excellent examples of the complexity of these communities and the difficulty in studying them. The papers by Aigner and others and Verner and others resulted from studies in which assessing the impacts of land management activities on birds was a major objective. While Verner and others reported on these impacts, both papers discussed many of the methodological problems associated with these types of studies. Furthermore, Verner and others noted that bird communities in a single grazed plot were relatively similar to those in a single ungrazed plot, although populations of two problematic birds, the brown-headed cowbird (*Molothrus ater*) and starling (*Sturnus vulgaris*), appeared to have increased with grazing.

Two papers provided basic natural history information on nesting habitats of two raptorial birds, the red-tailed hawk (*Buteo jamaicensis*) (by Tietje and others) and California spotted owl (*Strix occidentalis occidentalis*) (by Steger and others). These two natural history studies provide extremely useful information to wildlife scientists and managers recommending and implementing actions intended to conserve these two important raptors.

Structural components of hardwood rangeland habitats, such as logs and snags, are rarely studied, so the paper by Tietje and others on downed woody debris helps fill an obvious data gap. Data gaps for habitat components are particularly onerous because most conservation recommendations are directed at habitat components, not wildlife populations and communities.

Habitat Fragmentation

Habitat fragmentation is any process that reduces habitat continuity (Lord and Norton 1990). Oak (*Quercus* spp.) woodland habitats are fragmented by environmental processes and human activities across a wide range of spatial scales. To date, there has been very little research into either the spatial pattern of

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fragmentation in hardwood rangelands or the effects of habitat fragmentation on the distribution and abundance of wildlife species. Of the two papers presented in the Habitat Fragmentation section, one focused on fragmentation patterns and processes, and one was more concerned with wildlife effects.

Stephenson and others [these proceedings] considered regional trends in oak woodland habitats in southern California and described a coordinated regional planning effort to conserve remaining habitats. Garrison and Standiford combined plot data and growth model projections to characterize habitat changes due to tree cutting at 19 ranches in Shasta and Tehama counties. Habitat relationships models for 21 species predicted that only one species would be negatively affected by woodcutting, while seven would be positively affected and 13 would be unaffected.

Acknowledgments

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References

Aigner, Paul A.; Block, William M.; Morrison, Michael L. **Design recommendations for point counts of birds in California oak-pine woodlands: power, sample size, and count stations versus visits.** [These proceedings]

Garrison, Barrett A.; Standiford, Richard B. **A post-hoc assessment of the impacts to wildlife habitats from wood cutting in blue oak woodlands in the northern Sacramento Valley.** [These proceedings.]

Laudenslayer, William F., Jr.; Fargo, Roberta J. **Small nocturnal mammals in oak woodlands: some considerations for assessing presence and abundance.** [These proceedings]

Lord, Janice M.; Norton, David A. 1990. **Scale and the spatial concept of fragmentation.** Conservation Biology 4: 197-202.

Steger, George N.; Eberlein, Gary E.; Munton, Thomas E.; Johnson, Kenneth D. **Characteristics of California spotted owl nest sites in foothill riparian and oak woodlands of the southern Sierra Nevada, California.** [These proceedings].

Stephenson, John R.; Volgarino, Deveree A.; Nichols, G.A.; White, Thomas C. **Developing a conservation strategy for southern California forests and woodlands.** [These proceedings].

Tietje, William D.; Berlund, Tristan C.; Garcia, Sergio L.; Halpin, Christopher; Jensen, Wayne A. **Contribution of downed woody material by blue, valley, and coast live oaks in central California.** [These proceedings].

Tietje, William D.; Bloom, Peter H.; Vreeland, Justin K. **Characteristics of red-tailed hawk nest sites in oak woodlands of central California.** [These proceedings].

Tietje, William D.; Vreeland, Justin K.; Siepel, Nancy K.; Dockter, Jo Ann L. **Relative abundance and habitat associations of vertebrates in oak woodlands in coastal-central California.** [These proceedings].

Verner, Jared; Purcell, Kathryn L.; Turner, Jennifer G. **Bird communities in grazed and ungrazed oak-pine woodlands at the San Joaquin Experimental Range.** [These proceedings].

Characteristics of California Spotted Owl Nest Sites in Foothill Riparian and Oak Woodlands of the Southern Sierra Nevada, California[1]

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Abstract: *Forty-one California spotted owl (*Strix occidentalis occidentalis*) nest sites were examined in foothill riparian and oak woodlands at 1,140 to 4,200 feet in elevation in the Sierra National Forest and Sequoia National Park, California. Nest sites were generally located on the lower 1/3 of the slope where dense canopy cover (averaging 86 percent) and multiple layers of vegetation were present. Aspects at nest sites were either west, north, or east; southern aspects were not used. Slopes ranged from nearly flat to more than 100 percent, but preference for a particular range of slopes was not detected. We found 24 platform nests, 13 side cavity nests and four top cavity nests. Nests were located in California sycamore (*Platanus racemosa*), ponderosa pine (*Pinus ponderosa*), and five species of oaks (*Quercus *spp.). Nest trees averaged 24 inches in diameter (range 7 to 54 inches) with a mean tree height of 62 feet and nest height of 39 feet. Nest tree diameters were smaller, basal area of live trees lower, and the percent of platform nests greater than results reported for nests in Sierra Nevada conifer forests.*

California spotted owls (*Strix occidentalis occidentalis*) in the Sierra Nevada nest in a variety of tree species in different habitats. Historically, research has concentrated on nest sites in conifer habitats above 3,000 feet in elevation. Characteristics such as dense canopy and large decadent trees with cavities appear to be critical to successful nesting in conifer habitat (Verner and others 1992). Conifers with oak understory in southern California and stands dominated by canyon live oak (*Q. chrysolepis*) along the southern coast of California have been identified as habitats used by California spotted owls (Gould 1977, Gutiérrez and Pritchard 1990). Migrating spotted owls use oak woodlands along the Sierra Nevada as wintering areas (Laymon 1988, Verner and others 1991), and owls in the southern Sierra Nevada can be found in oak habitats throughout the year, including the breeding season (Steger and others 1993, Verner and others 1991). Despite these observations, little is known about nest site characteristics of Sierra Nevada oak woodland areas where breeding is known to occur. This paper describes the characteristics of nest trees, nest structures, associated vegetation, and physical attributes at spotted owl nest sites in the southern Sierra Nevada oak woodlands. Comparisons of nest sites on National Forest lands to those on National Park lands are also reported.

Study Area

This study was conducted in the southern Sierra Nevada in the Sierra National Forest (SNF) and Sequoia National Park (SNP), California (*fig. 1*). The SNF study area covered 61 mi^2, and the SNP study area covered 32 mi^2. The study areas ranged in elevation from 1,140 to 4,200 feet within blue oak-gray pine, montane hardwood, and valley-foothill riparian wildlife habitats as defined by Mayer and Laudenslayer (1988).

[1] An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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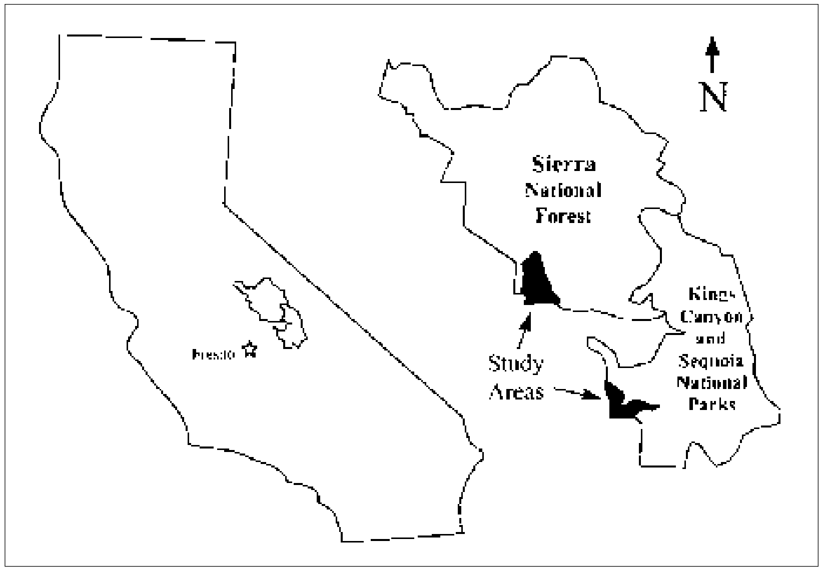

Figure 1—Locations of study areas in the Sierra National Forest (SNF) and Sequoia National Park (SNP), California.

Methods

California spotted owl nest trees were located from 1990 through 1995 using methods described by Forsman (1983). Data were collected at all known nest sites regardless of the owls' reproductive success. Nest trees were identified to species, and condition as a live tree or snag was recorded. The diameter of each nest tree was measured at breast height (DBH) (4.5 feet) with a diameter tape. Height of the nest tree and nest were measured with a Relaskop. Nests were described as platform (raptor nests or mistletoe), top cavity, or side cavity. Topographical information (aspect, slope, position on slope, elevation, type and distance to nearest water, and distance to and type of nearest road) was recorded at each nest site. Vegetation measurements around each nest were taken on a 0.3-acre plot that consisted of four 0.07-acre (33 feet × 98 feet) strip plots each starting 16 feet from the nest tree and radiating outward in each cardinal direction. Canopy cover was measured at 16, 33, and 82 feet from the nest tree along each strip plot using a spherical densiometer, and means of these measurements were calculated to determine the canopy cover for the plot. All live woody vegetation greater than 6 feet tall was considered trees, and all dead trees >5 inches DBH and >6 feet tall were considered snags. Those trees or snags with half or more of the bole rooted inside the plot were identified to species and measured for DBH and height. Large woody debris, greater than 10 inches in diameter, within the plot, was measured for small-end and large-end diameters and length. Live woody vegetation less that 6 feet tall was considered shrub cover and grouped by type: conifer, hardwood, shrub (evergreen and deciduous), and fern. Ground cover was classified as rock, soil, large litter (2 to 10 inches), small litter (<2 inches), herb, grass, moss, and lichen. Shrub cover and ground cover were measured along a line intercept through the middle of the 0.07-acre strip plots.

A two-sample *t*-test was used to evaluate differences between the vegetative measurements around nest sites on the SNF and SNP. Basal areas in square feet per acre and stems per acre for live trees and snags were calculated by vegetative category (oaks, conifers, and other species) and 10-inch stem diameter classes using the data from the 0.3-acre plots. The heights of live trees were categorized by the stem diameter classes, and means were calculated. Downed woody debris larger than 10 inches in diameter was used to calculate cubic feet and tons of debris per acre. Line intercept measurements (shrub cover and ground cover) were reported as the proportion of the line dominated by each of the categories. Means and standard deviations were calculated.

Results

Forty-one spotted owl nests in foothill riparian and oak woodland habitats were examined—26 in SNF and 15 in SNP. Thirty-six nests (88 percent) were found in oaks, two in California sycamores, two in ponderosa pines and one on a rock cliff. Interior live oak (*Q. wislizenii*), black oak (*Q. kelloggii*), and canyon live oak were the most commonly used for nests (*table 1*). All nest trees were live except for one black oak snag. Average DBH for all nest trees was 24 inches (± 12.6). Interior live oak had the smallest average DBH at 14.7 inches (± 6.0; range = 7–27 inches), and a single valley oak (*Q. lobata*) was the largest at 41 inches (*table 2*). Mean diameters of nest trees were consistently larger than the mean diameter of those same species from around the nest sites. Only 5 percent of the trees from around the nest sites had a DBH larger than the mean nest tree diameter. Height of nest trees and nests averaged 62 feet (± 22.8) and 39 feet (± 15.7), respectively. Canopy cover did not differ between the 16- and 33-foot samples (t = 0.295, df = 80, P = 0.768), the 16- and 82-foot samples (t = 0.03, df = 80, P = 0.975), or the 33- and 82-foot samples (t = -0.296, df = 80, P = 0.767). Combined canopy cover at all nest sites averaged 87 percent (± 14; range = 25-99 percent) (*table 1*) and did not differ between study areas (t = 0.672, df = 39, P = 0.505).

We found 24 (58.5 percent) platform, 13 (31.5 percent) side cavity, and 4 (10 percent) top cavity nests. All platform nests were associated with interior live oak or canyon live oak trees, except for one on a rock cliff and another in a ponderosa pine. Mean DBH of platform nest trees (17 inches ± 8.5) was significantly smaller (t = 5.53, df = 38, P < 0.01) than the mean DBH of trees that supported cavity nests (34 inches ± 10.7). The platform nest site found on the rock cliff in the SNF was a stick structure on a small ledge 32 feet up on a 40-foot cliff. Elevation at the nest site was 4,100 feet, and the canopy around the nest site was open (25 percent canopy cover).

Table 1—Structural attributes of California spotted owl nest sites in the Sierra National Forest (SNF) and Sequoia National Park (SNP) study areas, southern Sierra Nevada, California

Study area Tree species and rock	No. snags	No. live trees	Mean tree height		Mean nest height		Nest platform	Nest cavities	Mean canopy cover	
Sierra National Forest			*ft*	*SD*	*ft*	*SD*	*no.*	*no.*	*pct*	*SD*
Quercus chrysolepis	0	1	52	±0.0	46	±0.0	1	0	98.3	±0.3
Quercus kelloggii	0	3	50	±26.5	36	±10.0	0	3	89.9	±6.4
Quercus wislizenii	0	14	54	±12.8	39	±7.7	14	0	87.0	±9.7
Quercus douglasii	0	4	70	±31.3	36	±11.4	0	4	86.0	±14.5
Quercus lobata	0	1	66	±0.0	30	±0.0	0	1	88.6	±5.4
Platanus racemosa	0	2	82	±9.3	26	±4.5	0	2	86.2	±6.9
Pinus ponderosa	0	1	138	±0.0	92	±0.0	1	0	95.3	±2.9
Sequoia National Park										
Quercus chrysolepis	0	7	58	±13.0	49	±12.6	7	0	96.8	±3.5
Quercus kelloggii	1	5	60	±23.4	33	±10.5	0	6	79.7	±17.2
Pinus ponderosa	0	1	102	±0.0	82	±0.0	0	1	92.4	±3.2
Rock	-	-	-	-	-	-	1	-	25.4	±29.6

Table 2—Diameter of nest trees of California spotted owls and samples of diameters of similar tree species from around the nest trees in the Sierra National Forest (SNF) and Sequoia National Park (SNP) study areas, southern Sierra Nevada, California.

Study area / Tree species	Nest tree No.	Mean diameter		Sampled trees No.	Mean diameter		No. of trees larger than mean nest tree
		in.	*SD*		*in.*	*SD*	
Sierra National Forest							
Quercus chrysolepis	1	15.7	±0.0	33	10.5	±8.3	3
Quercus kelloggii	3	41.6	±17.1	29	12.8	±7.3	0
Quercus wislizenii	14	14.7	±6.0	466	9.1	±3.7	38
Quercus douglasii	4	35.5	±13.0	88	9.8	±6.9	2
Quercus lobata	1	40.9	±0.0	16	12.9	±6.0	0
Platanus racemosa	2	26.9	±0.3	70	13.0	±3.7	0
Pinus ponderosa	1	29.1	±0.0	20	16.3	±6.8	0
Sequoia National Park							
Quercus chrysolepis	7	21.0	±11.5	277	10.2	±4.4	9
Quercus kelloggii	5	30.1	±8.0	70	13.9	±5.2	0
Pinus ponderosa	1	36.6	±0.0	10	10.9	±7.6	0

Nest sites of California spotted owls were on slopes ranging from 0 to 105 percent (mean = 43.5 percent ± 24.5). No preference for a particular range of slopes was detected. Slopes at nest sites in the SNF (mean = 32.4 percent ± 18.8, range = 0-60 percent) were significantly different ($t = 4.7$, df = 39, $P = 0.0001$) from those in the SNP (mean = 62.7 percent ± 21.6, range = 28-105 percent). Nest sites tended to be located on the lower third of the slope, but distance to permanent water was usually greater than 330 feet in both study areas (*table 3*). Owls nested on all aspects except those ranging between 135 to 225 degrees (*fig. 2*). Owl nests tended to be greater than 330 feet from the nearest road in both study areas, although two nests were located within 33 feet of improved roads in the SNF study area (*table 3*).

Structural attributes of the vegetation around nests in the foothill riparian and oak woodlands were variable among sites and between study areas (*tables 4* and *5*). Total number of live trees at nest sites in both study areas averaged 874 stems per acre (± 622), with no significant difference between study areas ($t = 0.99$, df = 39, $P = 0.33$). We did find that approximately 85 percent of the total stems per acre were under 5 inches in DBH and there were more small oaks under 5 inches DBH on the SNP (411 ± 337) compared to the SNF (163 ± 112). Total basal area of live trees was greater on the SNP (130 sq. ft/acre) than on the SNF (105 sq. ft/acre) but did not differ significantly ($t = 1.50$, df = 39, $P = 0.15$). Oak trees with diameters ranging from <5 to 30 inches accounted for 86 and 68 percent of the basal area in the SNP and SNF, respectively. The SNP study area tended to have higher basal area and more hardwood stems with diameters between <5 to 30 inches, while the SNF had greater basal area and stems of larger (31- to 60-inch) hardwoods.

Plant species over 6 feet tall, other than oaks and conifers, accounted for approximately half of the live stems on both study areas, but represented only 15 percent of the total basal area (*table 4*). The majority of these other species were <5 inches DBH, had high variability in stem densities between plots, and were similar in number of stems and basal area on both study areas. Other species 5 to 60 inches in DBH were significantly greater in basal area ($t = 3.72$, df = 39,

Table 3—Physiographic attributes of California spotted owl nest sites in the Sierra National Forest (SNF) and Sequoia National Park (SNP) study areas, southern Sierra Nevada, California.

Physiographic attribute	SNF	SNP
Mean elevation *(ft)*	2045.0	3715.0
Mean slope *(pct)*	32.4	62.7
No. of nests by:		
Topographical position		
Upper 1/3	8	2
Middle 1/3	4	5
Lower 1/3	13	8
Distance to water *(ft)*		
<33	6	3
33-98	3	1
99-330	1	2
>330	16	8
Distance to road *(ft)*		
<33	2	0
33-98	0	0
99-330	3	0
>330	21	15

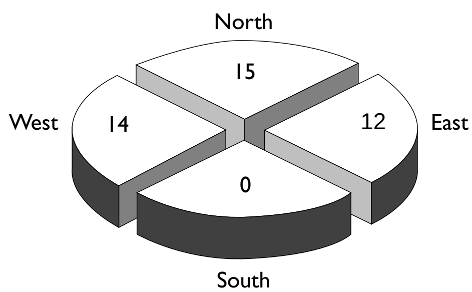

Figure 2—Frequency distribution of nest sites by aspect at 41 California spotted owl nests on the Sierra National Forest and Sequoia National Park, southern Sierra Nevada, California.

P = 0.001) and stem density (t = 3.18, df = 39, P = 0.003) on the SNF than on the SNP. Basal area of conifers, which were present at only 13 nest sites, accounted for only 4.5 (± 11.0) ft^2/acre and 7 stems/acre, 4 of which were <5 inches DBH.

Canopy structure for both study areas was composed of a dense understory (743 stems/acre) of trees <5 inches DBH averaging 13 feet in height, a dominant canopy structure made up of a moderately dense (129 stems/acre) layer of 5- to 30-inch DBH trees from 31- to 60- feet in height, and a sparse layer (<1 stem/acre) of 31- to 60-inch DBH trees from 68- to 102- feet in height (*table 4*).

An average of 14 (± 11.0) snags per acre were at nest sites in oak woodlands, with the majority (12 ± 8.9) being small (5- to 20-inch DBH) hardwoods (*table 5*). Basal area of snags was greater in the SNP (12.2 ± 13.0 ft^2/acre) than in the SNF (5.7 ± 5.6 ft^2/acre) but did not differ significantly (t = 1.72, df = 39, P = 0.11). Downed woody debris differed significantly (P = 0.05) between study sites (*table 5*). The SNP nest sites averaged 331 (±260) ft^3 (4 tons) per acre of woody debris, whereas those in the SNF contained only 156 (± 156) ft^3 (2 tons) per acre.

The vegetative cover on the forest floor at owl nest sites was similar in both study areas (*table 5*). Generally, we found about 20 percent cover of small shrubs and ferns, whereas the majority of ground cover was small litter (60 ± 25 percent) and grass (21 ± 24 percent). Two shrub cover attributes (evergreen shrub and fern) and one ground cover attribute (large ground litter) differed significantly (P = 0.03) between the study areas, but the overall quantities of these attributes were low (*table 5*).

Table 4—Live tree characteristics at California spotted owl nest sites in the Sierra National Forest (n = 26) *and the Sequoia National Park* (n = 15) *study areas in the southern Sierra Nevada, California*

Attributes	Diameter at breast height by size class	Sierra Mean	Sierra SD	Sequoia Mean	Sequoia SD	*t*-test	*P*
Live trees basal area		*ft² per acre*					
Oaks	<5 in.	14.3	±8.7	25.5	±29.2	1.45	0.17
	5-10 in.	21.1	±11.8	25.2	±19.9	0.73	0.47
	11-20 in.	28.8	±15.2	41.7	±25.5	1.79	0.09
	21-30 in.	7.3	±8.5	18.8	±20.9	2.04	0.06
	31-40 in.	4.4	±9.2	1.2	±4.5	1.49	0.14
	41-50 in.	1.2	±5.9	0.0	0.0	1.00	0.32
	51-60 in.	2.0	±10.2	0.0	0.0	1.00	0.32
Subtotal	5-60 in.	64.7	±26.8	89.9	±43.8	1.78	0.08
Conifers	<5 in.	0.4	±1.2	0.3	±1.4	0.15	0.88
	5-60 in.	4.7	±12.0	3.1	±6.7	0.55	0.58
Other species	<5 in.	12.6	±10.4	12.3	±11.4	0.07	0.93
	5-60 in.	7.8	±5.2	1.8	±4.8	3.72	0.001
Total basal area		**104.5**	**±34.2**	**130.0**	**±60.3**	**1.50**	**0.15**
Live trees, number		*stems per acre*					
Oaks	<5 in.	163.6	±111.6	410.9	±337.2	2.76	0.01
	5-10 in.	69.0	±41.0	80.9	±57.9	0.70	0.49
	11-20 in.	28.0	±12.9	34.6	±22.2	1.05	0.30
	21-30 in.	2.5	±2.8	5.8	±6.7	1.87	0.08
	31-40 in.	0.7	±1.4	0.2	±0.9	1.22	0.23
	41-50 in.	0.1	±0.7	0.0	0.0	1.00	0.32
	51-60 in.	0.1	±0.7	0.0	0.0	1.00	0.32
Subtotal	5-60 in.	100.4	±41.3	121.6	±68.9	1.08	0.28
Conifers	<5 in.	5.2	±14.4	1.3	±4.4	0.26	0.79
	5-60 in.	2.9	±6.4	2.9	±9.5	0.02	0.98
Other species	<5 in.	501.8	±593.3	456.6	±482.3	0.27	0.79
	5-60 in.	26.3	±18.8	7.0	±18.7	3.18	0.003
Total live trees		**800.0**	**±616.7**	**1000.5**	**±632.3**	**0.99**	**0.33**
Height		*feet*					
All live trees	<5 in.	13.0	±3.2	12.4	±3.5	0.18	0.86
	5-10 in.	32.0	±5.0	31.0	±7.9	0.47	0.64
	11-20 in.	48.0	±8.5	53.3	±20.6	0.32	0.75
	21-30 in.	57.8	±33.6	60.0	±34.2	0.47	0.73
	31-40 in.	68.9	—	—	—	—	—
	41-50 in.	98.4	—	—	—	—	—
	51-60 in.	101.7	—	—	—	—	—

Discussion

The presence of California spotted owls in the foothill riparian and oak woodlands of the Sierra Nevada is not widely documented. Grinnell and Miller (1944) described the life zones occupied by the California spotted owl as the Upper Sonoran and Transition, with the altitude of occurrence mostly between 2,500 and 6,000 feet. Gould (1977) described the spotted owl in the southern Sierra Nevada as being found almost exclusively in the mixed-conifer zone, although their use of oaks along the south coast of California was identified. Since 1977, as interest in the California spotted owl increased because of concerns over logging in the coniferous habitats, incidental sightings of spotted owls in oak habitats have become more common. Laymon (1988) identified oak woodlands as wintering areas for migrating spotted owls in the central Sierra Nevada. Steger and others (1993) and Verner and others (1992) reported year-round use with breeding in the oak woodlands of the southern Sierra Nevada. Steger and others (1993) described the crude density of spotted owls in oak

Table 5—*Snags, down logs, shrubs, and ground cover characteristics of California spotted owl nest sites in the Sierra National Forest* (n = 26) *and the Sequoia National Park* (n = 15) *study areas in the southern Sierra Nevada, California*

Attributes	Diameter at breast height by size class	Sierra Mean	Sierra SD	Sequoia Mean	Sequoia SD	*t*-test	*P*
Snags basal area		----- ft^2 per acre -----					
Oaks	5-10 in.	2.8	±2.6	2.0	±1.9	1.12	0.26
	11-20 in.	2.1	±3.9	3.1	±3.9	0.84	0.41
	21-30 in.	0.5	±2.6	1.5	±4.2	0.95	0.34
	31-40 in.	0.0	0.0	1.6	±6.5	1.00	0.33
	41-50 in.	0.0	0.0	2.1	±8.0	1.00	0.33
	51-60 in.	0.0	0.0	0.0	0.0	-	-
Subtotal	5-60 in.	5.4	±5.5	10.4	±12.3	1.49	0.15
Conifers	(All)	0.1	±0.3	1.8	±6.8	0.99	0.33
Other species	(All)	0.3	±0.7	0.1	±0.1	2.15	0.04
Total Snag basal area		**5.7**	**±5.6**	**12.2**	**±13.0**	**1.72**	**0.11**
Snags, number		----- *stems per acre* -----					
Oaks	5-10 in.	10.4	±8.5	8.1	±7.8	0.86	0.39
	11-20 in.	1.9	±3.3	2.7	±3.2	0.71	0.48
	21-30 in.	0.1	±0.7	0.4	±1.2	0.96	0.35
	31-40 in.	0.0	0.0	0.2	±0.9	1.00	0.33
	41-50 in.	0.0	0.0	0.2	±0.9	1.00	0.33
	51-60 in.	0.0	0.0	0.0	0.0	-	-
Subtotal	5-60 in.	12.5	±9.1	11.7	±8.5	0.26	0.79
Conifers	(All)	0.1	±0.7	2.6	±9.6	1.04	0.31
Other species	(All)	1.2	±2.1	0.2	±0.9	1.99	0.06
Total snags		**13.8**	**±10.4**	**14.6**	**±13.1**	**0.22**	**0.83**
Woody debris		----- *tons per acre*[1] -----					
All logs >10 in.		2.0	±2.0	4.3	±3.3	2.08	0.05
Woody debris		----- ft^3 *per acre* -----					
All logs >10 in.		155.8	±155.7	330.9	±260.1	2.08	0.05
Shrub cover		----- *percent* -----					
Conifer		0.3	±0.1	0.0	0.0	-	-
Hardwood		1.2	±1.1	2.0	±3.0	1.01	0.33
Evergreen		0.3	±0.8	2.8	±3.0	2.44	0.03
Deciduous		13.3	±12.9	11.5	±12.2	0.45	0.65
Fern		0.9	±1.9	5.4	±5.3	3.16	0.01
Total shrub cover		**15.8**	**±13.7**	**21.7**	**±14.1**	**1.19**	**0.24**
Ground cover		----- *percent* -----					
Rock		4.4	±5.9	7.2	±12.3	0.82	0.42
soil		4.2	±6.4	1.5	±1.8	2.01	0.06
Large litter		1.5	±1.0	2.8	±1.9	2.36	0.03
Small litter		57.0	±23.3	66.7	±26.0	1.18	0.24
Herbaceous		4.1	±7.8	3.2	±5.7	0.45	0.65
Grass		23.7	±23.5	15.2	±24.5	1.08	0.28
Moss		4.5	±5.7	2.9	±4.1	1.03	0.31
Lichen		0.3	±1.1	0.4	±1.6	0.20	0.85

[1] Assumes a specific gravity of 0.4 for downed woody debris.

woodlands of Sequoia National Park at 0.376 owls/mi^2, which is slightly lower than the density (0.529 owls/mi^2) in the mixed-conifer type. Further investigation of the distribution, population size, and reproductive potential of California spotted owls in the oak woodlands of the Sierra Nevada is needed.

California spotted owls do not build their own nest. They rely on naturally occurring sites such as large cavities, trees and snags with broken tops, or, to a lesser extent, platforms associated with abandoned raptor nests, squirrel nests, mistletoe brooms, or debris accumulations (Verner and others 1992). In the southern Sierra Nevada foothill riparian and oak woodland habitats, 59 percent of the spotted owl nests were on platforms. These platform structures were most likely stick nests abandoned by raptors, squirrels, or ravens. Platform nest trees in our study areas were significantly smaller in diameter than cavity nest trees. High incidences of platform nest utilization have been reported for the Mexican spotted owl (*S. o. lucida*) (Seamans and Gutiérrez 1995) and northern spotted owl (*S. o. caurina*) (Buchanan and others 1993) in mixed-conifer and conifer/ hardwood forests. In both of these studies the average nest tree diameters were smaller than those commonly reported for nest trees in conifer forests where cavity nesting is more common. In our study area, the presence of large platform structures, used by California spotted owls to nest, may allow reproduction in foothill riparian and oak woodlands where tree diameters are not large enough to provide cavities of suitable size for nesting.

California spotted owls in foothill riparian and oak woodlands selected nest structures in seven species of trees, with interior live oaks the most frequently used (34 percent). Nest trees in foothill riparian and oak woodlands had a mean diameter of 23 inches and a mean height of 59 feet and were smaller in diameter and shorter in height than those typically reported for conifer forests. For example, Gutiérrez and others (1992) reported that nest trees in conifer habitats were typically large, averaging 90 feet tall and 41 inches DBH, with more than 75 percent of the nest trees more than 30 inches DBH. Regardless of the size difference between nest trees in coniferous habitats and those reported here for the foothill riparian and oak woodlands, trees with larger diameters seem to support the nest structures selected by spotted owls, especially cavity nest sites.

One platform nest was located on a rock ledge in the SNP study area in 1992. Nest sites on rock ledges have been reported before for California spotted owls (Peyton 1910), but no recent observations of this nesting behavior have been made (Gutiérrez and others 1992). Mexican spotted owls have been observed nesting on cliff ledges and in potholes on cliffs (Ganey 1988, Seamans and Gutiérrez 1995).

Canopy cover at nest sites in oak woodlands averaged 86 percent. This is consistent with the average 75.4 percent canopy cover reported for nest sites in Sierra Nevada conifer forests (Gutiérrez and others 1992) and generally reflects canopy densities at nest sites for all three subspecies of spotted owls (Ganey 1988, Thomas and others 1990, Verner and others 1992).

In our study areas, most owls used the lower third of the slope and northern aspects for nesting. Aspect, slope, and position of nest sites in the lower third of drainage bottoms in foothill riparian and oak woodlands are probably related to the location of adequate canopy cover. Dense stands of oaks and sycamore are usually found near the bottom or on the north-facing aspects of drainages. Nesting on the lower third of the slope and use of primarily northern aspects have been reported for all spotted owl subspecies, although this type of activity is not consistent across all studies (Blakesley and others 1992, Buchanan and others 1993, Gutiérrez and others 1992, LaHaye 1988, Seamans and Gutiérrez 1995). Use of dense canopy, steep slopes, and northern aspects may also play a role in thermoregulation (Barrows and Barrows 1978). Distance to water from nest sites on our study areas was usually greater than 330 feet, the maximum distance measured. Thus water did not seem to be a limiting factor for nest location at our scale of measurement.

Vegetative structure associated with California spotted owl nests in foothill riparian and oak woodlands varied considerably between sites. The total basal area of live trees in the SNF (104.5 ft^2/ac) and SNP (130.0 ft^2/ac) represents a medium stand density class (71–155 ft^2/ac) for native hardwood species in California's central coast (Pillsbury 1979). Basal area was highest in the 11- to 20-inch tree diameter class in both SNF and SNP. In contrast, the highest basal areas for conifer nest sites of the California spotted owl were from the large tree component (>25 inches) (Gutiérrez and others 1992). Total basal areas for the oak woodland nest sites were roughly half those found at conifer nest sites. In the foothill riparian and oak woodlands of the southern Sierra Nevada, we found that approximately 100 oaks per acre in the 5- to 30-inch size class and 31- to 60-foot heights provided suitable nesting cover for California spotted owls. The presence of a few pairs of owls nesting in a relatively open site, as low as 25 percent canopy closure, is unusual, but the short-term need for an adequate nest structure may be compelling enough to pull birds from denser canopy-covered areas.

Concerns for the California spotted owl in foothill riparian and oak woodlands of the southern Sierra Nevada involve potential impacts from habitat disturbance. Fire, human occupation and residential development, logging, firewood cutting, and livestock grazing affect these habitats (Gould 1977, Verner and others 1992). In our study area, the SNP was found to have a significantly higher hardwood basal area and nearly three times as many stems per acre of oaks <5 inches DBH than the SNF. Possible reasons contributing to the differences between study areas may have been fire frequency and livestock grazing. Further investigation is need to determine whether these disturbances affect spotted owls.

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References

Barrows, Cameron; Barrows, Katherine. 1978. **Roost characteristics and behavioral thermoregulation in the spotted owl.** Western Birds 9(1): 1-8.

Blakesley, Jennifer A.; Franklin, Alan B.; and Gutiérrez, R.J. 1992. **Spotted owl roost and nest site selection in northwestern California.** Journal of Wildlife Management 56: 388-392.

Buchanan, Joseph B.; Irwin, Larry L.; McCutchen, Edwin L. 1993. **Characteristics of spotted owl nest trees in the Wenatchee National Forest.** Journal of Raptor Research 27(1): 1-7.

Forsman, Eric D. 1983. **Methods and materials for locating and studying spotted owls.** Gen. Tech. Rep. PNW-162. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 8 p.

Ganey, Joseph L. 1988. **Distribution and habitat ecology of Mexican spotted owls in Arizona**. Flagstaff: Northern Arizona University; 229 p. M.S. thesis.

Gould, Gordon I., Jr. 1977. **Distribution of the spotted owl in California.** Western Birds 8(4): 131-146.

Grinnell, Joseph; Miller, Alden H. 1944. **The distribution of the birds of California.** Pacific Coast Avifauna. No. 27: 1-608.

Gutiérrez, R.J.; Pritchard, J. 1990. **Distribution, density, and age structure of spotted owls on two southern California habitat islands.** Condor 92: 491-495.

Gutiérrez, R.J.; Verner, Jared; McKelvey, Kevin S.; Noon, Barry R.; Steger, George N.; Call, Douglas R.; LaHaye, William S.; Bingham, Bruce B.; Senser, John S. 1992. **Habitat relations of the California spotted owl.** In: Verner, Jared; McKelvey, Kevin S.; Noon, Barry R.; Gutiérrez, R.J.; Gould, Gordon I., Jr.; Beck, Thomas W., technical coordinators. The California spotted owl: a technical assessment of its current status. Gen. Tech. Rep. PSW-GTR-133. Albany, CA: Pacific Southwest Research Station, Forest Service, U. S. Department of Agriculture; 79-98.

LaHaye, William S. 1988. **Nest site selection and nesting habitat of the northern spotted owl (*Strix occidentalis caurina*) in northwestern California.** Arcata, CA: Humboldt State University; 111 p. Thesis.

Laymon, Stephen. A. 1988. **The ecology of the spotted owl in the central Sierra Nevada, California.** Berkeley: University of California; 285 p. Dissertation.

Mayer, Kenneth E.; Laudenslayer, William F., Jr., editors. 1988. **A guide to wildlife habitats of California.** Sacramento: California Department of Forestry and Fire Protection; 166 p.

Peyton, Lawrence. 1910. **Nesting of the spotted owl in northeastern Los Angeles County, California.** Condor 12: 122-123.

Pillsbury, Norman. H. 1979. **Inventory and quantification of central coast hardwood resources in California.** In: Plumb, Timothy R., technical coordinator. Proceedings of the symposium on the ecology, management and utilization of California oaks, 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 92-100.

Seamans, Mark E.; Gutiérrez, R.J. 1995. **Breeding habitat of the Mexican spotted owl in the Tularosa Mountains, New Mexico.** Condor 97: 944-952.

Steger, George N.; Munton, Thomas E.; Verner, Jared. 1993. **Preliminary results from a demographic study of spotted owls in Sequoia and Kings Canyon National Parks, 1990-1991.** In: Veirs, Stephen D., Jr.; Stohlgren, Thomas J.; Schonewald-Cox, Christine, eds. Proceedings of the fourth conference on research in California's National Parks. NPS/NRUC/NRTP-93/9. Davis, CA: Cooperative Park Studies Unit, University of California; 83-92.

Thomas, Jack W.; Foresman, Eric D.; Lint, Joseph B.; Meslow, E. Charles; Noon, Barry R.; Verner, Jared. 1990. **A conservation strategy for the northern spotted owl.** Washington, DC: U S. Government Printing Office; 427 p.

Verner, Jared; Gutiérrez, R.J.; Gould, Gordon I., Jr. 1992. **The California spotted owl: general biology and ecological relations.** In: Verner, Jared; McKelvey, Kevin S.; Noon, Barry R.; Gutiérrez, R.J.; Gould, Gordon I., Jr.; Beck, Thomas W., technical coordinators. The California spotted owl: a technical assessment of its current status. Gen. Tech. Rep. PSW-GTR-133. Albany, CA: Pacific Southwest Research Station, Forest Service, U S. Department of Agriculture; 55-77.

Verner, Jared; Steger, George N.; Eberlein, Gary P.; Leal, David A.; Munton, Thomas E. 1991. **Annual progress report: 1990. Part 1: Spotted owl home-range size and composition in the Sierra National Forest. Part 2: Demography of spotted owls in the Sierra National Forest and Sequoia/Kings Canyon National Parks.** Unpublished draft supplied by author.

Characteristics of Red-tailed Hawk Nest Sites in Oak Woodlands of Central California[1]

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Abstract: *Characteristics of nest sites of red-tailed hawks (*Buteo jamaicensis*) have not been described for the 3.1 million ha of California oak (*Quercus *spp.) woodlands. From 1992 to 1995, we located 44 active red-tailed hawk nests in oak woodlands in San Luis Obispo and Monterey Counties, California. We measured 19 characteristics that describe the nest, nest tree, vegetation, and topography within 0.04-ha circular plots centered on the nest tree and on randomly-selected, paired plots. Thirty-four nest trees were oaks. Tree diameter at breast height (dbh), height, and maximum canopy width were significantly greater (all* P $\leq$ *0.0001) for nest trees than for random trees (85.3 ± 4.1 cm [mean ± SE] vs. 62.6 ± 3.7 cm in dbh, 19.9 ± 1.1 m vs. 13.3 ± 0.7 m in height, and 11.4 ± 0.5 m vs. 9.1 ± 0.4 m trunk to drip line, respectively). Anthropogenic activities, including grazing, firewood cutting, and housing development should maintain a component of the largest trees in oak woodlands to conserve red-tailed hawk nest sites.*

Nesting habitat of red-tailed hawks (*Buteo jamaicensis*) has been described for several parts of North America (Bednarz and Dinsmore 1982, Belyea 1976, Bohm 1978, Gates 1972, Petersen 1979). One other study examined nesting habitat of red-tailed hawks in tropical habitats at the southeastern-most limit of their range (Santana and others 1986). These studies identified particular characteristics of nesting substrate and the landscape selected for nesting sites. To our knowledge, no study has yet evaluated nesting requirements of red-tailed hawks in California's 3.1 million ha of oak (*Quercus* spp.) woodlands.

Californians value their state's oak woodlands for livestock and wood production, esthetics, recreation, watershed protection, and wildlife habitat. In some areas of California, poor regeneration of some native oak species, urbanization, wood cutting, and poor land-management practices have raised concern about the long-term sustainability of oak woodlands (Pavlik and others 1991). If these woodlands continue to be degraded or destroyed, shortages of acceptable nest sites may limit nesting populations of red-tailed hawks.

Our objectives were to describe nest trees and associated vegetation and topographical characteristics of nest-sites of red-tailed hawks in oak woodlands of central California, and to determine if red-tailed hawks are selecting nest sites with particular characteristics. These data may serve as baseline information to aid managers in evaluating human effects on red-tailed hawk habitat and in its conservation.

Study Area

From 1992 to 1995, we located active nests of red-tailed hawks on three private livestock ranches (Avenales, Camatta, and Canyon) and on Camp Roberts Military Facility (CRMF) of the Army National Guard (*fig. 1*). The ranches were chosen primarily on the basis of an active livestock production enterprise on the ranch and the ability to gain access. These ranches are typical of central California oak woodlands and represent a continuum of stand densities and tree species compositions. Since the late 1800's, the primary land use on the ranches has been

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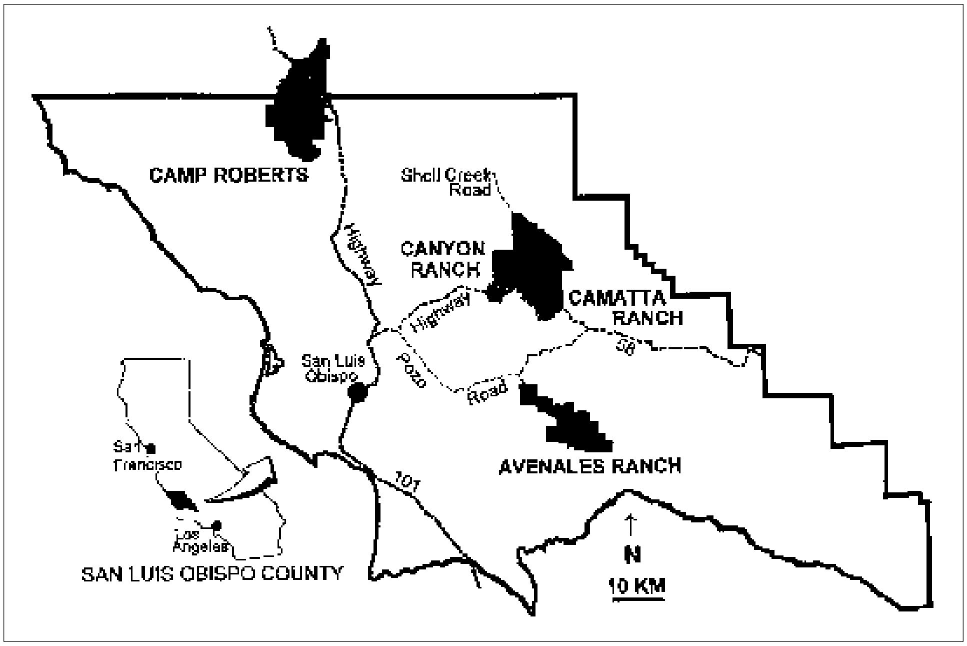

Figure 1—Location of the Avenales, Canyon, and Camatta Ranches and the Camp Roberts Military Facility on which 44 red-tailed hawk nests were located in oak woodlands, central California, 1992 to 1995.

cattle grazing. Livestock are grazed seasonally on the grasslands and open woodlands of the CRMF.

Topography on the four sites generally is hilly. The climate of the area is Mediterranean, characterized by warm, dry summers and cool, wet winters. Nearly all precipitation occurs during October to May. Snowfall is rare. The dominant tree species in the oak woodlands on these study sites are blue oak (*Quercus douglasii*) and coast live oak (*Q. agrifolia*). Gray pine (*Pinus sabiniana*) is interspersed with the blue oak, except at CRMF where gray pine does not occur. Valley oak (*Q. lobata*) occurs as solitary trees or small groups of trees in valley bottoms or associated with western sycamore (*Platanus racemosa*) and cottonwood (*Populus* spp.) in intermittent and perennial riparian areas. When present, understories of these oak woodlands consist mostly of toyon (*Heteromeles arbutifolia*), redberry (*Rhamnus crocea*), bigberry manzanita (*Arctostaphylos glauca*), and poison oak (*Toxicodendron diversilobum*). Chaparral (*Adenostoma* spp.) predominates on many south-facing slopes. Wild oats (*Avena* spp.), bromes (*Bromus* spp.), and fescues (*Festuca* spp.) occupy woodland floors and grassy openings; filaree (*Erodium* spp.), deerweed (*Lotus scoparius*), and hummingbird sage (*Salvia spathacea*) are common forbs.

Methods

Nest Location

During January to March from 1992 to 1995, we located active red-tailed hawk nests by searching along roads and by visually observing red-tailed hawks carrying nesting material or prey to nests. Additionally, several nests on CRMF were located during April to June, incidental to another field study on the facility. Frequent visits were made to nests with sign (e.g., sign of nest repair or nest-defense behaviors) of activity that year. We considered a red-tail nest active only when an adult red-tailed hawk was observed incubating on the nest anytime during the nesting season. A single exception was a nest seen being repaired by a hawk in February and a fledgling observed perched on the nest in June. Location, tree species, and hawk activity at nest trees was recorded during these initial visits. Nests were not approached closer than 100 m during the nesting period.

Plot Measurements

Nest Plots

We defined a nest plot as a 0.04-ha circular plot (11.3-m radius) centered on the nest tree (Titus and Mosher 1981). We collected 11 numerical and two categorical variables on nest plots and on associated random plots (*table 1*). Variables 1-5 describe the nest, nest tree, and associated random "nest tree." Variables 6-11 describe the vegetation structure of the 0.04-ha plots. Variables 12 and 13 describe topographic features of the 0.04-ha plots. Field measurements of these trees were taken during summer to winter after young had fledged.

Random Plots

We located a random plot approximately 200 m from each nest tree to evaluate characteristics of sites used versus sites available. For this comparison, a quadrant

***Table 1**—Description of two categorical and 11 numerical variables measured at nest sites of red-tailed hawks and at associated random sites, central California, 1992-1995.*

Mnemonic code	Variable description (units)
1. CNTR SPP	Species of central tree.
2. CNTR CAN POS	Canopy position of central tree, ocularly estimated from the ground—dominant: the tallest tree within 30 m of the central tree; codominant: almost equal in height to the dominant tree; intermediate: shorter than codominant trees and ≤ 75 pct under the canopy of another tree; and suppressed: ≥ 75 pct under the canopy of another tree.
3. CNTR DBH	Diameter (cm) at breast height (dbh) of central tree, measured with a diameter tape.
4. CNTR HT	Height (m) of central tree, measured with a clinometer.
5. CNTR DRIPLIN WID	Maximum distance (m) from trunk to dripline, measured with a tape.
6. PLOT TREE STMS	Number of living trees ≥ 5 cm dbh in a 0.04-ha plot centered on the central tree.
7. PLOT TREE COV	Tree canopy cover (pct) of a plot, averaged from 20 measurements taken with a spherical densiometer (Lemmon 1956): one reading in each of the cardinal directions at the central tree and at 7 m from the trunk in each of the cardinal directions.
8. PLOT SHRUB STMS	Number of living individual shrubs or clumps of living shrubs in a plot.
9. PLOT SHRUB COV	Ocular estimate of shrub cover (pct) in a plot.
10. PLOT GRND COV	Ocular estimate of herbaceous material cover (pct) in a plot.
11. PLOT DOWN WOOD	Ocular estimate of downed woody material (≥ 5 cm diameter and 1 m length) cover (pct) in a plot.
12. DIS VAL BOT	Distance (m) from central tree to nearest valley bottom (usually a perennial or seasonal stream), measured by pacing.
13. PLOT SLOPE	Slope (0°-90°) of a plot, measured with a clinometer.

was selected by two flips of a coin, the first for the N or S radius and the second for the E or W radius of the NE (1-90), SE (91-180), SW (181-270), or NW (271-360) quadrant. Two specific azimuths within the selected quadrant were then picked from a random numbers table; the first azimuth was used for the first 100 m of travel from the nest tree, the second for the second 100 m. This procedure was repeated in several cases when the direction of travel would have led to a large treeless opening. At the end point of the travel, the nearest tree of at least 43 cm diameter at breast height (dbh; 1.4 m above the ground) (43 cm dbh was the size of the smallest nest tree of the study) was selected. This tree was called the "nest tree" and formed the center of the 0.04-ha random plot. This approach to select random plots discouraged the preselection of "representative" or "typical" nesting areas in the oak woodlands, while it excluded trees and habitat types that were obviously unsuitable for nesting by red-tailed hawks (e.g., small trees and non-woodland habitats such as chamise and grassland). Not all measurements were made on each plot; therefore, some sample sizes differ.

Data Analysis

Descriptive statistics were calculated for six nest-specific variables: nest height, number of limbs supporting the nest and their average diameter, horizontal distance from the trunk to the nest, the percent of nest tree height at which the nest was located, and nest plot azimuth. Before analyses, the remaining 11 numeric variables (*table 1*) were tested for normality using Shapiro-Wilks tests (Conover 1980: 363) in PROC UNIVARIATE of SAS (SAS Institute Inc. 1988: 627-628; Schlotzhauer and Littell 1987: 117-119). We compared features of nest plots and associated random plots using paired-sample t-tests (for normally distributed variables), and Wilcoxon signed ranks tests (T, for non-normally distributed or small sample size variables). The log likelihood ratio (G) test for independence was used to detect hawk preference for trees of certain species or status, and for azimuth preference for nest trees only. Differences were considered significant when $P \leq 0.10$. Statistical procedures were conducted in PROC UNIVARIATE of PC-SAS (SAS Institute Inc. 1988: 617-634; Schlotzhauer and Littell 1987: 201-210).

Results

Nest Trees

We located 44 active red-tailed hawk nests, all but three during 1993 and 1994: 6, 16, and 22 on the Camatta/Canyon, Avenales, and Camp Roberts areas, respectively (*fig. 1*). In a study conducted in Orange County, California, Wiley (1975) located red-tailed hawk nests an average of 0.84 km apart (0.15 to 2.09 km) in intensively searched areas. With the conservative approach of using approximately twice that distance (i.e., 1.6 km) as our minimum distance for distinguishing nests of different pairs of red-tailed hawks, and our knowledge of the years the nests were active, we estimate that 39 of the 44 nests (89 percent) on our study sites were built by different pairs of hawks. Nests were in seven species of trees: 25, eight, and one in blue, valley, and coast live oaks, respectively; four in western sycamore, three in gray pine, two in eucalyptus (*Eucalyptus* spp.), and one in cottonwood. Proportions of tree species used for nest trees versus the proportions of random "nest tree" species available were similar ($G = 3.82$, df = 3, $P = 0.2817$).

Mean height and nest height of nest trees were 19.9 m ± 1.1 m (mean ± SE) and 15.8 m ± 0.8 m, respectively; 60 percent of nests were in the top 20 percent of the nest tree. Mean distance from the nest to the trunk (4.5 m ± 0.6 m, n = 22) was approximately 40 percent of the distance between the trunk of the nest tree and the maximum distance from the trunk to the dripline (11.4 m ± 0.5 m, n = 44). The number of limbs supporting nests and the average diameter of those limbs averaged 3.3 ± 0.1 and 6.9 cm ± 0.5 cm, respectively. Of 33 0.04-ha plots in which trees other than the central tree occurred, height of the nest tree (19.7 m ± 1.4 m) was approximately twice the height of surrounding trees within the plot (9.6 m ± 0.9 m) (Wilcoxon $T = 280.5$, df = 33, $P < 0.0001$).

Of the 44 nest plots, 70 percent were on hillsides and 30 percent were on valley floors. Of all nest plots on hillsides, slopes averaged 13.7°. The aspect frequencies in each of four categories of the azimuth of nest plots on hills differed from equiprobable frequencies (G = 14.42, df = 3, P = 0.0024) (*fig. 2*).

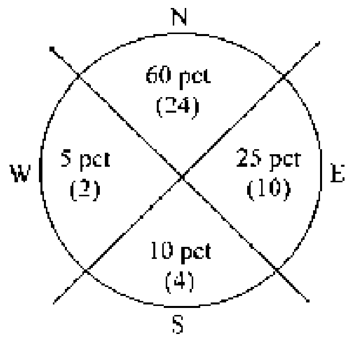

Figure 2—Slope aspects of 40 red-tailed hawk nests located on hillsides on four sites in oak woodlands, central California, 1992 to 1995.

Nest Versus Random Plots

The 11 numerical central tree and plot variables tested between nest and random plots (plot azimuth was not compared between nest and random plots) revealed three significant differences (*table* 2). All significant differences were measures of tree size. Central tree dbh (85.3 cm ± 4.1 cm vs. 62.6 m ± 3.7 cm, Wilcoxon T = 402, n = 44, P < 0.0001), height (19.9 m ± 1.1 m vs. 13.3 m ± 0.7 m, Wilcoxon T = 455, n = 44, P < 0.0001), and maximum canopy width (11.4 m ± 0.5 m vs. 9.1 m ± 0.4 m, paired t = 4.38, df = 43, P < 0.0001) were greater for nest trees than for random trees. Canopy position of central trees was dominant more often (G = 18.98, df = 1, P < 0.0001) on nest plots (38 of 44) than on random plots (19 of 44). All other nest versus random plot comparisons tested were not significant (all P > 0.10) (*table* 2).

Discussion

As in several other studies of red-tailed hawk nesting habitats, we found that red-tailed hawks in California oak woodlands use large trees for nesting (Bednarz and Dinsmore 1982, Belyea 1976, Santana and others 1986, Titus and Mosher 1981). Data from this study indicate this predilection clearly, despite our conservative approach of selecting "nest trees" on random plots that were at least the size of the smallest nest tree (43 cm dbh) measured. In another research project (Tietje and others, these proceedings) in which measurements were taken of 1,233 randomly selected trees in dense oak woodland on the Camp Roberts Military Facility, only 5.6 percent (69) were 43 cm dbh, indicating the limited occurrence and, therefore, strong preference for large trees on the area used in this study.

Tall trees likely afford several advantages to nesting red-tailed hawks and other *Buteo* species, including protection from predators, a substantial and safe base for the nest (Solonen 1982), and placement above the surrounding understory trees, which facilitates vigilance and accessibility to hunting areas. Red-tailed hawks (*Buteo jamaicensis* spp.) occur throughout the United States (Bent 1937). In some geographic areas within the range of the red-tailed hawk where large trees are unavailable, other substrates are used. For example, in Arizona, the western red-tailed hawk (*B. j. jamaicensis*) nests in the saguaro (*Carnegiea gigantea*) and paloverde (*Cercidium macrum*) at heights of only 1.8 to 9.1

Table 2—Central tree and 0.04-ha plot characteristics of nest plots of red-tailed hawks and associated random plots, central California, 1992-1995.

Variable[1]	Statistic	Nest site	Random site	Test statistic[2]	n^3	*P*
CNTR DBH (cm)	Mean	85.3	62.6	*T* = 402	44	<0.0001
	SE	4.1	3.7			
	Range	43.2-166.9	40.4-163.3			
CNTR HT (m)	Mean	19.9	13.3	*T* = 455	44	<0.0001
	SE	1.1	0.7			
	Range	11.0-43.9	7.3-29.3			
CNTR DRIPLIN WID (m)	Mean	11.4	9.1	*t* = 4.38	44	<0.0001
	SE	0.5	0.4			
	Range	6.4-23.2	4.6-18.0			
PLOT TREE STMS (no.)	Mean	6.6	4.7	*T* = 35	44	0.6175
	SE	1.3	0.6			
	Range	0-38.0	0-15.0			
PLOT TREE COV (pct)	Mean	65.0	64.7	*t* = 0.942	44	0.9254
	SE	2.2	2.6			
	Range	28.3-94.5	28.0-98.3			
PLOT SHRUB STMS (no.)	Mean	2.1	3.3	*T* = 9	41	0.5525
	SE	0.7	1.6			
	Range	0-21.0	0-55.0			
PLOT SHRUB COV (pct)	Mean	2.9	4.2	*T* = 7.5	44	0.6586
	SE	1.1	2.1			
	Range	0-30.0	0-75.0			
PLOT GRND COV (pct)						
	Mean	81.6	78.3	*T* = 25	42	0.5778
	SE	4.1	4.7			
	Range	<1-100.0	<1-100.0			
PLOT DOWN WOOD (pct)	Mean	5.0	4.5	*T* = 0	13	1.0000
	SE	1.6	0.9			
	Range	0-20.0	0-10.0			
DIS VAL BOT (m)						
	Mean	88.1	96.1	*t* = -0.5664	42	0.5742
	SE	15.2	15.2			
	Range	0-450.0	0-350.0			
PLOT SLOPE (°)	Mean	13.7	14.3	*T* = -51	43	0.4996
	SE	2.0	1.9			
	Range	0-67.0	0-55.0			

[1]See *table 1* for description of variables.
[2]Test statistics are paired sample *t*-tests (*t*) for normally distributed variables or Wilcoxon signed rank tests (nonparametric paired samples) (*T*) for non-normally distributed or low sample size variables.
[3]*n* is the number of pairs in which values for both nest and random sites were available for testing.

m (Bent 1937: 168). Whether removal of large trees in oak woodlands would prompt use of remaining small trees, and whether their use would adversely affect red-tailed hawk populations, is unknown.

Tree species probably is unimportant to nest-site selection, as long as the tree's growth form, size, and location in the landscape permit accessibility and vigilance. The method we used to select random plots provided little opportunity for selection of trees outside the stand that contained the nest tree. Therefore, this method might have biased selection of random trees towards the same species as the nest tree. This may have masked selection for uncommon species of trees on the study areas, such as valley oak, gray pine, and eucalyptus trees, which were usually larger than trees of other species. Moreover, relatively little searching was conducted in riparian areas. Our observations suggest that riparian areas may have been disproportionately used by red-tailed hawks.

Common measurements in other studies of nesting habitat of *Buteo* and *Accipiter* hawks are distance to water, valley bottom, and forest edge. These measures may not be meaningful in oak woodlands because the woodlands are not large expanses of contiguous forest and valley bottoms are frequently wide, flat expanses with few trees. Additionally, we found a difference among aspect frequencies of nest plots. This difference may be attributed to the occurrence of most oak trees on more mesic north and east slopes rather than any preference by red-tailed hawks for aspect of nest sites.

Management Implications

The sustainability of much of California's 3.1 million ha of oak woodland is currently problematic. In some areas, some of the 19 native oak species are not regenerating well (Bolsinger 1988; Brown and Davis 1991; Griffin 1971, 1976). Two species of highest concern, valley oak and blue oak, were among those most used by red-tailed hawks in this study. Most (80 percent) California oak woodland is privately owned and used primarily for livestock production (Tietje and Schmidt 1988). Livestock grazing may affect use by red-tailed hawks to the extent that it impedes tree regeneration and affects rodent populations. Grazing selectively decreases certain rodent (*Peromyscus* spp.) populations and increases others (Linsdale 1946). It may enhance red-tailed hawk habitat by increasing population size and availability of ground squirrels (*Spermophilus beecheyi*), which are likely an important prey species for red-tailed hawks, and whose populations generally fare well in grazed areas (Linsdale 1946).

Other land-use activities likely are more serious threats than livestock grazing to woodland sustainability. Larger trees are sometimes cut for firewood (McCreary 1996); however, firewood generally is not being cut on a large scale in California oak woodlands (Bleier 1991). The primary concern within the past decade over the loss of oak trees is the permanent removal of trees and degradation of habitat by urbanization and intensive agriculture. Home building and other types of development converted approximately 40,500 ha of the 3.1 million ha of oak woodland during 1969 to 1982 and, as of 1985, 110,000 ha were in the process of conversion (Bolsinger 1988).

Red-tailed hawks generally are tolerant of housing and other human development. In Puerto Rico, Santana and others (1986) located nests within 300 m of dwellings, though they speculated that hawks would decline in numbers with the expected development of woodlands in Puerto Rico. In California oak woodlands, large-parcel development might be tolerated by red-tailed hawks, but increased noise, pets, road construction, removal of large trees, and potential prey reduction make this tolerance unlikely.

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References

Bednarz, James C.; Dinsmore; James J. 1982. **Nest-sites and habitat of red-shouldered and red-tailed hawks in Iowa**. Wilson Bulletin 94: 31-45.

Belyea, G.Y. 1976. **A nesting study of the red-tailed hawk in southern Michigan**. East Lansing: Michigan State University; 88 p. Ph.D. dissertation.

Bent, Arthur C. 1937. **Life histories of North American birds of prey (part 1)**. U.S. National Museum Bulletin 167: 1-409.

Bleier, Cathy. 1991. **CDF monitors oak harvest on hardwood rangelands**. In: Standiford, Richard B., editor. Oaks 'n Folks Newsletter, July 1991. Located at: University of California at Berkeley, Department of Environmental Science, Policy, and Management, Berkeley, CA; 4-5.

Bohm, R.T. 1978. **A study of nesting red-tailed hawks in central Minnesota.** Loon 10 (3): 129-137.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas.** Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Brown, Rodney W.; Davis, Frank W. 1991. **Historical mortality of valley oak (Quercus lobata, Née) in the Santa Ynez Valley, Santa Barbara County, 1938-1989.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-GTR-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 202-207.

Conover, W. J. 1980. **Practical nonparametric statistics.** 2d ed. New York: John Wiley & Sons, Inc.; 493 p.

Gates, John M. 1972. **Red-tailed hawk populations and ecology in east-central Wisconsin.** Wilson Bulletin 84: 421-433.

Griffin, James R. 1971 **Oak regeneration in the upper Carmel Valley, California.** Ecology 52: 862-868.

Griffin, James R. 1976. **Regeneration in *Quercus lobata* savannas, Santa Lucia Mountains, California**. American Midland Naturalist 95: 422-435.

Lemmon, Paul E. 1956. **A spherical densiometer for estimating forest overstory density.** Forest Science 2(4): 314-320.

Linsdale, Gean M. 1946. **The California ground squirrel.** Berkeley: University of California Press; 475 p.

Pavlik, Bruce M.; Muick, Pamela C.; Johnson, Sharon; Popper, Marjorie. 1991. **Oaks of California.** Los Olivos, CA: Cachuma Press; 184 p.

Petersen, LeRoy. 1979. **Ecology of great-horned owls and red-tailed hawks in southeastern Wisconsin.** Tech. Bulletin No. 111. Madison, WI: Wisconsin Department of Natural Resources; 63 p.

Santana, Eduardo C.; LaBoy, Eddie N.; Mosher, James A.; Temple, Stanley A. 1986. **Red-tailed hawk nest sites in Puerto Rico.** Wilson Bulletin 98: 561-570.

SAS Institute Inc. 1988. **SAS procedures guide** [computer program, version 6.03]. Cary, NC: SAS Inst. Inc.; 705 p.

Schlotzhauer, Sandra D.; Littell, Ramon C. 1987. **SAS system for elementary statistical analysis.** Cary, NC: SAS Inst. Inc.; 416 p.

Solonen, T. 1982. **Nest-sites of the common buzzard (*Buteo buteo*) in Finland.** Ornis Fennica 59: 191-192.

McCreary, Douglas., **Natural Resource Specialist, University of California at Berkeley.** [Telephone conversation with William D. Tietje]. 4 January 1996.

Tietje, William D.; Schmidt, Robert H. 1988. **California's Integrated Hardwood Range Management Program.** In: McCabe, Richard E., editor. Transactions of the North American Wildlife and Natural Resources Conference; 1988 March 18-23; Louisville, KY. Volume 53. Washington, DC: Wildlife Management Institute; 67-77.

Tietje, William D.; Vreeland, Justin, K.; Siepel, Nancy; Dockter, Jo Ann L. **Relative numbers and habitat associations of vertebrate fauna in oak woodlands in central California.** 1996 [These proceedings].

Titus, Kimberly; Mosher, James A. 1981. N**est-site habitat selected by woodland hawks in the central Appalachians**. Auk 98:270-281.

Wiley, James W. 1975. **The nesting and reproductive success of red-tailed hawks and red-shouldered hawks in Orange County, California, 1973**. Condor 77: 133-139.

Small Nocturnal Mammals in Oak Woodlands: Some Considerations for Assessing Presence and Abundance[1]

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Abstract: *We live-trapped small, nocturnal mammals between 1993 and 1995 in three oak (*Quercus *spp.) woodland sites in eastern Fresno County, California. Interior live oak (*Quercus wislizenii*) and blue oak (*Q. douglasii*) were the dominant tree species. Tree canopy structure ranged from open and discontinuous to dense and continuous. Dusky-footed woodrats (*Neotoma fuscipes*) were captured in both Sherman and Tomahawk traps; almost all were taken at woodrat houses. California mice (*Peromyscus californicus*) and brush mice (*P. boylii*) were most successfully captured in Sherman traps both on trap grids and at woodrat houses. Most dusky-footed woodrat houses were either atypical or combination types.*

Repeat live-trapping on sampling grids and determining abundance of various kinds of animal "sign" are commonly used methods for assessing presence and abundance of small mammals. Although such estimates are widely used, they are based on unconfirmed assumptions about animal movements and microhabitat associations. Different types of traps may bias trapping success toward some species and against others (Beacham and Krebs 1980, Boonstra and Krebs 1978, Boonstra and Rodd 1984, Bury and Corn 1987, Cockrum 1947, O'Farrell and others 1994, Singleton 1987, Slade and others 1993, Williams and Braun 1983, Willy 1985). Location of traps, especially in relation to cover, may also bias trapping success (Murray 1957, O'Farrell and others 1994, Sakai and Noon 1993). Placement of traps in undesirable habitat, exclusively on the ground, or away from normal travel paths, may bias trap success against some species and for others. Some animals are more likely to be associated with dense cover whereas others prefer open areas. Most sampling grids are located on the ground and are unlikely to adequately sample arboreal animals. Other animals follow discrete travel paths and will not be captured if traps are not located close to their routes of travel.

Indirect methods of assessing abundance of mammals, such as animal track and pellet counts, can also give unreliable results. Abundance of dusky-footed woodrats (*Neotoma fuscipes*) is sometimes estimated by counting their houses, but animal use may be incorrectly assessed if the sample area includes houses which are abandoned, used but not resided in, or difficult to detect.

In our investigations of dusky-footed woodrats and other nocturnal small mammals in oak (*Quercus* spp.) woodlands of the southern Sierra Nevada, we have encountered a number of problems in detecting and assessing abundance of different species. The objectives of this paper are to identify some of the problems associated with using (1) standard trap grid methods to assess the presence and abundance of small mammals, (2) particular types of live traps, and (3) house counts as an index of dusky-footed woodrat abundance.

Study Area

The study area consisted of three 2.25-ha oak woodland sites known as Pine Flat, Camp 4-1/2, and Secata, in the foothills of the Sierra Nevada in eastern Fresno County. Elevation ranged from 300 m to 450 m. All three sites were within 2 km

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of the Kings River. Pine Flat was the most densely vegetated site, with an overstory dominated by interior live oak (*Quercus wislizenii*) and gray pine (*Pinus sabiniana*), and with a thick understory of interior live oak, ceanothus (*Ceanothus* spp.), poison oak (*Toxicodendron diversilobum*), and manzanita (*Arctostaphylos* spp.). Camp 4-1/2 had a moderate overstory of blue oak (*Q. douglasii*), interior live oak, and California buckeye (*Aesculus californica*), and a relatively sparse understory of poison oak and ceanothus. Secata was the most open site, dominated by blue oak, with small patches of interior live oak and California buckeye. The understory was very sparse, consisting of ceanothus, chaparral honeysuckle (*Lonicera interrupta*), redberry (*Rhamnus crocea*), and manzanita.

Methods

Within each study site, we randomly positioned one 7-by-7 station trap grid with 15-m spacing. Beginning in 1993, one each of Sherman XLK folding traps (7.7 cm × 9.5 cm × 30.5 cm) and Tomahawk No. 201 steel mesh (1.25-cm × 2.5-cm mesh) traps (12.7 cm × 12.7 cm × 40.6 cm) were set at each trap grid station. Tomahawks were also set at woodrat houses, both on the ground and in nearby trees. Traps at the houses were positioned along obvious woodrat paths, if present. During the 1994 and 1995 trapping seasons, only Shermans were set on the grid (one trap at each station), but Tomahawks continued to be set at the houses. Additional trapping was done in autumn 1995, using a small number of Shermans for a few nights at woodrat houses, both on the ground and in nearby trees to determine if Sherman traps were capable of capturing dusky-footed woodrats.

Trapping ran from mid-spring to early summer and from late summer to mid-autumn in 1993, 1994, and 1995. Traps were set in the evening and checked the next morning. All small mammals captured were identified, measured, ear-tagged (using National Band and Tag Co. monel tags), and released. Trap nights (*table 1*) ranged from 4525 Sherman trap nights on trap grids to 10 Sherman trap nights in trees at woodrat houses.

Table 1—Number of nights, number of study sites, and number of years trapped for each combination of trap type (Sherman XLK or Tomahawk No. 201) and trap location

Trap location	Nights trapped	Study sites	Years
Sherman[1]/Grid[2]	4,525	3	3
Tomahawk[3]/Grid	2,064	3	1
Sherman/House[4]	52	1	1
Tomahawk/House	2,106	3	3
Sherman/Tree[5]	10	1	1
Tomahawk/Tree	1,877	3	3

[1]Sherman XLK live traps
[2]On 7 × 7 station trap grids with 15-m spacing
[3]Tomahawk No. 201 live traps
[4]On the ground at woodrat houses
[5]In trees at woodrat houses

Capture rates per 1000 trap nights for dusky-footed woodrat, brush mouse (*Peromyscus boylii*), and California mouse (*P. californicus*) were determined for each trap type (Sherman or Tomahawk) and trap location (trap grid, at woodrat houses on the ground, or at woodrat houses in trees) on each site for 1993, 1994, and 1995. Means and standard errors of capture rates for each combination of trap type and trap location were calculated and plotted.

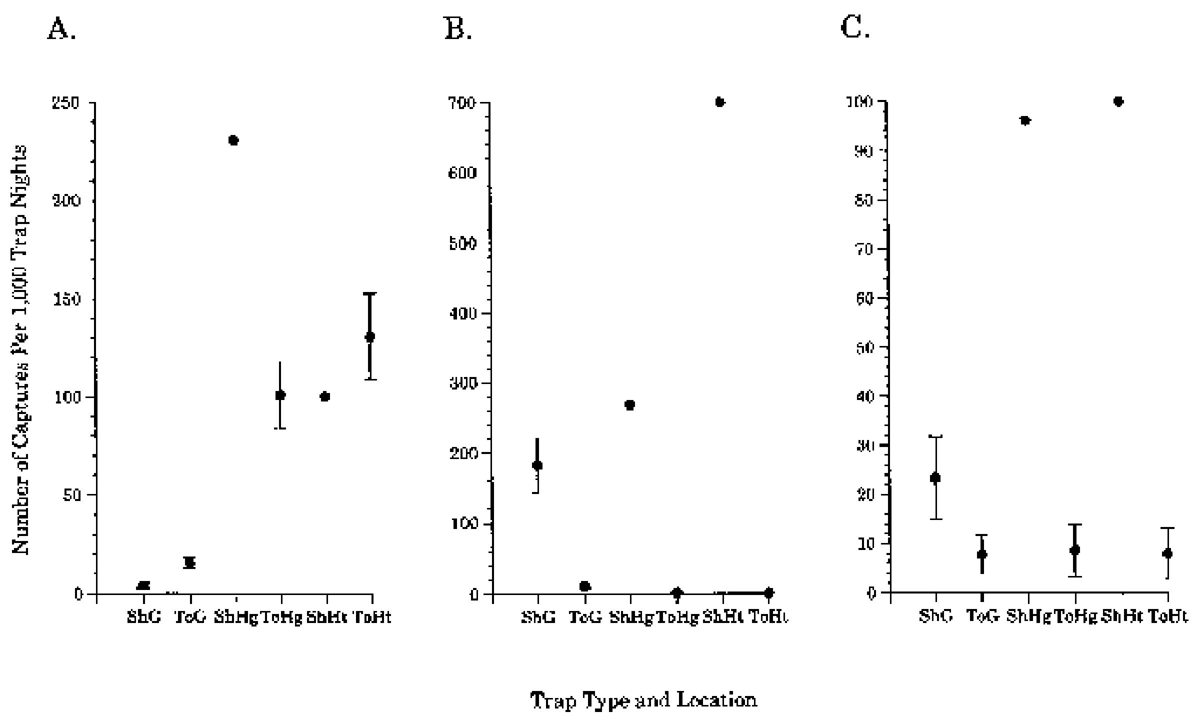
All sites were systematically searched for woodrat houses, which were marked, mapped, and classified as typical, atypical, or combination. Typical houses were composed of a large number of sticks, with the primary dwelling within the pile of sticks. Atypical houses contained very few to no sticks, with the primary dwelling within a tree cavity, rock crevice, log, or underground hole. Combination houses had characteristics of both typical and atypical houses. Abundance of each woodrat house type was determined for each site. Woodrat use of houses was determined by capturing woodrats at houses, observing woodrats to enter houses, determining the condition of houses, and the presence of woodrat urine or fecal pellets.

Woodrat activity was observed after they were released. Woodrat activities were also observed during days and evenings at several houses during the course of this study.

Results

Dusky-footed woodrats were most successfully captured in both trap types at houses on the ground or in nearby trees (*fig. 1A*). Very few woodrats were captured on the standard trap grids in either trap type. Brush mice were successfully trapped in Sherman traps, but were rarely captured in Tomahawk traps (*fig. 1B*). Capture rates increased when Shermans were set at woodrat houses. On the trap grid, our success in capturing California mice with Sherman traps was slightly better than with Tomahawks (*fig. 1C*). As with brush mice, capture rate increased with Shermans set at woodrat houses.

Figure 1—Numbers of (A) dusky-footed woodrat, (B) brush mouse, (C) California mouse captured/1000 trap nights ± 1 se. Trap codes are: Sh = Sherman XLK and To = Tomahawk No. 201. Location codes are: G = Grid, Hg = on the ground at woodrat houses, and Ht = in trees at woodrat houses.



A large number of traps were found empty with mouse-size fecal droppings and the bait missing and/or the door closed (127 closed and empty/1000 traps). Tomahawk traps have 1.25-cm × 2.5-cm mesh openings and gaps between the doors of a sufficient size to permit the escape of brush mice and smaller California mice, especially juveniles, which could result in decreased trap success for these species.

The most obvious woodrat houses on our study sites were "stick-houses" we classified as typical. Locating atypical and combination houses was more difficult because of the lack of large piles of sticks normally associated with woodrat houses. Typical woodrat houses ranged from 32 percent of the houses found on Camp 4-1/2 to only 6 percent at Secata (*fig. 2*). Atypical houses, the most difficult to locate, ranged from 65 percent at Secata to 17 percent at Pine Flat.

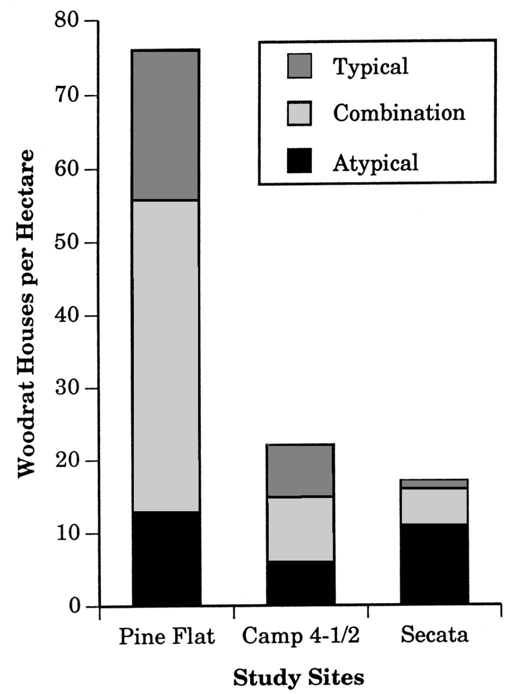


Figure 2—Woodrat houses found on each study site (numbers of houses/ha).

Discussion

Trap type and placement can have substanital effects on assessments of the diversity and abundance of small mammals. If we had trapped only on the grid throughout this study, zero to very few dusky-footed woodrats would have been captured. Capture success for dusky-footed woodrats was greatly improved by placing Tomahawk traps at woodrat houses, both in nearby trees and on the ground. Although based on relatively few trap nights, capture rates for all three dominant rodent species increased when Sherman traps were set at the houses.

Our results show that capture success can be strongly influenced by trap type. Willy (1985) found that Tomahawk traps captured only woodrats whereas Shermans captured other species as well. In addition, Tomahawks captured woodrats at a higher rate than Shermans. O'Farrell and others (1994) found that wire mesh live traps captured 36 percent more animals than Sherman traps, and wire mesh traps captured nine of ten small mammal species detected, six of these species more successfully than the Shermans. Shermans successfully captured seven species but were only slightly more effective than the wire mesh traps in capturing two species.

Trap location can also affect capture success because successfully trapping animals depends on microhabitat associations, and temporal and three-dimensional patterns of movement within specific home ranges. Murray (1957) found that species composition and richness varied significantly between parallel trap lines depending on vegetation species present and amount of cover. This suggested "...nonrandom distribution of the animals in relation to the trap lines such that small differences in placement of traps in these areas could seriously alter the results" (Murray 1957:449). In a conifer-deciduous forest ecotone, Kirkland and Griffin (1974) reported that meadow voles (*Microtus pennsylvanicus*) were closely associated with grassy areas and rock shrews (*Sorex dispar*) were found only in rocky areas. In desert communities, Price (1978) found that Bailey's pocket mouse (*Perognathus* [= *Chaetodipus*] *baileyi*) and desert pocket mouse (*P.* [= *C.*] *penicillatus*) were found most often in association with large bushes and trees, Merriam's kangaroo rats (*Dipodomys merriami*) most often in large open spaces, and Arizona pocket mouse (*P. amplus*) most often in small open spaces. In coastal oak woodlands, Tietje (1995) concluded that dusky-footed woodrats are associated with dense, shrubby understories. Sakai and Noon (1993) concluded that the dusky-footed woodrat's patchy distribution can affect abundance estimates from trap grids since the estimates depend on grid size and placement. We also found that dusky-footed woodrats were distributed nonrandomly as we captured animals more successfully in traps placed at woodrat houses than on the trap grids. If we had relied solely on grid trapping, woodrat presence and abundance would have been greatly underestimated, from zero to very few animals, depending on the site and time of year.

Density estimates of several species of *Peromyscus*, including pinyon mouse (*P. truei*) and California mouse, often parallel the densities of dusky-footed woodrats and their houses. These mice often construct their nests within woodrat houses and, upon release, individuals of both species often enter woodrat houses (Cranford 1982; Merritt 1974, 1978). Our findings, although based on relatively few trap nights, indicate that both brush mice and California mice are more successfully captured near woodrat houses. We did not search woodrat houses for Peromyscus nests and, therefore, cannot confirm nesting of either species in woodrat houses.

The extent to which members of a particular species, or individual animals, restrict their movements also affects trap success. Often, woodrats that were successfully captured at houses during a particular trapping session were not captured during a subsequent session on the grid, even when traps were positioned near, but not at, these same houses. This suggests that capture success was also affected by the woodrats' specific movements within their home ranges. Barnum and others (1992) found that white-footed mice (*Peromyscus leucopus*) usually used regular paths along logs of a specific size range and which were protected by vegetative cover. The dusky-footed woodrats we have studied also appear to use particular travel routes. Our study sites included several well-established ground trails between houses and under ground cover. However, observations of rats upon release, day and evening observations, and results from trapping at various openings of a house (both on the ground and in trees), showed that dusky-footed woodrats on our sites generally used paths along limbs which extend from their houses. Even when a direct route along the ground covered a shorter distance, woodrats almost always chose paths along limbs. Linsdale and Tevis (1951) also concluded that dusky-footed woodrats were quite arboreal, observing that arboreal routes were used in preference to ground trails. They also found that trails were usually under dense cover and never found in grassland. Cranford (1977) determined through radiotelemetry that dusky-footed woodrat activity was greatest in 75 to 100 percent cover, and that 40 percent of telemetry fixes were from positions above the ground.

Abundance of animal "sign" is also used for assessing presence and abundance of animals. Dusky-footed woodrat presence is often determined by the presence of their stick-houses (Hammer and Maser 1973, Sakai and Noon 1993, Vogl 1967), which have been primarily described as large, conspicuous, conical piles of sticks with numerous passageways and chambers (Ashley and Bohnsack 1974, Cameron 1971, English 1923, Gander 1929, Linsdale and Tevis 1951, Vestal 1938). There are a few instances in the literature mentioning the use of atypical houses by dusky-footed woodrats; however, they were apparently not considered a common occurrence. Gander (1929) found dusky-footed woodrat houses made in hollow limbs and rock crevices. Davis (1934) found several houses built upon large rocks with deep fissures, including one house that was merely a nest chamber within a rock crevice. In our study, if counts of conspicuous houses were used to estimate dusky-footed woodrat numbers, they would have been seriously underestimated. As noted by Sakai and Noon (1993), estimates based on woodrat house counts are biased to the extent that cryptic (atypical) houses go uncounted. Within our study area, the majority of houses were combination or atypical. Some houses were so inconspicuous that they were found only after a woodrat was observed going into the house. These were usually houses that were built within the hollow of a tree with no apparent use of sticks. Owing to the inconspicuous nature of many houses, it is likely that some were not discovered during the study.

When using house counts to estimate the abundance of dusky-footed woodrats, it is assumed that each house is inhabited by only one woodrat, except when a female has young (English 1923, Gander 1929, Linsdale and Tevis 1956). However, more than one adult woodrat may occupy any house at any given time. For instance, during the breeding season, male and female woodrats will often occupy the same houses, however, once pregnant, the female will force the male to "move" to another house (English 1923, Linsdale and Tevis 1951). Not all woodrat houses are necessarily occupied. Houses may be recently abandoned or may be used only sporadically. According to Linsdale and Tevis (1951), "A rat will place cuttings on a house that it uses, but does not occupy permanently." We found that some woodrats, although repeatedly captured at a particular house, retreated into another house after being released.

Adequate assessment of animal populations is essential in developing successful conservation strategies for wildlife. Although estimates of absolute abundance of animals are desirable, they are often not achievable. Estimates of relative abundance can be useful substitutes, but assessment methods should be unbiased or biased equally among sites and species to be compared. Our results suggest that various trap types and trap locations capture different small mammal species at different rates. Trapping designs that reflect patterns of microhabitat use, spatial distributions, and movements of the small mammals of interest should provide more useful estimates of relative abundance. Development of such trapping designs may require careful searches of the study area to locate different microhabitats, woodrat houses and other habitat elements that small mammals use, and employ a combination of trap types in a variety of locations.

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References

Ashley, Tom R.; Bohnsack, Kurt K. 1974. **Seasonal abundance of Acarine populations in the sleeping nests of the dusky-footed woodrat, *Neotoma fuscipes* Baird in southern California, U.S.A.** Proceedings of the 4th International Congress of Acarology 4: 615-621.

Barnum, Sarah A.; Manville, Christiana J.; Tester, John R.; Carmen, William J. 1992. **Path selection by *Peromyscus leucopus* in the presence and absence of vegetative cover.** Journal of Mammalogy 73(4): 797-801.

Beacham, Terry D.; Krebs, Charles J. 1980. **Pitfall vs. live-trap enumeration of fluctuating populations of *Microtus townsendii*.** Journal of Mammalogy 61(3): 486-499.

Boonstra, Rudy; Krebs, Charles J. 1978. **Pitfall trapping of *Microtus townsendii*.** Journal of Mammalogy 59(1): 136-148.

Boonstra, Rudy; Rodd, Helen F. 1984. **Efficiency of pitfalls versus live-traps in enumeration of populations of *Microtus pennsylvanicus*.** Canadian Journal of Zoology 62: 758-765.

Bury, R. Bruce; Corn, Paul Stephen. 1987. **Evaluation of pitfall trapping in northwestern forests: trap arrays with drift fences.** Journal of Wildlife Management 51(1): 112-119.

Cameron, Guy N. 1971. **Niche overlap and competition in woodrats.** Journal of Mammalogy 52(2): 288-296.

Cockrum, E. Lendell. 1947. **Effectiveness of live traps versus snap traps**. Journal of Mammalogy 28(2): 186.

Cranford, Jack A. 1977. **Home range and habitat utilization by *Neotoma fuscipes* as determined by radiotelemetry.** Journal of Mammalogy 58(2): 165-172.

Cranford, Jack A. 1982. **The effect of woodrat houses on population density of *Peromyscus*.** Journal of Mammalogy 63(4): 663-666.

Davis, A.C. 1934. **Notes on the insect inhabitants of wood rat houses in California.** Bulletin of the Southern California Academy of Sciences 33: 12-24.

English, Pennoyer F. 1923. **The dusky-footed wood rat (*Neotoma fuscipes*).** Journal of Mammalogy 4(1): 1-9.

Gander, Frank F. 1929. **Experiences with wood rats, *Neotoma fuscipes macrotis*.** Journal of Mammalogy 10: 52-58.

Hammer, E. Wayne; Maser, Chris. 1973. **Distribution of the dusky-footed woodrat, *Neotoma fuscipes* Baird, in Klamath and Lake Counties, Oregon.** Northwest Science 47(2): 123-127.

Kirkland, Gordon L., Jr.; Griffin, Rebecca J. 1974. **Microdistribution of small mammals at the coniferous-deciduous forest ecotone in northern New York.** Journal of Mammalogy 55(2): 417-427.

Linsdale, Jean M.; Tevis, Lloyd P., Jr. 1951. **The dusky-footed wood rat.** Berkeley: University of California Press; 664 p.

Linsdale, Jean M.; Tevis, Lloyd P., Jr. 1956. **A five-year change in an assemblage of wood rat houses.** Journal of Mammalogy 37(3): 371-374.

Merritt, Joseph F. 1974. **Factors influencing the local distribution of *Peromyscus californicus* in northern California.** Journal of Mammalogy 55(1): 102-114.

Merritt, Joseph F. 1978. ***Peromyscus californicus*.** Mammalian Species 85: 1-6.

Murray, Keith F. 1957. **Some problems of applied small mammal sampling in western North America.** Journal of Mammalogy 38(4): 441-451.

O'Farrell, Michael J.; Clark, William A.; Emmerson, F.H.; Juarez, Stephen M.; Kay, Fenton R.; O'Farrell, Theda M.; Goodlett, Tracy Y. 1994. **Use of a mesh live trap for small mammals: are results from Sherman live traps deceptive?** Journal of Mammalogy 75(3): 692-699.

Price, Mary V. 1978. **The role of microhabitat in structuring desert rodent communities.** Ecology 59(5): 910-921.

Sakai, Howard F.; Noon, Barry R. 1993. **Dusky-footed woodrat abundance in different-aged forests in northwestern California.** Journal of Wildlife Management 57(2): 373-382.

Singleton, Grant R. 1987. **A comparison of the effectiveness of pitfall and Longworth live-trapping techniques in population studies of house mice.** Acta Theriologica 32(15): 245-259.

Slade, Norman A.; Eifler, Maria A.; Gruenhagen, Ned M.; Davelos, Anita L. 1993. **Differential effectiveness of standard and long Sherman livetraps in capturing small mammals.** Journal of Mammalogy 74(1): 156-161.

Tietje, William. 1995. **Woodrat abundance and habitat measurements in oak woodland at Camp Roberts, California: preliminary results**. Transactions of the Western Section of The Wildlife Society 31: 53-57.

Vestal, Elden H. 1938. **Biotic relations of the wood rat (*Neotoma fuscipes*) in the Berkeley Hills.** Journal of Mammalogy 19(1): 1-36.

Vogl, Richard J. 1967. **Wood rat densities in southern California manzanita chaparral.** Southwestern Naturalist 12(2): 176-179.

Williams, Daniel F.; Braun, Suzanne E. 1983. **Comparison of pitfall and conventional traps for sampling small mammal populations.** Journal of Wildlife Management 47(3): 841-845.

Willy, Allison G. 1985. **The habitat associations of the dusky-footed woodrat (*Neotoma fuscipes*) in Marin County, CA.** Berkeley: University of California; 66 p. M.S. thesis.

Bird Communities in Grazed and Ungrazed Oak-Pine Woodlands at the San Joaquin Experimental Range[1]

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***Abstract**: Ten years of spot-mapping censuses in grazed and ungrazed plots at the San Joaquin Experimental Range, Madera Co., California, indicate likely changes in abundance of several bird species. Data do not, however, indicate that any species is in jeopardy as a result of grazing in the foothill woodlands. Brown-headed cowbirds are probably more abundant in the woodlands with cattle than without cattle, but we have no evidence that cowbird nest parasitism is a threat to any host species. Finally, the European starling's possible impact on native cavity-nesting species is uncertain, but we suspect it is significant for some species.*

In 1934, the USDA Forest Service purchased private ranchlands in foothill woodlands of the western Sierra Nevada to establish the San Joaquin Experimental Range (SJER). The stated objective of this acquisition was to undertake range research in California, which "...is most important for the stability of a large industry and for the maintenance of public values to be rendered by grazing lands" (Kotok 1933). Foremost among the public values of interest at the time were a viable livestock industry, sustainable water resources, and rangeland production. Other values were also recognized, including the rich wildlife communities that occur in the foothill woodlands. Publications based on studies of a wide variety of species in all vertebrate classes at SJER began to appear in the late 1930's and early 1940's (Duncan and Coon 1985).

The primary objective of the present study was to evaluate spot mapping as a method to estimate the densities of breeding bird populations. Secondarily, we hoped to attain some insights into possible effects of long-term grazing on bird communities in oak-pine woodlands of the western Sierra Nevada. This second objective was possible only because a 32-ha parcel was set aside in 1934 and has been excluded from livestock grazing ever since. In this paper, we compare the breeding bird community in this ungrazed parcel with that in a grazed study area of equal size. Although the study lacks replication because only one ungrazed parcel was available, we nonetheless believe that some useful biological inferences can be drawn from the results.

Study Area

With an area of approximately 1,875 ha and ranging in elevation from 215 to 520 m, SJER is located in the western foothills of the Sierra Nevada, approximately 31 km northeast of Madera, California. The climate is characterized by cool, wet winters and hot, dry summers. Mean annual precipitation from 1934 to 1994 was 46.7 cm, with about 95 percent of that falling as rain from October through April. Snow is unusual, and daily maximum temperatures have exceeded freezing on all but 2 days in 57 years of weather data taken at the headquarters area. A sparse woodland overstory of blue oak (scientific names of plants in *table 1*), interior live oak, and foothill pine covers most of SJER. An understory of scattered shrubs includes mainly buckbrush, chaparral whitehorn, redberry, and Mariposa manzanita. In a few smaller patches, the overstory is primarily blue oak, and a

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Table 1—Vegetation attributes (mean ±standard deviation)[1] on the ungrazed and grazed plots at the San Joaquin Experimental Range (original data from Waters 1988 and personal communication)

Attribute	Ungrazed plot	Grazed plot	*t*-value	*P*
Mean canopy cover (pct)	26.65 ± 26.53	29.48 ± 17.45	0.56	[a]0.5749
Tree densities (stems/ha)	54.69 ± 58.68	54.69 ± 40.60	0	[a]1.0000
Foothill pine (*Pinus sabiniana*)	30.62 ± 50.79	15.94 ± 26.70	1.62	[a]0.1110
Blue oak (*Quercus douglasii*)	7.50 ± 12.27	10.62 ± 16.64	0.95	[a]0.3431
Interior live oak (*Quercus wislizenii*)	15.00 ± 18.82	25.94 ± 23.58	2.29	[a]0.0247
California buckeye (*Aesculus californica*)	1.56 ± 6.45	2.19 ± 8.90	0.36	[a]0.7181
Mean shrub cover (pct)	20.60 ± 14.40	6.10 ± 7.33	5.68	[a]*<0.0001*
Buckbrush (*Ceanothus cuneatus*)	14.30 ± 13.39	2.13 ± 4.90	5.40	[b]*<0.0001*
Chaparral whitethorn (*Ceanothus leucodermis*)	0	1.13 ± 3.42	2.09	[b]0.0432
Redberry (*Rhamnus crocea*)	1.95 ± 3.24	0.80 ± 2.53	1.77	[b]0.0810
Coffeeberry (*Rhamnus californica*)	1.18 ± 2.96	0.70 ± 2.69	0.76	[b]0.4502
Poison oak (*Toxicodendron diversilobum*)	1.73 ± 4.65	0.18 ± 0.71	2.08	[b]0.0434
Mariposa manzanita (*Arctostaphylos mariposa*)	1.38 ± 3.37	0.85 ± 1.86	0.87	[b]0.3873
Dead shrubs	1.50 ± 3.17	1.10 ± 2.19	0.66	[b]0.5136
Mean shrub height (m)	2.21 ± 0.81	1.73 ± 1.25	2.04	[a]0.0455

[1]Forty systematically located, circular subplots of 0.08 ha each were sampled on each plot. Significant *P*-values are in italics.
[a]Bonferroni adjustment for multiple comparisons requires a *P*-value of 0.0125 or less for significance at the 0.05 level.
[b]Bonferroni adjustment for multiple comparisons requires a *P*-value of 0.0071 or less for significance at the 0.05 level.

shrub understory is meager or missing. Some areas of typical annual grassland extend throughout the remainder of SJER where the overstory and understory are not dense enough to shade them out or are lacking altogether.

Duncan and others (1985) provided the most recent full summary of the avifauna at SJER, but extensive studies of birds there since 1985 have considerably expanded our knowledge of birds of the area. Available records now total 193 species of birds detected at SJER, but 45 of those have been recorded only once or twice, leaving 148 species that occur at the Range with any regularity. Only 56 of those species are confirmed breeders; common barn-owls (*Tyto alba*) and wrentits (scientific names of most birds in *table 2*) probably also breed at SJER, but their nests or fledglings have yet to be located there.

Methods

Vegetation on the two 29.7-ha plots was sampled by Waters (1988) following the methods of James and Shugart (1970). An "ungrazed plot" was established in the small parcel that was set aside in 1934 to be secure from grazing, and a "grazed plot" of equal size was delineated in a site with approximately the same tree canopy cover, based on inspection of aerial photographs. The two plots were 1.33 km apart. Only major attributes of trees and shrubs were sampled (*table 1*) to provide approximate comparisons of the structure of woody vegetation on the plots. Within each plot, Waters systematically located 40 circular subplots of 0.08 ha each. Unpaired *t*-tests were used to compare measures of vegetation between plots; Bonferroni adjustments for multiple comparisons required *P*-values of 0.0125 and 0.0071 for significance at the 0.05 level (see *table 1*).

We estimated the numbers of territorial birds on the plots for 9 years, 1985 through 1993, using the internationally standardized spot-mapping method (Anonymous 1970, Robbins 1970). To assist field crews with their mapping, steel fence posts with alpha-numeric codes identified all intersections at 30-m intervals on grids covering both plots. Most visits to the plots were done in April each year, but starting and ending dates were adjusted to some extent by spring phenology. The earliest starting date was 22 March, and the latest was 5 April. The earliest ending date was 25 April, and the latest was 5 May. Beginning

Table 2—Mean numbers of territories (±standard deviation) of birds, by nesting guild, per year (n = 9) on an ungrazed and a grazed plot, San Joaquin Experimental Range, from 1985 to 1993[1]

Guild Species	Ungrazed plot	Grazed plot	*t*-value	*P*
Primary cavity nesters				
Acorn woodpecker (*Melanerpes formicivorus*)	4.8 ± 1.8*	5.2 ± 1.6*	1.02	0.3359
Nuttall's woodpecker (*Picoides nuttallii*)	0.8 ± 0.3*	1.2 ± 0.7*	1.79	0.1108
Hairy woodpecker (*Picoides villosus*)	0.3 ± 0.5	0	2.00	0.0805
Northern flicker (*Colaptes auratus*)	0.2 ± 0.3	0.2 ± 0.3	0.00	1.0000
Guild total	6.2 ± 1.7	6.6 ± 2.0	1.10	0.3027
Mean species richness	2.8 ± 0.7	2.4 ± 0.5	2.00	0.0805
Secondary cavity nesters				
Plain titmouse (*Parus inornatus*)	14.1 ± 5.8*	19.6 ± 8.3*	4.50	0.0020
Bewick's wren (*Thryomanes bewickii*)	6.8 ± 3.3*	5.1 ± 1.7*	1.76	0.1156
Ash-throated flycatcher (*Myiarchus cinerascens*)	5.3 ± 1.3*	7.9 ± 2.2*	3.36	0.0099
House wren (*Troglodytes aedon*)	4.9 ± 4.7	6.6 ± 4.6*	5.35	*0.0007*
European starling (*Sturnus vulgaris*)	2.6 ± 1.9*	4.2 ± 1.1*	2.05	0.0743
White-breasted nuthatch (*Sitta carolinensis*)	2.4 ± 1.3*	3.2 ± 1.5*	1.90	0.0939
Western bluebird (*Sialia mexicana*)	1.4 ± 1.1	1.9 ± 0.9*	1.34	0.2165
Violet-green swallow (*Tachycineta thalassina*)	0.9 ± 0.8	3.4 ± 2.8	3.07	0.0154
American kestrel (*Falco sparverius*)	0	0.4 ± 0.5	2.87	0.0207
Guild total	38.5 ± 6.6	52.2 ± 9.2	3.49	*0.0082*
Mean species richness	7.4 ± 0.7	8.3 ± 0.5	2.29	0.0516
Tree nesters				
Mourning dove (*Zenaida macroura*)	8.6 ± 3.4*	8.5 ± 2.5*	0.11	0.9127
Bushtit (*Psaltriparus minimus*)	7.3 ± 3.4*	7.3 ± 3.7*	0.07	0.9478
Lesser goldfinch (*Carduelis psaltria*)	6.9 ± 3.4*	5.7 ± 2.2*	1.19	0.2670
House finch (*Carpodacus mexicanus*)	4.9 ± 3.6	5.4 ± 4.5	0.76	0.4714
Anna's hummingbird (*Calypte anna*)	4.3 ± 1.3*	3.5 ± 1.0*	1.65	0.1382
Bullock's oriole (*Icterus bullockii*)	1.5 ± 0.8*	0	6.00	*0.0003*
Blue-gray gnatcatcher (*Polioptila caerulea*)	1.1 ± 1.1	1.9 ± 1.4	2.36	0.0462
Lawrence's goldfinch (*Carduelis lawrencei*)	1.0 ± 1.6	0.9 ± 1.2	0.22	0.8337
Hutton's vireo (*Vireo huttoni*)	0.9 ± 0.8	1.0 ± 0.7	0.45	0.6646
Western kingbird (*Tyrannus vociferans*)	0.6 ± 0.5	0	3.35	0.0100
Red-tailed hawk (*Buteo jamaicensis*)	0.4 ± 0.4	0.2 ± 0.4	0.82	0.4379
Great horned owl (*Bubo virginianus*)	0.2 ± 0.4	0	1.84	0.1038
Phainopepla (*Phainopepla nitens*)	0.2 ± 0.5	0.1 ± 0.2	1.00	0.3466
American robin (*Turdus migratorius*)	0.1 ± 0.2	0.1 ± 0.3	0.43	0.6811
Cooper's hawk (*Accipiter cooperi*)	0.1 ± 0.2	0	1.51	0.1690
Long-eared owl (*Asio otus*)	0.1 ± 0.3	0	1.00	0.3466
Common raven (*Corvus corax*)	0.1 ± 0.2	0	1.51	0.1690
Guild total	38.3 ± 8.3	34.5 ± 7.9	1.77	0.1140
Mean species richness	9.8 ± 1.6	7.7 ± 1.5	4.50	*0.0020*
Shrub nesters				
Western scrub-jay (*Aphelocoma californica*)	8.1 ± 3.7*	6.8 ± 2.8*	1.60	0.1465
California towhee (*Pipilo crissalis*)	6.2 ± 2.0*	4.4 ± 1.7*	5.68	*0.0005*
California thrasher (*Toxostoma redivivum*)	1.1 ± 1.0	0	3.22	0.0122
Wrentit (*Chamaea fasciata*)	0.4 ± 0.5	0	2.53	0.0353
Greater roadrunner (*Geococcyx californianus*)	0.2 ± 0.4	0.1 ± 0.2	0.80	0.4468
Guild total	16.1 ± 4.9	11.3 ± 4.2	7.49	*0.0001*
Mean species richness	3.3 ± 0.9	2.1 ± 0.3	3.77	*0.0054*
Ground nesters				
California quail (*Callipepla californica*)	6.8 ± 3.2*	6.4 ± 2.1*	0.27	0.7960
Canyon wren (*Catherpes mexicanus*)	0.4 ± 0.4	0.4 ± 0.4	0.29	0.7824
Lark sparrow (*Chondestes grammacus*)	0.2 ± 0.5	0.4 ± 0.7	0.69	0.5121
Rufous-crowned sparrow (*Aimophila ruficeps*)	0	0.3 ± 0.4	2.29	0.0509
Rock wren (*Salpinctes obsoletus*)	0	0.1 ± 0.2	1.00	0.3466
Turkey vulture (*Cathartes aura*)	0	0.1 ± 0.2	1.00	0.3466

(continued)

(Table 2, continued)

Guild Species	Ungrazed plot	Grazed plot	*t*-value	*P*
Guild total	7.4 ± 2.9	7.7 ± 2.0	0.25	0.8103
Mean species richness	1.8 ± 0.8	2.7 ± 1.1	1.74	0.1209
Other species				
Brown-headed cowbird *(Molothrus ater)*	4.2 ± 1.4*	3.2 ± 1.5	2.13	0.0660
Total	4.2 ± 1.4*	3.2 ± 1.5	2.13	0.0660
Mean species richness	1.0 ± 0	0.9 ± 0.3	1.00	0.3466
Summary for all species				
Total territories	110.8 ±14.5	115.4 ±19.6	1.17	0.2761
Species richness	26.2 ± 2.6	23.9 ± 1.6	3.50	*0.0081*
Pairs/ha	3.7 ± 0.49	3.9 ± 0.60	1.17	0.2741

[1]Within each guild, species are listed in descending order of abundance. Bonferroni adjustments for multiple comparisons of differences in density between plots require a *P*-value of 0.0012 for significance at the 0.05 level for individual species and 0.01 for guild totals and species richness. Significant *P*-values are in italics. An asterisk (*) designates species holding territories on a plot in all years of the study.

within 10 minutes of local sunrise in generally fair weather, observers walked along alternate lines of the grids and systematically noted on field maps the locations of all birds detected, using specific codes to designate, as possible, sex, vocalizations, movements, and other specific behaviors (copulation, territorial defense, carrying nest materials or food, and so on). Based on 12 such visits per season to each plot, composite maps of all detections of each species were transferred to separate maps for each species. Observers then interpreted the maps to identify clusters of detections believed to localize the territories of individuals or pairs of each species. Any territory that overlapped the plot boundary was tallied as half a territory when summing the total number of territories of a species on the plot.

Because results on the two plots could be paired within years ($n = 9$), paired *t*-tests were used to compare species richness, the numbers of territories of individual species, and the collective totals for nesting guilds between the plots. We tested for normality using the Shapiro-Wilk test (SAS 1988). Given a basic alpha level of 0.05, Bonferroni adjustments for multiple comparisons gave alpha levels of 0.0100 for comparisons of species richness, 0.0012 for comparisons of species abundances, and 0.0100 for comparisons of guild abundances (excluding "other nesters") between plots. The appropriate alpha level for comparing differences in abundance among guilds *within* plots is 0.0050 (again excluding "other nesters").

Results

Woody Vegetation

Tree densities and percentages of canopy cover were essentially the same on both plots, but foothill pine dominated tree cover on the ungrazed plot and interior live oak dominated on the grazed plot (*table 1*). Total shrub cover on the ungrazed plot was 3.4 times that on the grazed plot ($t = 5.68$; $n = 40$; $P < 0.0001$). Buckbrush, the dominant shrub species on both plots, had 6.8 times the cover on the ungrazed compared to the grazed plot ($t = 5.40$; $n = 40$; $P < 0.0001$). In addition, shrubs on the grazed plot were clearly more affected by browsing than those on the ungrazed plot, although many shrubs on the ungrazed plot were heavily browsed by black-tailed deer (*Odocoileus hemionus*). Browsed shrubs tended to have very dense foliage and shapes like inverted pears or urns.

Comparing Bird Communities

Among the 58 species of birds that have nested at SJER, 42 have been recorded as territorial on the two plots collectively, with 38 on the ungrazed plot, and 33 on the grazed plot. On each plot, only 16 species held territories in all 9 years of the study, and 14 of those species were the same on both plots. Neither the total numbers of territories nor territorial densities differed significantly between plots (*table* 2). Mean species richness on the ungrazed plot was significantly greater than that on the grazed plot, but few differences were found between the abundances of individual species on the two plots (*table* 2). Among species that held territories on both plots at least in some years, California towhees and Bullock's orioles were significantly more abundant on the ungrazed plot, and house wrens were significantly more abundant on the grazed plot. According to Simpson and others (1960:422), given the same means, standard deviations, and paired *t*-values, no other species would test significantly different between plots even with an infinite number of years sampled.

Eight species have held territories only on the ungrazed plot during the course of this study: one primary cavity nester—hairy woodpecker; five tree nesters—Cooper's hawk, great horned owl, western kingbird, common raven, and Bullock's oriole; and two shrub nesters—wrentit and California thrasher. These species have all been detected regularly during the breeding period in grazed locations at SJER away from the grazed plot. Only the hairy woodpecker, wrentit, and California thrasher are considered to be uncommon to rare breeders at the Range, but our annual (1985-1995) point counts in March and April at 210 counting stations throughout SJER produce low numbers of these species at various places at SJER nearly every year.[3]

Only four species have held territories on the grazed plot but not on the ungrazed plot: a secondary cavity nester (American kestrel) and three ground nesters (turkey vulture, rock wren, and rufous-crowned sparrow).

Comparing Guilds

On the ungrazed plot, the pooled abundances of species in the nesting guilds (excluding brown-headed cowbirds) all differed significantly among themselves ($P < 0.005$) except primary cavity nesters vs. ground nesters and secondary cavity nesters vs. tree nesters. On the grazed plot, all guilds differed among themselves except primary cavity nesters vs. ground nesters and shrub nesters vs. ground nesters. The rank order of abundance of territories by guild was the same on each plot—secondary cavity nesters were most abundant, then tree nesters, shrub nesters, ground nesters, primary cavity nesters, and other species (*table* 2). In terms of species, the ungrazed plot had more tree-nesting species (both mean and total numbers) than any other guild, followed by secondary cavity nesters. Although the grazed plot had a higher total number of tree-nesting species than secondary cavity nesters, the mean number of tree nesters on the grazed plot was less than that of secondary cavity nesters.

Collectively, the nesting guilds that depend on trees for nest sites (primary and secondary cavity nesters and tree nesters) comprised 76.3 percent of the species and 75.0 percent of the territorial individuals on the ungrazed plot, and 69.7 percent of the species and 80.8 percent of the territorial individuals on the grazed plot. Particularly striking in these comparisons was the marked contrast in abundance between secondary cavity nesters (45.2 percent of all territories) and tree nesters (29.9 percent of territories) on the grazed plot but not on the ungrazed plot (34.8 percent vs. 34.6 percent) (*table* 2). The grazed plot had significantly more territories of secondary cavity nesters than the ungrazed plot,

[3] Unpublished data on file, Forestry Sciences Laboratory, Fresno, CA.

and eight of nine species of secondary cavity nesters had more territories, but not significantly more, on the grazed grid.

For most guilds on both plots, the percentages of total territories were about the same or slightly smaller than the corresponding percentages of total species. In contrast, however, the numbers of territories held by secondary cavity nesters were out of proportion to the numbers of species that were secondary cavity nesters—by 1.65 times on the ungrazed plot and by 1.66 times on the grazed plot.

Another striking aspect of these bird communities was the small representation by shrub nesters—only 5 species (13.2 percent) and 16.0 territories (14.5 percent) on the ungrazed plot, and 3 species (9.1 percent) and 11.3 territories (9.8 percent) on the grazed plot. Significantly more territories were held by shrub nesters on the ungrazed than on the grazed plot, but the proportional difference (1.4 times) did not approach that in total shrub cover (3.4 times) or cover by buckbrush (6.8 times). Buckbrush was the predominant shrub species used for nesting on the ungrazed plot, but shrub nesters on the grazed plot tended to use interior live oaks with a shrub-like growth form.

The European Starling

Although the numbers of starling territories did not differ significantly between plots, starlings on the grazed plot outnumbered those on the ungrazed plot by 1.62 times ($t = 2.05$; $P = 0.07$). More importantly, starlings were observed nesting and foraging in most areas of the grazed plot, which generally had only a relatively sparse ground cover of short grasses and forbs as a result of grazing. On the other hand, starlings did not forage over most of the ungrazed plot, which had a nearly continuous ground cover of tall grasses and forbs. Most of their foraging there occurred in the northwest corner of the plot, which included a small section of horse pasture. All starling nests on the ungrazed plot were located near plot edges, most of them in or adjacent to the horse pasture. Unlike most other species nesting on these plots, starlings have overlapping territories, with up to three pairs nesting in different cavities in the same tree. On the ungrazed plot, most of these territories were concentrated in the horse pasture.

Discussion

Avian Biodiversity

Although all major habitat divisions contribute to bird species richness in these two communities, avian biodiversity is largely driven by the availability of tree cover. Secondary cavity-nesting species comprise a very high proportion of the nesting species and territories. Most excavated nest cavities in these habitats can be attributed to the acorn and Nuttall's woodpeckers, as northern flickers and hairy woodpeckers are uncommon to rare nesters in these study areas. Consequently, although most species of secondary cavity nesters do use natural cavities to some extent, they still depend on the acorn and Nuttall's woodpeckers for a continuing supply of nesting sites. These are, therefore, keystone species upon which 35-45 percent of the nesting birds in the community depend.

The fact that territories of secondary cavity nesters were significantly more abundant on the grazed than on the ungrazed plot may have reflected the fact that the grazed plot had 1.6 times more cavity trees and 1.4 times more nest cavities than the ungrazed plot (Waters 1988:25). Such a relationship could be expected if available nest cavities limited the number of secondary cavity nesters on these plots. On the basis of an exhaustive cavity-blocking experiment on these two plots in 1985 and 1986, however, Waters (1988) concluded that cavities were not limiting the numbers of secondary cavity nesters.

Most of the species that held territories on the ungrazed plot but not the grazed plot have been found nesting in other locations at SJER where grazing occurs. This is the case with the Cooper's hawk, great horned owl, long-eared owl, hairy woodpecker, western kingbird, common raven, California thrasher, and Bullock's oriole. Grazing has probably reduced the numbers of some of these species in the oak-pine woodlands, but it has certainly not threatened their populations. These woodlands provide only marginal habitat for the hairy woodpecker, which finds optimum habitats in the conifer forests at higher elevations in the Sierra Nevada.

Possible Concerns Related to Grazing

Direct Effects

Reduction in shrub cover and in grass and forb biomass are the most conspicuous effects of grazing on habitats important to these bird communities. The greater cover by shrubs on the ungrazed plot probably accounts for the significantly greater number of territories of shrub nesters there, and it almost certainly accounts for the fact that territories of wrentits and California thrashers were found only on the ungrazed plot. Both of these species are associated with dense chaparral (Grinnell and Miller 1944). Because the scattered shrubs and patches of shrubs at SJER are approaching the lower elevational limit of shrubs in the western foothills of the Sierra Nevada, they probably represent marginal habitat for wrentits and California thrashers. Both species are more abundant at higher elevations in the foothills, where more extensive shrubfields occur. Consequently, although grazing in the foothills has most likely resulted in a decline in numbers of these two species, this has probably not put either of them in jeopardy in the western Sierra Nevada as a whole.

Indirect Effects

European Starling—Since its initial occurrence in California in the early 1940's (Grinnell and Miller 1944:572), the European starling has become abundant and widespread, especially in woodland habitats at lower elevations. It was first recorded at SJER in the early 1960's and several nesting pairs were established by 1970 (Duncan and others 1985). No nesting pairs were present on either the grazed or ungrazed plot in 1978,[4] but a few pairs were nesting on each plot by 1985 (Waters 1988).

Data from our extensive point-count work throughout the grazed landbase of SJER from 1985 through 1995[3] show that the starling's numbers nearly doubled there in the last 5 years compared to the first 5 years. This may have resulted from their learning to forage well enough to breed successfully in the oak-pine woodlands. According to Duncan and others (1985:30), large flocks of starlings were seen feeding in wet swales along the entrance road to SJER in March 1974. Stomach contents of 21 birds collected then contained almost exclusively the larvae of the range crane fly (*Tipula* sp.). Because we have not seen starlings forage in the tall grasses and forbs on the ungrazed plot, we believe their range extension and increase in abundance in the foothill woodlands have been enhanced by grazing, which results in short grasses and forbs so the birds can forage easily on the ground.

Starlings use nest cavities similar in size and shape to those used by native species, especially western bluebirds and violet-green swallows (Purcell 1995). Consequently, their successful "invasion" of foothill oak-pine woodlands may negatively affect some species of secondary cavity nesters there. Starlings often used nest cavities that were used in prior years by other secondary cavity nesters. In addition, we have seen starlings use cavities for winter roosts at SJER, some of which we knew to be used previously for winter roosts by other species.

[4]Personal observation, J. Verner.

Indirectly then, by enhancing habitats for starlings, grazing in the foothills may be having a negative influence on the numbers of some native cavity-nesting bird species.

Brown-headed Cowbird—Because cowbirds regularly associate with cattle for access to supplemental food sources, they are probably more abundant in the foothill oak-pine woodlands today than they would be in the absence of grazing. Grinnell and Miller (1944:437) state that their numbers "...increased phenomenally in the Sacramento Valley since 1927, if not earlier." Because the center of each plot was only 225 m from the nearest edge, cowbirds on the ungrazed plot would have ready access to supplemental food sources associated with nearby livestock. This may explain why we did not observe a significant difference in the numbers of cowbirds between the two plots, and it also makes it unlikely that we would ever detect a significant difference between plots in the rate of cowbird nest parasitism on any host species.

None of our data suggested that nest parasitism by cowbirds has threatened the viability of any host species that currently breeds at SJER, although it may depress populations of some hosts, such as the California gnatcatcher and Hutton's vireo. Although cowbirds probably contributed to the extirpation of the least Bell's vireo (*Vireo bellii pusillus*) from central California (Goldwasser and others 1980), the lowland distribution of this species probably did not include SJER.

Other Studies

We are not aware of any similar study elsewhere in the oak-pine woodlands that ring the Central Valley of California. The generally minor impacts of grazing on the bird communities reported in this study, however, contrast markedly with similar studies in other habitats. This is particularly the case in riparian habitats, where densities of some bird species differ by orders of magnitude in response to grazing (for example, Taylor 1986 and recent review by Ohmart 1994). An excellent review by Bock and others (1993:296) summarized existing literature on the relations of neotropical migrant bird populations to grazing:

> Among 35 plains species for which data are available, 9 responded positively to grazing, 8 responded negatively, 8 showed a graded response, from generally negative in shorter grasslands to generally positive in taller grasslands, while 8 were unresponsive or inconsistent. A similar comparison for riparian woodlands revealed that 8 of 43 species responded positively to grazing, while 17 were negatively affected, and 18 were unresponsive or showed mixed responses. Data for shrubsteppe habitats are much more limited, but only 3 of 23 species probably have been positively affected, at least by current grazing practices, while 13 probably have been negatively influenced, and at least 7 species showed mixed responses. Virtually nothing is known about effects of grazing on birds of coniferous forests.

A Need for Replication

This study is based on a comparison between one grazed and one ungrazed plot. As such, it is an unreplicated case study. On the basis of more extensive knowledge from throughout their ranges in the western Sierra Nevada, however, we believe that our results at SJER attain more general significance when taken in the context of the known habitat relations of these bird species. Nonetheless, additional comparisons involving other matched pairs of grazed and ungrazed pastures are needed to confirm or negate results of this study. Opportunities for such replication exist at the Hopland Research and Extension Center in Mendocino County—pastures of 126 and 48 ha that have excluded livestock grazing since the late 1950's (Timm 1996)—and the Sierra Foothill Research and Extension Center in Yuba County—pastures of 66 and 44 ha that have excluded livestock grazing since 1972 (Connor 1996).

Conclusions

Overall, results of this study do not show that grazing has led to the loss of any bird species that regularly nests in this foothill oak-pine woodland. The direct effects of reduced shrub cover and height by grazing on shrub-nesting birds are not as pronounced as we might expect. It is almost certainly true that the number of cowbirds in these woodlands is higher with cattle present than would be the case without them. Whether nest parasitism by cowbirds is a serious concern for any host species remains to be evaluated; however, no evidence of such an impact is yet available. Similarly, the question of the starling's possible impact on other secondary cavity nesters remains uncertain at this time, although we suspect it could be significant for some native species, especially if starlings continue to increase in abundance at SJER.

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References

Anonymous. 1970. **Recommendations for an international standard for a mapping method in bird census work.** Bird Study 16: 249-254.

Bock, Carl E.; Saab, Victoria A.; Rich, Terrell D.; Dobkin, David S. 1993. **Effects of livestock grazing on neotropical migratory landbirds in western North America.** In: Finch, Deborah M.; Stangel, Peter W., eds. Status and management of neotropical migratory birds. Proceedings of workshop; 1992 September 21-25; Estes Park, CO. Gen. Tech Rep. RM-229. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 296-309.

Connor, J. Michael, Superintendent, Sierra Foothill Research and Extension Center, Browns Valley, CA. [Telephone conversation with Jared Verner]. 17 January 1996.

Duncan, Don A.; Coon, Susan L. 1985. **Publications from the San Joaquin Experimental Range, 1935-1985. CATI/850902.** Fresno: California Agricultural Technology Institute, California State University, Fresno; 101 p.

Duncan, Don A.; Ritter, Lyman V.; Newman, Thomas F. 1985. **Vertebrate fauna of the San Joaquin Experimental Range, California: a 50-year checklist.** CATI/850901. Fresno: California Agricultural Technology Institute, California State University, Fresno; 41 p.

Goldwasser, Sharon; Gaines, David; Wilbur, Sanford R. 1980. **The least Bell's vireo in California: a de facto endangered race.** American Birds 34: 742-745.

Grinnell, Joseph; Miller, Alden H. 1944. **The distribution of the birds of California.** Berkeley, CA: Pacific Coast Avifauna 27: 1-615.

James, F.E.; Shugart, H.H. 1970. **A quantitative method of habitat description.** Audubon Field Notes 24: 727-736.

Kotok, E.I. [Letter and report to Mr. Earle H. Clapp, Research Branch, USDA Forest Service, Washington, D.C.]. 19 September 1933. 12 p. Located at: U.S. Department of Agriculture, Forestry Sciences Laboratory, Fresno, CA.

Ohmart, Robert D. 1994. **The effects of human-induced changes on the avifauna of western riparian habitats.** Studies in Avian Biology 15: 273-285.

Purcell, Kathryn L. 1995. **Reproductive strategies of open- and cavity-nesting birds.** Reno: University of Nevada; 110 p. Ph.D. dissertation.

Robbins, Chandler S. 1970. **Recommendations for an international standard for a mapping method in bird census work.** Audubon Field Notes 24: 723-726.

SAS Institute, Inc. 1988. **SAS/STAT user's guide: statistics.** Release 6.03 edition. Cary, NC: SAS Institute, Inc.; 1028 p.

Simpson, George Gaylord; Roe, Anne; Lewontin, Richard C. 1960. **Quantitative zoology.** New York: Harcourt, Brace, and World, Inc.; 440 p.

Taylor, Daniel M. 1986. **Effects of cattle grazing on passerine birds nesting in riparian habitat.** Journal of Range Management 39: 254-258.

Timm, Robert M., Superintendent, Hopland Research and Extension Center, Hopland, CA. [Telephone conversation with Jared Verner]. 17 January 1996.

Waters, Jeffrey R. 1988. **Population and habitat characteristics of cavity-nesting birds in a California oak woodland.** Arcata, CA: Humboldt State University; 100 p. M.S. thesis.

Relative Abundance and Habitat Associations of Vertebrates in Oak Woodlands in Coastal-Central California[1]

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Abstract: *We estimated relative abundance and assessed habitat associations of small mammals, birds, amphibians, and reptiles in oak (*Quercus *spp.) woodlands from 1993 to 1995 at Camp Roberts in California's central coast. Within taxa, relative abundance was highest for dusky-footed woodrats (*Neotoma fuscipes*) (9.7 percent trap success), plain titmice (*Parus inornatus*) (49.4 territories per 40 ha), slender salamanders (*Batrachoseps *spp.) (2.2 percent detection rate) and skinks (*Eumeces *spp.) (3.1 percent detection rate). Percent cover of shrubs, grass, and downed wood were the three strongest correlated habitat components (mean of the absolute value of all correlation coefficients [* $|r_s|$ *] = 0.64, 0.62, and 0.59, respectively) for abundant species of small mammals. Percent shrub cover and litter weight were correlated with abundant birds, and herpetofauna, respectively (mean* $|r_s|$ *= 0.57 and 0.49, respectively). Within taxa, woodrats, dark-eyed juncos (*Junco hyemalis*), and slender salamanders exhibited the strongest habitat associations across all habitat components (mean* $|r_s|$ *= 0.74, 0.73, and 0.44, respectively). Dense oak woodlands with shrubby understory and downed woody material supported the greatest numbers of vertebrate fauna.*

Only limited information is available about the characteristics that make oak (*Quercus* spp.) woodland valuable wildlife habitat. Previous research has developed some fundamental information on wildlife-habitat relationships in oak woodlands (Block 1989; Block and Morrison 1987, 1990; Block and others 1988; Morrison and others 1991; Verner and Ritter 1985, 1988). This paper attempts to add to the existing body of information by summarizing 2.5 years of wildlife habitat-relationships data collected before conducting an experimental treatment to assess the effects of fire on oak woodland biodiversity. This study also identifies habitat components of particular importance to several common species of terrestrial vertebrates in blue oak woodlands of the California central coast, where wildlife-habitat relationships are little studied.

Landowners, land-use planners, and other land managers can use information from this study to develop management strategies for California's oak woodlands. In addition, the information generated may serve as input to the model validation needs of the California Wildlife Habitat Relationships (CWHR) System (Airola 1988), which frequently is used to predict the effects of environmental and anthropogenic perturbations on wildlife.

Study Area

Camp Roberts, a military facility of the California Army National Guard, is located in northern San Luis Obispo County 18 km north of Paso Robles, California. The northern portion of Camp Roberts is in Monterey County. The facility comprises 17,800 ha, of which approximately 7,200 ha are classified as oak woodland (Camp Roberts 1989). The dominant tree species in the overstory is blue oak (*Quercus douglasii*) with a variable contribution of coast live oak (*Q. agrifolia*). Where it occurs, understory is comprised of toyon (*Heteromeles*

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arbutifolia), redberry (*Rhamnus crocea*), bigberry manzanita (*Arctostaphylos glauca*), ceanothus (*Ceanothus* spp.), poison oak (*Toxicodendron diversilobum*), and, infrequently, chamise (*Adenostoma fasciculatum*). On the woodland floor, wild oats (*Avena* spp.), bromes (*Bromus* spp.), and fescues (*Festuca* spp.) predominate. Common forbs include deerweed (*Lotus scoparius*), filaree (*Erodium* spp), and hummingbird sage (*Salvia spathacea*).

Methods

Experimental Design

Using topographic maps and ground reconnaissance, we selected oak stands within the southern half of Camp Roberts where there is the least potential for interference with military activities and where most of the dense oak woodlands at Camp Roberts occur. To accommodate a treatment, we selected blue oak stands with varying contributions of coast live oak that were >16 ha in size and had an estimated canopy cover of >50 percent. Within these stands, we established nine, square 5.8-ha plots in the summer of 1993. We used a compass and meter tape to lay out a 17 × 17 sampling grid (289 intersections every 15 m in two directions).

Vegetation Sampling

Vegetation surveys were conducted in the spring and summer of 1995. Densities of living and dead trees were determined by the point-centered quarter method (Cottam and Curtis 1956). Distance (≤10 m) to the nearest living and dead trees ≥5.1 cm dbh (diameter at breast height [1.4 m above ground level]) and their species were recorded. On trees that bifurcated at or below breast height, the distance to the nearest stem ≥5.1 cm dbh was measured. We also recorded the number of saplings ≥1.4 m in height and <5.1 cm dbh that occurred within 5 m of the center point. Forty-five sapling and tree samples were taken per plot.

At alternate intersections on all plot grid lines (145 intersections per plot), percent cover of tree canopy, shrub foliage, ground vegetation, and downed woody material were derived from vertical interceptions ("hits") at six points spaced 1.7 m along each of the ropes (12 points per intersection × 145 intersections per plot × nine plots = 15,660 points); occurrence of downed wood >5.1 cm diameter was recorded when within 30 cm of points. We collected all herbaceous material within a 30-cm by 30-cm frame centered on one randomly selected point along one of the ropes. Litter (i.e., organic material lying on the ground before the previous season's production) was separated from the current season's production of herbaceous material, air dried, and weighed to the nearest 1 g.

Animal Sampling

Small Mammal Trapping

Small mammal trapping was conducted in the fall (3 October to 18 November) of 1993, the spring (8 May to 3 June) and fall (10 October to 11 November) of 1994, and the spring (9 May to 10 June) and fall (9 October to 10 November) of 1995 by placing a single Sherman live trap (trap size: 7.6 cm by 9.5 cm by 30.5 cm) at each of the 289 intersections on each plot. Traps were baited with a mixture of corn, oats, and barley laced with molasses and checked for 5 consecutive days. Captured animals were ear-tagged and released. Species, capture location, sex, age (juvenile or adult), and tag number were recorded. After the fall 1993 trapping bout, two study plots were shifted four lines (i.e., line E became line A), resulting in the loss of 680 trap-nights (17 traps per line × four lines × five nights × two plots). These 680 points were not used for summaries or analyses. Total trapping effort on the nine study plots was 64,345 trap nights (1,445 trap nights per bout × five trapping bouts per study plot × nine study plots - 680 trap nights).

Bird Census

Two or three field biologists, trained to identify birds by sight and sound, recorded pairs of breeding birds during 1994 (6 April to 4 May) and 1995 (27 March to 26 April) by spot mapping. To facilitate consistent sampling effort within each plot, we mapped territories along four evenly-spaced grid lines. The initial line and direction walked was alternated clockwise around the plot for each visit. Two to three plots per person were visited each day. The first visit began within 30 minutes of sunrise. We recorded the grid location and activity of each detected bird. Ten to 12 separate visits per plot were conducted each year. Following guidelines from Bibby and others (1992:58), we updated and interpreted individual species maps after each visit. Bird territories by species and plot were delineated each year after the field season.

Amphibian and Reptile Monitoring

In January and February 1994, we placed a single 1.3-cm by 61.0-cm by 61.0-cm plywood coverboard (Grant and others 1992) flush with the ground within 2 m of each intersection on alternate lines on each plot (136 coverboards per plot). Once weekly, during 24 January to 26 April 1995, we recorded species and number of amphibians and reptiles observed under the coverboards.

Data Analyses

We pooled habitat data and animal data by taxa within plots. Data were assessed for normality using Shapiro-Wilks tests (Conover 1980:363) and visual inspection of normal-probability plots and histograms in PROC UNIVARIATE of PC-SAS (SAS Institute Inc. 1988:627-628, Schlotzhauer and Littell 1987:117-119). Although all habitat variables and most response variables were normally distributed, nonparametric analyses were used because sample sizes were small (n = 9) after pooling. Consequently, we used Spearman rank correlation (r_s) (Zar 1984:318) in PROC CORR of PC-SAS (SAS Institute Inc., 1988:209-235) to assess habitat associations for the six most abundant (≥100 individuals captured per five bouts) small mammal species, four most abundant (≥10 territories occurring on ≥8 plots) bird species, and four most abundant (≥60 observations) amphibian and reptile species. To determine which habitat components were most important for each taxa, we averaged absolute values (| |) of correlation coefficients (therefore, mean $|r_s|$) for each habitat component across species within taxa). To determine the average strength of each species' habitat associations, we averaged absolute values of correlation coefficients for each species across habitat components. Differences were considered significant when $P \leq 0.05$. Power (1 - β) is reported for significant coefficients (Zar 1984:312).

Results

Habitat

Across all nine plots, density of live stems (including saplings) ranged from 130.4 to 461.1 stems per ha, and density of snags ranged from 9.4 to 35.7 per ha (*table 1*). Live tree canopy and shrub cover ranged from 40.2 to 70.1 and 0 to 35.4 percent of plots, respectively. Grass, forbs, downed wood, and unvegetated ground comprised 38.1 to 71.6 percent, 1.4 to 6.3 percent, 1.1 to 6.5 percent, and 8.4 to 14.8 percent of ground cover, respectively. Stem density, snag density, tree canopy cover, shrub cover, and percent ground cover of downed wood were proportionally related. Grass cover was approximately inverse to live tree canopy cover and shrub cover. Litter weight varied from 8.5 g per 900 cm^2 to 27.8 g per 900 cm^2 (*table 1*).

Table 1—Habitat characteristics of nine vegetation variables used to assess habitat associations of small mammals, birds, reptiles, and amphibians on nine 5.8-ha plots in oak woodlands, Camp Roberts, California, spring and summer 1995.

	Plot range[1]								
Habitat characteristic	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)	Mean (SE)
Live tree density (stems/ha)[2,3]	130.4	181.8	224.8	233.4	241.9	274.2	330.5	423.6	461.1
Snag density (stems/ha)[2]	9.4	15.2	16.6	22.5	22.8	24.4	28.6	34.8	35.7
Tree canopy cover (pct)	40.2 (2.1)	45.3 (2.5)	53.2 (2.8)	53.7 (2.7)	55.9 (2.6)	56.3 (2.6)	61.7 (2.4)	67.8 (2.5)	70.1 (2.6)
Shrub cover (pct)	0 (0)	2.4 (0.8)	3.8 (0.9)	8.3 (1.3)	9.9 (1.5)	13.2 (1.7)	20.8 (2.5)	24.3 (2.6)	35.4 (2.7)
Grass cover (pct)	38.1 (2.2)	43.9 (2.3)	46.7 (1.9)	48.7 (2.2)	50.0 (2.5)	56.9 (1.8)	58.3 (1.6)	67.1 (1.8)	71.6 (1.5)
Forb cover (pct)	1.4 (0.3)	2.1 (0.6)	2.2 (0.5)	2.7 (0.4)	3.2 (0.5)	3.2 (0.6)	3.2 (0.6)	3.9 (0.7)	6.3 (0.8)
Downed wood cover (pct)	1.1 (0.4)	2.2 (0.5)	2.6 (0.5)	3.4 (0.6)	3.6 (0.6)	3.6 (0.7)	3.7 (0.6)	3.8 (0.6)	6.5 (0.8)
Unvegetated ground (pct)	8.4 (0.7)	8.9 (0.7)	9.6 (0.9)	10.2 (0.9)	10.7 (0.9)	12.4 (1.1)	12.9 (0.9)	13.3 (0.9)	14.8 (1.1)
Litter weight (g)	8.5 (0.9)	13.4 (1.5)	13.7 (1.5)	14.6 (1.9)	14.9 (1.5)	21.6 (1.9)	23.0 (2.4)	27.8 (2.2)	27.8 (3.1)

[1] Means from the nine plots are ranked from least to greatest, left to right, within rows.
[2] Live tree density and snag density were determined using the point-centered quarter method (Cottam and Curtis 1956). Standard errors are not associated with either density estimate because a formula for calculating standard error was not presented in the paper.
[3] Includes saplings, which were measured using fixed-radius plots and therefore have an associated standard error. Mean saplings/ha ranged from 0 ± 0 stems/ha to 121.7 ± 26.2 stems/ha. Maximum standard error (on a mean of 99.0 stems/ha) was 30.5 stems/ha.

Small Mammals

Richness and Numbers

During 64,345 trap-nights of effort, we recorded 14,076 captures of 5,767 individuals of 10 species of small mammals (*table 2*). Dusky-footed woodrats (*Neotoma fuscipes*), piñon mice (*Peromyscus truei*), California pocket mice (*Perognathus californicus*), brush mice (*Peromyscus boylii*), deer mice (*Peromyscus maniculatus*), and California mice (*Peromyscus californicus*) were the six most abundant species captured with 32, 19, 18, 16, 10, and 2 percent of total individual captures, respectively (*table 2*). Among these species, trap success was greatest for woodrats (9.7 percent of total captures) and least for California mice (0.5 percent of total captures); average captures per animal were greatest for woodrats (3.3) and least for deer mice (1.6). Four species had <100 individual captures per five bouts (*table 2*). We also captured ground squirrels (*Spermophilus beecheyi*) on three study plots and pocket gophers (*Thomomys bottae*) on two plots; we did not record these captures.

Habitat Relationships

Percent shrub cover was the strongest correlated habitat component for California mice (r_s = 0.97), woodrats (r_s = 0.95), piñon mice (r_s = 0.83), and California pocket mice (r_s = 0.51) (*table 3*). Percent tree canopy cover and percent unvegetated ground cover were the strongest correlates for brush mice and deer mice, respectively (r_s = 0.68 and 0.82, respectively). All species were negatively correlated with percent grass cover (r_s = -0.12 [deer mice] to -0.88 [woodrats]) and positively correlated with percent shrub cover (r_s = 0.08 [deer mice] to 0.97 [California mice]) and percent unvegetated ground cover (r_s = 0.05 [brush mice] to 0.82 [deer mice]). Across all habitat components, woodrats exhibited the

Table 2—Capture statistics of 10 species of small mammals captured in Sherman live traps on nine 5.8-ha plots (64,345 trap-nights) in oak woodlands, Camp Roberts, California, spring and fall, fall 1993 to fall 1995.

Species	Total captures	Individual captures	Total trap success[1]	Percent of individuals captured[2]	Average captures per animal[3]
Dusky-footed woodrat (*Neotoma fuscipes*)	6,207	1,871	9.65	32.44	3.32
Piñon mouse (*Peromyscus truei*)	2,798	1,119	4.35	19.40	2.50
California pocket mouse (*Perognathus californicus*)	1,799	1,014	2.80	17.58	1.77
Brush mouse (*Peromyscus boylii*)	1,762	916	2.74	15.88	1.92
Deer mouse (*Peromyscus maniculatus*)	929	597	1.44	10.35	1.56
California mouse (*Peromyscus californicus*)	341	108	0.53	1.87	3.16
California vole (*Microtus californicus*)	105	81	0.16	1.40	1.30
Merriam's chipmunk (*Tamias merriami*)	73	27	0.11	0.47	2.70
Heermann's kangaroo rat (*Dipodomys heermanni*)	46	18	0.07	0.31	2.56
W. harvest mouse (*Reithrodontomys megalotis*)	16	16	0.02	0.28	1.00
Total	14,076	5,767	21.88	100.00	2.44

[1] Total captures expressed as a percent of total trap-nights (64,345).
[2] Individual captures expressed as a percent of total number of individuals captured (5,767).
[3] Total captures ÷ individual captures.

Table 3—Spearman rank correlations (r_s) between total individual captures of six relatively abundant species of small mammals and six habitat characteristics on nine 5.8-ha plots in oak woodlands, Camp Roberts, California, spring and fall, fall 1993 to fall 1995.

Habitat characteristic	Dusky-footed woodrat	Pinon mouse	California pocket mouse	Brush mouse	Deer mouse	California mouse
Tree canopy cover (pct)	0.62	0.72*	0.13	0.68*	-0.17	0.72*
P[1]	0.08	0.03	0.73	0.04	0.67	0.03
Shrub cover (pct)	0.95*	0.83*	0.51	0.47	0.08	0.97*
P	<0.01	0.01	0.16	0.21	0.83	<0.01
Grass cover (pct)	-0.88*	-0.80*	-0.36	-0.67*	-0.12	-0.86*
P	<0.01	0.01	0.34	0.05	0.77	0.01
Forb cover (pct)	0.61	0.54	-0.12	0.41	0.44	0.44
P	0.08	0.13	0.76	0.28	0.24	0.23
Unvegetated groundcover (pct)	0.47	0.47	0.30	0.05	0.82*	0.14
P	0.21	0.21	0.43	0.90	0.01	0.71
Downed wood cover (pct)	0.90*	0.73*	0.37	0.55	-0.02	0.96*
P	<0.01	0.03	0.32	0.12	0.97	<0.01

[1] *P*-value of correlation coefficients. Power of significant coefficients ranged from 0.5080 ($r_s = 0.67$) to 0.9992 ($r_s = 0.97$). All $n = 9$. Asterisks denote significance at $P \leq 0.05$.

strongest habitat correlations (mean $|r_s| = 0.74$, range = -0.88 to 0.95), whereas deer mice were least strongly correlated (mean $|r_s| = 0.28$, range = -0.17 to 0.82) (*table 3*). Only California pocket mice were not significantly correlated with at least one habitat component (all correlation $P > 0.05$).

Birds

Richness and Numbers

We delineated territories of 24 bird species during 212 visits in spring 1994 and 1995. Territories were not delineated for 50 other species because fewer than three detections were recorded or the species' behavior precluded such delineation (e.g., western scrub-jays [*Aphelocoma californica*]). Plain titmice (*Parus inornatus*), dark-eyed juncos (*Junco hyemalis*), house finches (*Carpodacus mexicanus*), and white-breasted nuthatches (*Sitta carolinensis*) were the most frequently observed species with an annual average of 49.4, 21.5, 13.0, and 10.2 territories, respectively (*table 4*).

Table 4—Average (annual) number and density of breeding-bird territories (derived from spot-mapping observations) of 24 bird species on nine 5.8-ha study plots in oak woodland, Camp Roberts, California, spring 1994 and spring 1995.

Species	Mean no. territories	SE	No. territories/40 ha
Plain titmouse (*Parus inoratus*)	64.5	6.5	49.4
Dark-eyed junco (*Junco hyemalis*)	28.0	0.5	21.5
House finch (*Carpodacus mexicanus*)	17.0	0.5	13.0
White-breasted nuthatch (*Sitta carolinensis*)	13.3	1.8	10.2
Lesser goldfinch (*Carduelis psaltira*)	8.5	1.5	6.5
Anna's hummingbird (*Calypte anna*)	6.5	0.5	5.0
Blue-gray gnatcatcher (*Polioptila caerulea*)	5.3	1.8	4.1
Lawrence's goldfinch (*Carduelis lawrencei*)	5.3	1.3	4.1
California towhee (*Pipilo crissalis*)	4.5	2.0	3.5
Common bushtit (*Psaltriparus minimus*)	4.5	4.5	3.5
Hutton's vireo (*Vireo huttoni*)	4.3	1.8	3.3
Western bluebird (*Sialia mexicana*)	3.8	1.3	2.9
Bewick's wren (*Thryomanes bewickii*)	3.0	0.5	2.3
Lark sparrow (*Chondestes grammacus*)	3.0	0	2.3
Nuttall's woodpecker (*Picoides nuttallii*)	3.0	0.5	2.3
Spotted towhee[1] (*Pipilo maculatus*)	2.8	0.3	2.2
House wren (*Troglodytes aedon*)	1.8	0.3	1.4
Orange-crowned warbler (*Vermivora celata*)	1.8	0.8	1.4
Northern flicker (*Colaptes auratus*)	1.0	0	0.8
Bullock's Oriole (*Icterus bullockii*)	1.0	0.5	0.8
California quail (*Callipepla californica*)	0.5	0.5	0.5
Acorn woodpecker (*Melanerpes formicivorus*)	0.3	0.3	0.2
Brown-headed cowbird (*Molothrus ater*)	0.3	0.3	0.2
Cooper's hawk (*Accipiter cooperii*)	0.3	0.3	0.2
Total	183.8	24.3	140.8

[1]Formerly rufous-sided towhee.

Habitat Relationships

Percent shrub cover was the strongest correlated habitat component for dark-eyed juncos (r_s = 0.79), white-breasted nuthatches (r_s= -0.64), and house finches (r_s= 0.46) (*table 5*). Tree canopy cover was the strongest correlated habitat component for plain titmice (r_s = 0.40). Juncos exhibited the strongest habitat correlations across all habitat components (mean $|r_s|$ = 0.73, range = 0.65 to 0.79); titmice exhibited the weakest habitat correlations across all habitat components (mean $|r_s|$ = 0.28; range = -0.16 to 0.40). Only dark-eyed juncos were significantly ($P \leq 0.05$) correlated with any habitat component.

Table 5—Spearman rank correlations (r$_s$) between average number of territories (derived from spot-mapping observations) of four relatively abundant songbird species and four habitat characteristics on nine 5.8-ha plots in oak woodlands, Camp Roberts, California, spring 1994 and spring 1995.

Habitat characteristic	Plain titmouse	Dark-eyed junco	House finch	White-breasted nuthatch
Live stem density (trees/ha)	0.15	0.71*	0.14	-0.38
P[1]	0.70	0.03	0.73	0.31
Standing snag density (stems/ha)	-0.16	0.65	0.07	-0.29
P	0.68	0.06	0.86	0.44
Tree canopy cover (pct)	0.40	0.78*	0.44	-0.50
P	0.28	0.01	0.24	0.17
Shrub cover (pct)	0.39	0.79*	0.46	-0.64
P	0.29	0.01	0.21	0.06

[1] *P*-value of correlation coefficients. Power of significant coefficients ranged from 0.5793 (r_s = 0.71) to 0.7454 (r_s = 0.79). All n = 9. Asterisks denote significance at $P \leq 0.05$.

Amphibians and Reptiles

Richness and Numbers

We recorded 1,516 observations of 15 to 17 species of amphibians and reptiles during 17,136 coverboard checks in 1995: five or six species of lizards, two or three salamanders, six snakes, one toad, and one frog species (*table 6*). Skinks (*Eumeces* spp.), western fence lizards (*Sceloporus occidentalis*), Slender salamanders (*Baltrachoseps* spp.), and gopher snakes (*Pituophis melanoleucus*) were the four most relatively abundant species with 35, 26, 25, and 4 percent of total observations, respectively, and 3.1, 2.3, 2.2, and 0.4 percent of total possible observations, respectively (*table 6*). Eleven species had <60 total observations.

Habitat Relationships

Percent tree canopy cover, percent shrub cover, percent forb cover, and litter weight were the strongest correlated habitat components for slender salamanders, gopher snakes, skinks, western fence lizards, respectively (r_s = 0.82, 0.59, 0.46, and 0.59, respectively) (*table 7*). All species were positively correlated with percent shrub cover (r_s = 0.10 [fence lizards] to 0.59 [gopher snakes]), percent forb cover (r_s = 0.06 [gopher snakes] to 0.46 [skinks]), percent downed wood cover (r_s = 0.15 [fence lizards] to 0.58 [gopher snakes]), and litter weight (r_s = 0.28 [skinks] to 0.62 [slender salamanders]), and negatively correlated with percent grass cover (r_s = -0.05 [fence lizards] to -0.53 [slender salamanders]). Slender salamanders exhibited the strongest habitat correlations across all habitat components (mean $|r_s|$ = 0.44, range = -0.53 to 0.82); western fence lizards exhibited the weakest habitat correlations across all habitat components (mean $|r_s|$ = 0.20, range = -0.05 to 0.59). Only slender salamanders were significantly (P $\leq$ 0.05) correlated with any habitat component.

Table 6—Amphibians and reptiles observed under 136 coverboards during 14 consecutive weeks on each of nine 5.8-ha plots (17,136 board checks), Camp Roberts, California, 24 January to 26 April, 1995.

Species	Total observations	Percent success[1]	Percent of total observations[2]
Reptiles—Lizards			
Skink (*Eumeces* spp.)	535	3.12	35.29
Western fence lizard (*Sceloporus occidentalis*)	388	2.26	25.59
California legless lizard (*Anniella pulchra*)	33	0.19	2.26
Southern alligator lizard (*Gerrhonotus coeruleus*)	15	0.09	0.99
Side-blotched lizard (*Uta stanburiana*)	13	0.08	0.86
Reptiles—Snakes			
Gopher snake (*Pituophis melanoluecus*)	60	0.35	3.96
Striped racer (*Coluber constrictor*)	33	0.19	2.18
Common king snake (*Lampropeltis getulus*)	28	0.16	1.85
Ring-necked snake (*Diadophis punctatus*)	18	0.11	1.19
Garter snake (*Thamnophis sirtalis*)	1	0.01	0.07
Nightsnake (*Hypsiglena torquata*)	1	0.01	0.07
Amphibians—Salamanders			
Slender salamander (*Batrachoseps* spp.)	383	2.24	25.26
Ensatina (*Ensatina eschscholtzii*)	1	0.01	0.07
Amphibians—Frogs and toads			
Western toad (*Bufo boreas*)	6	0.04	0.40
Unidentified frog	1	0.01	0.07
Total	1,516	8.85	100.00

[1]Total observations expressed as a percent of total coverboard checks (17,136).
[2]Total species observations expressed as a percent of total observations (1,516).

Table 7—Spearman rank correlations (*r_s*) between total observations of four relatively abundant amphibian and reptile species and seven habitat characteristics on nine 5.8-ha plots in oak woodlands, Camp Roberts, California, 24 January to 26 April, 1995.

Habitat characteristic	Slender salamander	Gopher snake	Skink	Western fence lizard
Litter weight (g)	0.62	0.47	0.28	0.59
P[1]	0.08	0.20	0.47	0.10
Tree canopy cover (pct)	0.82*	0.34	-0.15	0.22
P	0.01	0.37	0.70	0.58
Shrub cover (pct)	0.32	0.59	0.23	0.10
P	0.41	0.10	0.55	0.80
Grass cover (pct)	-0.53	-0.40	-0.08	-0.05
P	0.14	0.28	0.83	0.90
Forb cover (pct)	0.44	0.06	0.46	0.27
P	0.24	0.88	0.22	0.48
Unvegetated ground cover (pct)	0.02	-0.12	0.42	-0.03
P	0.97	0.76	0.26	0.93
Downed wood cover (pct)	0.35	0.58	0.31	0.15
P	0.35	0.10	0.42	0.70

[1]*P*-value of correlation coefficients. Power of the one significant coefficient was 0.8051. All $n = 9$. Asterisks denote significance at $P \leq 0.05$.

Discussion

Small mammal, reptile, and amphibian species richness was similar to that described in other published studies in oak woodlands in California. Compared to Block and Morrison (1991), small mammal species richness and composition at Camp Roberts was similar (12 species from Camp Roberts, including ground squirrels and pocket gophers, for which we did not specifically survey, versus 15 species from their study). We cannot compare our bird species richness data with those in other studies (Block 1989; Block and Morrison 1987, 1991; Verner 1987) because we spot mapped only selected species with at least three detections of a singing male. We found two fewer species of lizards and four fewer species of amphibians than Block and Morrison (1991). Differences in species composition between studies within the small mammal, amphibian, and reptile taxa likely can be attributed to different geographic areas and census methods.

When comparing relative abundance of small mammal species common to both studies, the list from Camp Roberts is similar to live-trapping capture rates of Block and Morrison (1991) with the notable exception of woodrats. Woodrats ranked fifth in the Block and Morrison (1991) study and first at Camp Roberts. Little is published on the density of breeding bird territories estimated from spot mapping. However, numbers are available for the plain titmouse, an abundant species at Camp Roberts, where density was one-and-a-half times the April estimate for an ungrazed oak woodland at the San Joaquin Experimental Range, Madera County (49.4 per 40 ha at Camp Roberts versus 31.2 per 40 ha in Madera County [Verner and Lyman 1988]). The ranked list of relative abundances in oak woodland of amphibian and reptile species collected with pitfall traps by Block and Morrison (1991) is similar to the list from coverboards used at Camp Roberts.

At Camp Roberts, many species of terrestrial vertebrates were associated with shrubby areas of dense oak woodland with downed wood: seven species were significantly ($|r_s| \geq 0.67$ [critical correlation coefficient when n = 9 and $\alpha = 0.05$ (two-tailed)], $P \leq 0.05$) associated with one or more of these habitat components. Although small mammals were strongly associated with dense woodlands, habitat relationships were less pronounced for birds, reptiles, and amphibians. A larger sample size may be needed to detect strong habitat associations, given the relatively low number of individuals present in these groups.

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References

Airola, Daniel A. 1988. **Guide to the California wildlife habitat relationships system**. Prepared for the State of California Resources Agency, Dept. of Fish and Game. Sacramento, CA; 74 p.

Bibby, Colin J.; Burgess, Neil D.; Hill, David A. 1992. **Bird census techniques**. San Diego, CA: Academic Press, Harcourt Brace Jovanovich Publishers; 257 p.

Block, William. 1989. **Spatial and temporal patterns of resource use by birds in California oak woodlands**. Berkeley: University of California; 364 p. Unpublished Ph.D. dissertation.

Block, William M.; Morrison, Michael L. 1987. **Conceptual framework and ecological considerations for the study of birds in oak woodlands**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-GTR-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 163-173.

Block, William M.; Morrison, Michael L. 1990. **Wildlife diversity on the central Sierra foothills**. California Agriculture 44(2): 19-22.

Block, William M.; Morrison, Michael L. 1991. **Influence of scale on the management of wildlife in California oak woodlands**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-GTR-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 96-104.

Block, William M.; Morrison, Michael L.; Slaymaker, John C.; Jongejan, Gwen. 1988. **Design considerations for the study of amphibians, reptiles, and small mammals in California's oak woodlands: temporal and spatial patterns**. In: Szaro, Robert C.; Severson, Keith E.; Patton, David R., technical coordinators. Proceedings of the symposium on management of amphibians, reptiles, and small mammals in North America; 1988 July 19-21; Flagstaff, AZ. Gen. Tech. Rep. GTR-RM-166. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 247-253.Camp Roberts EMAP. 1989. Oakland, CA: Hammon, Jensen, Wallen & Associates. Prepared for: Army National Guard.

Camp Roberts. 1989. EMAP Phase II, Environmental Management Analysis Plan; [sheet].

Conover, W.J. 1980. **Practical nonparametric statistics**. 2d ed. New York: John & Sons, Inc.; 493 p.

Cottam, Grant; Curtis; John T. 1956. **The use of distance measures in phytosociological sampling**. Ecology 37: 451-460.

Grant, Bruce W.; Tucker, Anton D.; Lovich, Jeffrey E.; Mills, Anthony M.; Dixon, Philip M.; Gibbons, J. Whitfield. 1992. **The use of coverboards in estimating patterns of reptile and amphibian biodiversity**. In: McCullough, Dale R.; Barrett, Reginald H., eds. Wildlife 2001: populations [Proceedings of the international conference on population dynamics and management of vertebrates (exclusive of primates and fish)].; 1991 July 29-31; Oakland, CA. London; New York: Elsevier Science Publications Ltd.; 379-403.

Morrison, Michael L.; Block, William M.; Verner, Jared. 1991. **Wildlife-habitat relationships in California's oak woodlands: where do we go from here?**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-GTR-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 105-109.

SAS Institute Inc. 1988. **SAS procedures guide** [computer program, version 6.03]. Cary, NC: SAS Institute Inc.; 705 p.

Schlotzhauer, Sandra D.; Littell, Ramon C. 1987. **SAS system for elementary statistical analysis**. Cary, NC: SAS Institute Inc.; 416 p.

Verner, Jared. 1987. **Preliminary results from a system for monitoring trends in bird populations in oak-pine woodlands**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-GTR-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 214-222.

Verner, Jared; Ritter, Lyman. 1985. **A comparison of transects and point counts in oak-pine woodlands of California**. Condor 87: 47-68.

Verner, Jared; Ritter, Lyman. 1988. **A comparison of transects and spot mapping in oak-pine woodlands of California**. Condor 90: 401-419.

Zar, Jerrold H. 1984. **Biostatistical analysis**. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall, Inc.; 718 p.

Developing a Conservation Strategy for Southern California Forests and Woodlands[1]

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Abstract: *We report on efforts to conduct an ecoregion-scale assessment of biological resources in the forests and woodlands of southern California. Key ecological questions under consideration are: How important are undeveloped habitat corridors between southern California mountain ranges? Is there adequate habitat on public lands for species dependent on oak woodlands? What are the long-term, ecological ramifications of current fire management policies? What are the ecological effects of existing and projected future levels of resource utilization and recreation use on public lands? We describe a four-step approach to addressing these questions: (1) compile and integrate spatial data on landscape patterns; (2) determine temporal trends in landscape change based on the influence of ecological processes and human land use; (3) identify local species/habitat relationships; and (4) use spatially explicit models to simulate and predict the effects of landscape change on the distribution and abundance of plant and animal populations.*

Forest and woodland habitats are uncommon in arid southern California. They are scattered among vast expanses of chaparral in the mountains, along streamside corridors, and in foothill savannas. Their location in generally rugged "back country," away from coastal urban centers and the existence of public forest reserves, has allowed sizable portions of southern California's forests and woodlands to remain undeveloped. However, with the coastal lowlands almost completely urbanized, development is rapidly expanding into the foothills, enveloping privately owned oak woodlands and surrounding the public forests. Already disjunct mountain ranges are becoming further separated by urbanization occurring between them. The localized occurrences of forest and woodland habitats in southern California could increase the effect of further habitat loss and fragmentation on dependent wildlife and plant populations, because many of these populations are already small and tenuously interconnected. In addition, there is increasing public demand for resources and recreation areas on public lands, and the cumulative effects of fire suppression and air pollution are thought by some to be threatening the health of montane forests (Minnich and others 1995).

Recognizing these issues and the potential "window of opportunity" that still exists to address them, the Southwestern California Ecoregion Planning Group (SWEPG), a committee representing 25 local, state, federal, and private land management agencies and organizations, recommended developing a conservation strategy for forest and woodland habitats in southern California. The USDA Forest Service has taken the lead on this effort because it administers the majority of public forest lands in the region. Other participating agencies include the USDI Fish & Wildlife Service, California Department of Fish & Game, the California State Parks, and the National Biological Service. The objectives and process steps for this strategy are shown in *table 1*. The focus is on the sustainability and management of public lands, but the influence of private lands on the continued viability of forest and woodland-dependent plants and animals is also being considered.

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Table 1—Objectives and process steps for the southern California forest & woodland conservation strategy.

Conservation Strategy Objectives

1. *To develop, adopt, and implement a scientifically credible strategy for maintaining the biological diversity of forest and woodland habitats in southern California.*
2. *To compile and integrate existing information on local natural resources and land uses by developing data layers and analysis tools that are specific to southern California and useful to land management agencies in future project planning and the pursuit of managing sustainable ecosystems.*

Process Steps

1. ***Conduct an ecological assessment*** - *Target completion date: December 1997*.
   An ecoregion-scale, interdisciplinary assessment of the condition of biological resources in forest and woodland habitats of southern California. It will integrate GIS data layers of landscape patterns, species distributions, and human land uses with ecological models to evaluate spatial and temporal landscape changes and their effects on species' viability. This information is needed to develop a scientifically credible conservation strategy. The focus will be on public lands.
2. ***Develop conservation strategy with cooperating agencies*** - *Target completion date: May 1998*.
   Information from the ecological assessment will be used to develop an interagency conservation strategy that identifies specific objectives, actions, and responsibilities for maintaining biological diversity in the forests and woodlands of the southwestern California ecoregion. This will take the form of one or several Memoranda of Understanding (MOUs) with cooperating agencies.
3. ***Implement strategy recommendations consistent with existing management policies***
   Conservation strategy recommendations that do not conflict with existing management directives (e.g., Forest Land Management Plans, agency policies) can be implemented immediately.
4. ***Pursue updates or amendments to Forest Plans***
   To implement conservation strategy recommendations that require new Forest Plan Standards and Guidelines, the Forest Service will need to initiate the National Environmental Policy Act (NEPA)/National Forest Management Act (NFMA) process for updating or amending those plans. The four southern California National Forests are considering consolidating updates of each Forest's Plan into a single, regional effort.
5. ***Finalize a conservation agreement with the U.S. Fish & Wildlife Service***
   This agreement will document the specific actions and responsibilities for which each party agrees to be accountable in regard to species conservation in the forests and woodlands of southern California. With this agreement, the Fish & Wildlife Service formally recognizes the adequacy of actions being taken by the Forest Service, and other participating agencies, in regard to the protection of species that are covered in the agreement.

Montane coniferous forests in southern California lie predominately on public lands, but most of the region's foothill oak woodlands are privately owned (*fig. 1*). The public lands fall within many different jurisdictional units; there are four separate National Forests, one National Recreation Area, six State Parks, six counties each with small reserve systems, and an unknown number of State Fish & Game Ecological Reserves. Off public lands, some of the 16 Indian Reservations in the region contain extensive oak and conifer woodlands as do several private reserves, such as the Nature Conservancy's Santa Rosa Plateau Preserve. A regional-scale conservation strategy is needed because most of the local land management issues either cross jurisdictional unit boundaries (e.g., plant and animal populations) or are common to many of the jurisdictional units (e.g., fire management, recreation, and resource demands).

This paper describes our efforts to conduct an ecoregion-scale assessment of biological resources. The information compiled and analyzed in this assessment will provide the scientific framework for development of a conservation strategy. Our objective is to conduct a detailed analysis of the following four key ecological issues:

- **How important are undeveloped habitat corridors between the southern California mountain ranges?** Which species exist as regional metapopulations dependent on the movement of individuals between the ranges? Which of these species will be

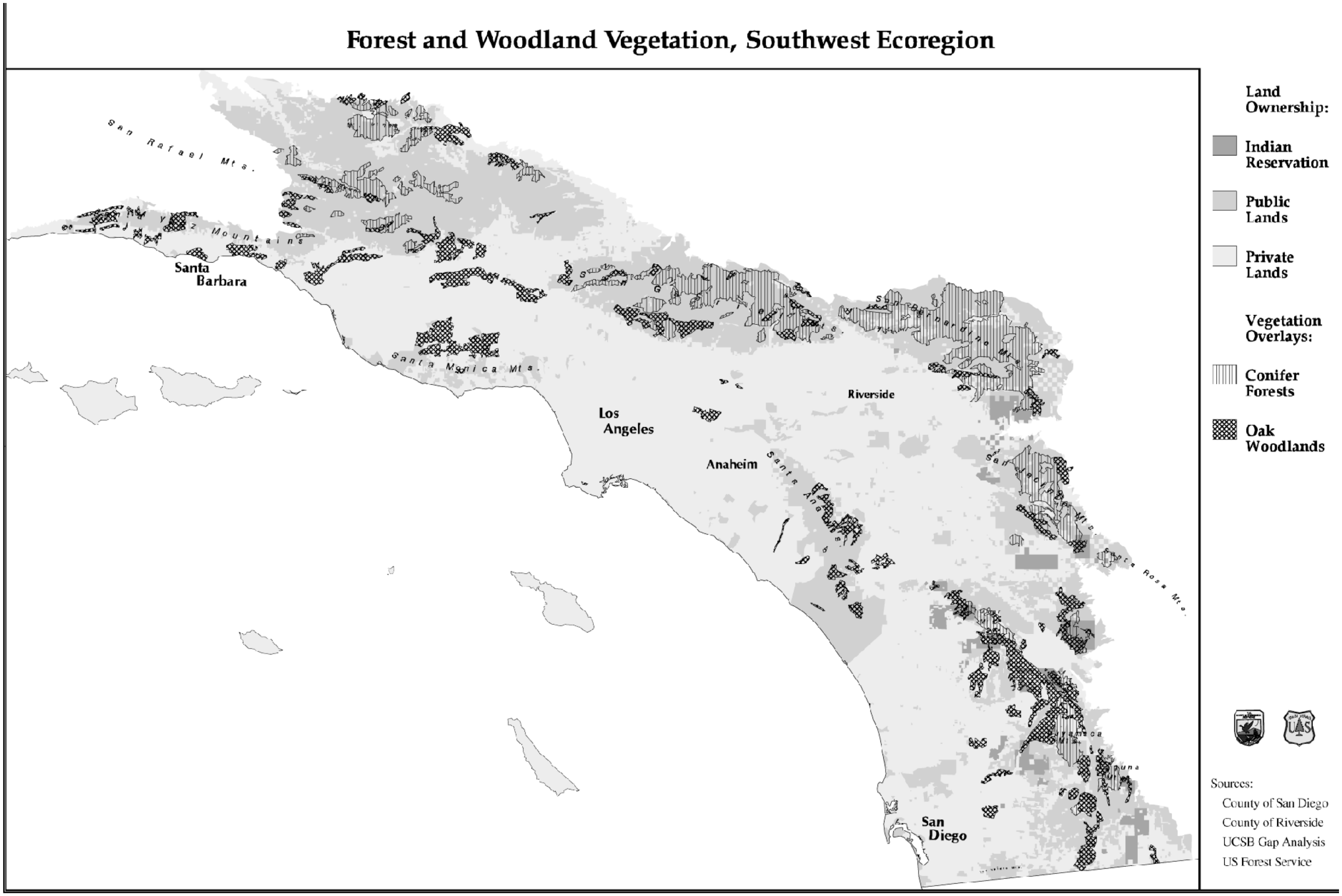


Figure 1—Shows the distribution of oak woodlands and coniferous forests in the southwestern California ecoregion and the underlying land ownership pattern.

seriously affected by further urban and rural development between the ranges? Are there specific linkages that are vital? Can important habitat corridors be identified for these species?

- **What are the ecological effects of further low-density, rural development in foothill oak woodland habitats?** Which species are likely to disappear (or decline dramatically) from oak (*Quercus* spp.) woodlands that become enveloped by low-density, rural development? Is there adequate habitat for these species on public lands?
- **What are the long-term, ecological ramifications of current fire management policies?** Which species and/or plant communities are likely to be seriously affected by current fire regimes? How can fire and habitats be managed to avoid or significantly reduce those effects?
- **What are the ecological effects of existing levels of resource utilization (e.g., grazing, mining, timber, water) and recreation use on public lands?** Which species and/or plant communities are likely to be seriously affected by existing land-use trends on public lands? How can land-use practices be modified to avoid or reduce those effects?

These are basic questions, but difficult ones to investigate because of the dynamic and unpredictable nature of ecological and human processes in both space and time. Hansen and Urban (1992) suggest that knowledge of local landscape patterns and the life histories of local species are needed to predict future animal community dynamics. We agree and add to that the need to understand how prevailing land uses are likely to change landscape patterns over time. Therefore, we have embarked on a 4-step assessment approach:

1. Compile and integrate the best available spatial data on landscape patterns in southern California.
2. Identify temporal trends in human land use and ecological processes (i.e., how have natural disturbance regimes and succession shaped landscape patterns; how have human land-use/ land management practices changed these patterns; what future changes should be expected).
3. Compile information on the distribution, life histories, and habitat requirements of forest- and woodland-dependent plants and animals in southern California. Identify those species, guilds, and communities that may be sensitive to changing landscape patterns or prevailing land uses.
4. Address the key ecological questions through the use of modeling and data analysis: Spatially explicit models will be used to investigate relationships between changes in landscape patterns and species' distributions;
    - Quantitative analyses of population trends (for the few species for which such data are available);
    - Qualitative viability assessments using expert panels.

This process is patterned after assessments conducted for the forests of the Pacific Northwest (Thomas and others 1993, Mellen and others 1995) and the Interior Columbia River Basin (Marcot and others 1995). In the remainder of this paper, I will briefly describe our progress to date for each of the process steps.

Compiling Spatial Data on Landscape Patterns

Reliable, fine-scale maps of landscape patterns are fundamental to assessing and understanding how ecological processes operate across large landscapes. Of particular importance for our analyses are maps of vegetation patterns, abiotic physical patterns (i.e., topography, hydrography, geology, and climate), and human land use/land ownership patterns. While becoming increasingly available in digital format, spatial data invariably exist in a variety of spatial resolutions (defined by minimum mapping units or MMU) and are frequently limited in extent to specific jurisdictional units such as a single county or National Forest.

In southern California, there are many coverages of limited extent and few of the entire ecoregion. A spatial database prepared as part of the national Gap Analysis Program (Davis and others 1995) is one of the few that provides complete ecoregion coverage. It provides mid-scale (100-ha MMU) information on the distribution of vegetation types and land ownership. However, species/habitat relationships models require finer-scale habitat maps. Consequently, we have compiled and combined a variety of more localized maps. Vegetation maps with a 2-ha MMU have recently been developed for the four National Forests and the Santa Monica Mountains National Recreation Area (Franklin and Woodcock, in press). We have integrated these with similar scale maps developed for San Diego, Orange, and Riverside counties. This compilation provides a 2-ha MMU vegetation map for more than 90 percent of non-urban lands in the southwestern ecoregion. We are using the Gap Analysis data to fill in the remaining areas.

Terrain coverages for slope, aspect, and elevation have been derived from 30-m, U.S. Geological Survey (USGS) Digital Elevation Models (DEMs). Hydrography (streams, lakes, and springs) was obtained at a 1:24,000 scale for National Forest lands from Cartographic Feature Files (CFFs) and at a 1:100,000 scale for the rest of the ecoregion from USGS stream reach files. Watershed boundaries were obtained from the State's CalWater project. Climatic data for the entire ecoregion have recently been developed, at a 1-km^2 resolution, by Joel Michaelsen at University of California at Santa Barbara. This dataset provides both monthly and annual averages for precipitation and temperature as well as winter low- and summer high-temperature extremes. Regional fire history maps dating back to the 1920's are also being digitized.

Landownership coverages were obtained from the State's Teale Data Center. Road networks were available from the CFFs at a 1:24,000 scale for the National Forests and at 1:100,000 scale from USGS for the remaining areas. Urban areas were identified in the various vegetation maps; however, rural areas embedded in natural vegetation were often not identified in these maps. Therefore, we used 10-m SPOT satellite imagery and road and structure locations from the CFFs to identify areas of rural development. Developed and dispersed recreation areas, grazing allotments, historic and current timber harvesting areas, water diversion/extraction sites, mines, and air pollution impact zones are also being digitized.

Identifying Temporal Trends in Human Land Use and Ecological Processes

To evaluate and predict landscape change, we must develop an understanding of the primary ecological and human forces that shape the southern California landscape. Aside from climate, topography, and substrate, which are generally beyond human control, the ecological processes of succession and natural disturbance are the primary forces which have shaped natural vegetation patterns. In southern California, fire is clearly the dominant disturbance agent, but floods have also played an important role in shaping riparian systems.

Human land-use practices have also profoundly influenced the landscape patterns we see today. Some of these effects are obvious (e.g., urbanization), while others are much more subtle (e.g., changes in stand structure or species composition). It is important to put today's landscape into context by documenting, to the extent possible, what conditions were like before the arrival of European people. Of course, landscape patterns were not static then either, but fluctuated within a natural range of variability (influenced by the practices of Native American peoples). Characterizing that natural range of variability will provide a baseline condition from which we can more reliabily evaluate how modern land-use activities have changed landscape patterns over time (Toth and others 1994). We are currently reviewing the literature and contacting local experts to determine historic conditions and natural ranges of variability. Of particular interest are historic conditions of the following factors: (1) stand density and tree size distributions for each forest and woodland vegetation type; (2) fire return intervals and burn intensities for each vegetation type; and (3) hydrologic regimes (e.g., streamflow patterns and flood frequencies).

Concurrent with this, information on historic and current land-use trends is being gathered. We intend to document, to the extent possible, the history of timber harvesting, livestock grazing, mining, recreation, water diversion/ extraction and development. Existing studies on air pollution effects in local forests will also be reviewed. For each land-use issue, high-use/impact areas will be identified and mapped. Also, we intend to review trends in acres burned to gauge the effectiveness of fire-suppression actions.

With this information, we should gain insight into how and where specific land uses have influenced changes in landscape patterns over the past century. These insights combined with knowledge of current and expected future land use trends will enable us to predict "landscape trajectories" (Hansen and Urban 1992). For example, it is widely believed that many years of effective fire suppression in western U.S. forests have put these landscapes on a trajectory of increasingly higher stand densities and fuel accumulations that will lead to increased tree mortality and, ultimately, large, high-intensity fires (Minnich 1988, Toth and others 1994, Verner and others 1992). In the foothill oak savannas of San Diego and Riverside counties, the prevalent trajectory of landscape change is a move from intensive livestock grazing to rural, ranchette-style development. By taking a close look at historic changes, it may be possible to detect additional trends that can improve our ability to predict future landscape change.

Compiling Species Life Histories and Information on Land-Use Effects

To predict how animal and plant populations respond to landscape changes, we must identify, to the extent possible, where they occur, what habitat and specific life history requirements they have, and how those requirements are affected by prevailing land uses. For example, many animal species utilize oak woodland habitat, but only a subset of those species can persist in woodlands enveloped by rural development. It is a species' specific life history requirements that determine its ability to tolerate such effects.

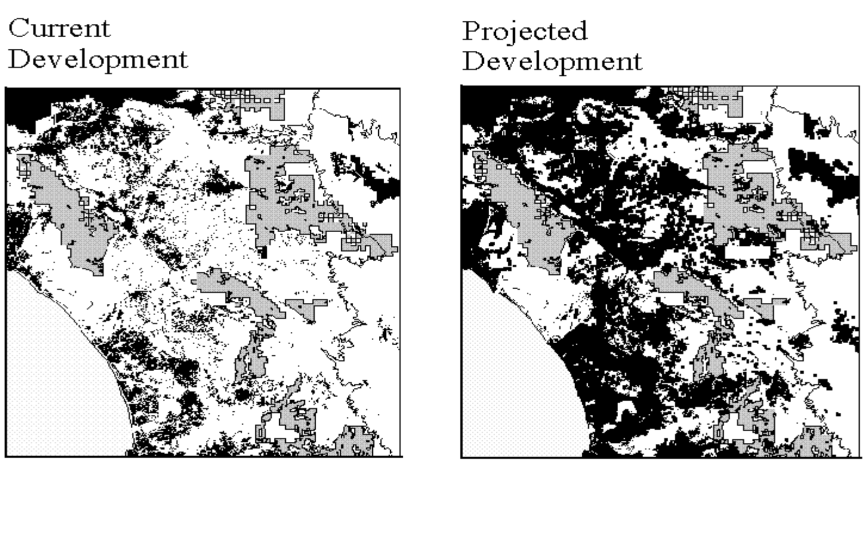
We are gathering species-specific information primarily from existing databases, the scientific literature, and local experts. However, with funding from the National Biological Service we are also working with cooperators at local universities to collect additional field data on the habitat relationships of forest and woodland bats, reptiles, amphibians, and butterflies. All of the information is being entered into a "habitat relationships and land-use effects" database. This Oracle database is specific to southern California and builds upon the statewide California Wildlife Habitat Relationships (WHR) and Natural Diversity Database (NDDB) systems, by emphasizing land-use effects and spatial characteristics such a minimum patch size, home range size, and dispersal capabilities. Sources and confidence levels of the habitat relationships and land-use effects information is also being gathered. We believe this is important because there is a great deal of variability in the amount and reliability of information available on different species.

The database will be used to link species-specific habitat characteristics with spatial GIS (geographic information system) data on landscape patterns. Focus species, guilds, and plant communities are identified on the basis of: (1) *Rarity* — including species formally listed as threatened, endangered, or proposed, Forest Service sensitive species, and State Species of Special Concern; (2) *Sensitivity to prevailing landscape trajectories*—includes species sensitive to habitat fragmentation, species groups dependent on habitat patterns that are negatively influenced by current fire regimes, and species sensitive to specific land uses; (3) *Representative of a habitat type or species group* — includes umbrella or indicator species for specific habitat types or species groups; (4) *Importance to biological diversity* — includes plant communities like riparian and oak woodlands that are particularly important to the maintenance of biodiversity. Current and historic locations of focus species are being compiled and digitized into GIS data layers. We are also obtaining species locations information from the Department of Fish & Game's GIS version of the Natural Diversity Database (NDDB).

Modeling and Analysis

The objective of this project is to meaningfully address the key ecological issues described earlier. Our ability to do this hinges on how effectively we can predict: (1) how the identified land uses and landscape trajectories are likely to change the distribution of habitats over time; and (2) how the focus species will be affected by these landscape changes given their habitat requirements, known distributions, and dispersal capabilities. These spatial interactions can be simulated by integrating information on temporal processes (ecological and human) with our existing data on current landscape patterns.

Figure 2—Shows the existing (left) and projected future (right) spatial pattern of private land development (shown in black) relative to National Forest lands in the southern portion of the ecoregion. Note how development is filling in the areas between Forest lands.



Ideally, we would like to use a stochastic, spatially explicit model to simulate landscape changes from disturbance, succession, and land use (sensu Mladenoff and others l996). However, such models have a large number of mechanistic parameters (e.g., vegetation growth rates, disturbance probabilities, rates of spread) that must be estimated for the specific landscape. Lacking the information and expertise to confidently estimate these parameters, we are using simple GIS-based, deterministic models to reclassify our existing spatial data in ways that simulate temporal land-use trends. Taking what is learned about how, and at what rate, land uses or ecological processes are likely to change specific habitats or geographic areas, we can simulate how these changes will be expressed across the landscape. For example, the spatial distribution of future private land development can be estimated simply by identifying likely areas on the basis of zoning, slope restrictions, and land ownership (*fig.* 2). We also intend to model spatial trends in resource utilization, recreation use, and disturbance/succession interactions. Admittedly, this is a crude way to generate future landscapes, and the predicted spatial and temporal patterns of highly dynamic processes like disturbance/succession interactions will be very hypothetical. However, if our rates of change are within a reasonable range and a series of possible landscape patterns are generated from them, we will have a means to assess the sensitivity of focus species and guilds to current land use trends.

GIS-based predictive models of habitat suitability (sensu Duncan and others 1995, Pereira and Itami 1991) will be developed for all focus species for which there is sufficient information to effectively characterize suitable habitats. Habitat suitability will be modeled for other species on the basis of a guild approach (Mellen and others 1995). These habitat models will incorporate spatial requirements such as minimum patch size, home range size, and maximum dispersal distance. Species will be grouped according to the spatial scale at which they operate (based on home range size) and by the type of habitat pattern they require (patterns being those distinguishable at the 2-ha MMU scale that we have mapped). For example, some species occupy only a single habitat type, while others require two major structural stages or habitat types in proximity (e.g., breeds in mature forests but forages in openings), and others are habitat generalists that use many different vegetation types.

These habitat models will provide an effective way to examine how species distributions are likely to be affected by potential changes in landscape patterns. However, we recognize that many species are strongly affected by habitat attributes that we have not mapped, and thus the described models will be poor predictors of their distribution. Viability concerns for these species will be evaluated qualitatively with the help of individuals who know the most about them.

For the spotted owl and mountain lion, two species that are well studied and identified as being potentially dependent on habitat corridors between the mountain ranges, we will use spatially explicit population models (SEPMs) (Beier 1993, McKelvey and others 1992, Schumaker 1995) to assess population viability and assist in the identification of critical habitats and corridors. SEPMs are stochastic models that incorporate digital maps of the landscape (that can be changed over time) with habitat-specific demographic parameters. Dispersal processes are also simulated. This makes it possible to investigate how landscape changes affect specific population processes like survivorship and dispersal success. However, the complexity of SEPMs and problems associated with parameter estimation have led others to note that they may give the "illusion of exactitude in the absence of hard information" (Doak and Mills 1994). We are cognizant of these issues and will use the models as tools for exploring specific questions rather than as definitive population viability analyses.

We are also analyzing population trends and habitat relationships for riparian bird species using point count observations taken annually from 1988 to 1995 at more than 200 locations in riparian areas across the four southern California National Forests. Observed trends will be compared with land-use changes in these areas to see whether correlations can be detected.

Finally, we will enlist the help of local experts on specific species groups to assist in interpreting the modeling results and to provide qualitative assessments of long-term viability for the focus species and guilds. This will be done either by consulting experts individually or through convening panels.

Conclusions

We have identified key ecological issues concerning the maintenance of biological diversity in the forests and woodlands of southern California and described our approach for addressing them. This approach focuses largely on landscape patterns—what they are today, how they came to be that way, how they are likely to change, and how species are affected by them. Although it is hard to dispute the importance of these factors, unfortunately there are enormous gaps and uncertainties in our knowledge of them. Nevertheless, we believe there is great utility in compiling what is known and using spatially explicit, computer-based analysis tools to explore possible scenarios and identify potentially important patterns and relationships. Unequivocal determinations will be scarce; the nature of the questions and the information we have to bear on them simply will not provide that. However, there is considerable opportunity to gain insights that will improve our ability to recommend conservation actions and to have a means to assess the effect of those actions.

Although many factors threaten the ecological integrity of forests and woodlands in southern California, we remain optimistic that it is possible to conserve and protect these habitats for the long term—as sources of renewable resources, public places for outdoor recreation, and viable refugias for the diverse assemblage of wildlife and plants that depend on them. To make this vison a reality, a regional-scale conservation strategy is needed. The success of that strategy will depend on the degree to which it is implemented in a proactive, adaptive manner, with monitoring to see what does and does not work, and course corrections made accordingly.

References

Beier, Paul. 1993. **Determining minimum habitat areas and habitat corridors for cougars.** Conservation Biology 7: 94-108.

Davis, Frank W.; Stine, Pete W.; Stoms, David M.; Borchert, Mark I.; Hollander, A.D. 1995. **Gap analysis of the actual vegetation of California. 1. The southwestern region.** Madrono 42: 40-78.

Doak, Daniel F.; Mills, L. Scott. 1994. **A useful role for theory in conservation.** Ecology 75: 615-626.

Duncan, Brean W.; Breininger, David R.; Schmalzer, Paul A.; Larson, Vickie L. 1995. **Validating a Florida scrub jay habitat suitability model, using demography data on Kennedy Space Center.** Photogrammetric Engineering & Remote Sensing 61: 1361-1370.

Franklin, Janet; Woodcock, Curtis E. [In press]. **Multiscale vegetation data for the mountains of southern California: spatial and categorical resolution.** In: Quattrochi, D.A.; Goodchild, M.F., eds. Scaling of remotely sensed data for GIS. Chelsea, MI: Lewis Publishers.

Hansen, Andrew J.; Urban, Dean L. 1992. **Avian response to landscape pattern: the role of species life histories.** Landscape Ecology 7(3): 163-180.

Marcot, Bruce G.; Croft, L.; Jones, J.; Karl, M.G.; Lehmkuhl, J.; Leonard, S.G.; Naney, R.; Nelson, K.; Niwa, C.; Sandquist, R.; Zieroth, E.. 1995. **Terrestrial ecology assessment.** Unpublished draft from the Interior Columbia Basin Ecosystem Management Project.

McKelvey, Kevin; Noon, Barry R.; Lamberson, Roland H. 1992. **Conservation planning for species occupying fragmented landscapes: the case of the northern spotted owl.** In: Kareiva, P.M.; Kingsolver, J.G.; Huey, R.B., eds. Biotic interactions and global change. Sunderland, MA: Sinauer; 424-450.

Mellen, Kim; Huff, Mark; Hagestedt, Rich. 1995. **"Habscapes": reference manual and user's guide.** Internal Forest Service Document, Mt. Hood National Forest.

Minnich, Richard A. 1988. **The biogeography of fire in the San Bernardino Mountains of California: a historical study.** Univ. of California Publications in Geography 28. Berkeley, CA: Univ. of California Press.; 1-120.

Minnich, Richard A.; Barbour, Michael G.; Burk, Jack H.; Fernau, Robert F. 1995. **Sixty years of change in Californian conifer forests of the San Bernardino mountains.** Conservation Biology 9: 902-914.

Mladenoff, David J.; Host, George E.; Boeder, Joel; Crow, Thomas R. 1996. **Landis: a spatial model of forest landscape disturbance, succession, and management.** In: Goodchild, M.F.; Steyaert, L.T.; Parks, B.O., eds. GIS and environmental modeling: progress and research issues. Fort Collins, CO: GIS World, Inc.; 175-179.

Pereira, Jose M.; Itami, Robert M. 1991. **GIS-based habitat modeling using logistic multiple regression: a study of the Mt. Graham red squirrel.** Photogrammetric Engineering & Remote Sensing 57: 1475-1486.

Schumaker, Nathan A. 1995. **Habitat connectivity and spotted owl population dynamics.** Ph.D. Dissertation. Seattle: College of Forest Resources, University of Washington; 126 p.

Thomas, Jack Ward; Raphael, Martin G.; Anthony, Robert G.; Forsman, Eric D.; Gunderson, A. Grant; Holthausen, Richard S.; Marcot, Bruce G.; Reeves, Gordon H.; Sedell, James R.; Solis, David M. 1993. **Viability assessments and management considerations for species associated with late-successional and old-growth forests of the Pacific Northwest.** Portland, OR: U.S. Department of Agriculture, National Forest System, Forest Service Research; 530 p.

Toth, Edward; Laboa, Jane; Nelson, Duane; Hermit, Raymond, technical coordinators. 1994. **Ecological support team workshop proceedings for the California spotted owl environmental impact statement.** USDA Forest Service, Pacific Southwest Region.

Verner, Jared; McKelvey, Kevin S.; Noon, Barry R.; Gutierrez, R.J.; Gould, Gordon I., Jr.; Beck, Thomas W., technical coordinators. 1992. **The California spotted owl: a technical assessment of its current status.** Gen. Tech. Rep. PSW-GTR-133. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 285 p.

A Post-Hoc Assessment of the Impacts to Wildlife Habitat from Wood Cutting in Blue Oak Woodlands in the Northern Sacramento Valley[1]

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***Abstract**: Impacts to wildlife habitat from wood cutting in woodlands dominated by blue oak (*Quercus douglasii*) were assessed with vegetation data gathered from 103 0.1-acre circular plots sampled in August-September 1993 in Shasta and Tehama counties, California. Plots were located at 19 cattle ranches in areas where wood had been cut. Using growth model projections for a 50-year period for all ranches combined, average tree diameter at breast height was 9.0-12.5 inches and 9.0-11.6 inches, while average tree canopy cover was 16-34 percent and 53-70 percent for cut and uncut conditions, respectively. Models of habitat relationships for 21 wildlife species were used to evaluate impacts, and one species was negatively affected, seven species were positively affected, and 13 species were unaffected by tree cutting.*

Wood cutting in California's hardwood rangelands has been a persistent land use probably since the late 1700's when domestic livestock were introduced to California (Mayer and others 1986). Wood is cut to modify rangeland and provide wood products. Bolsinger (1988) estimated that, between 1945 and 1985, almost 1.2 million acres of California's estimated 7.4 million acres of hardwood woodlands had been converted to other habitats through wood cutting and clearing. Through the mid-1900's, forage improvement through tree removal was the primary reason for cutting. Firewood was a source of additional income from the harvested wood.

Wood cutting for rangeland modification and firewood products continues throughout the state, particularly in the northern Sacramento Valley where more than 50 percent of California's firewood is harvested in hardwood rangelands dominated by blue oak (*Quercus douglasii*). Between 1988 and 1992, wood was cut on almost 25,000 acres of California hardwood rangelands (Standiford and others 1996).

California's hardwood rangelands are very important wildlife habitat. At least 313 of the 650 species of amphibians, reptiles, birds, and mammals in the California Wildlife Habitat Relationships (CWHR) System were predicted to occur in the state's five hardwood rangeland habitat types (Blue Oak, Blue Oak-Foothill Pine, Valley Oak, Coastal Oak, and Montane Hardwood) (Garrison 1996).

The large number of wildlife species occurring in hardwood rangelands, combined with the estimated 2,000 species of vascular plants and 5,000 species of invertebrates (Pavlik and others 1991), results in hardwood rangelands having some of the highest levels of species richness of any equivalent broad habitat group in California. Wildlife species include several important game animals, such as mule deer (*Odocoileus hemionus*), California quail (*Callipepla californica*), and wild turkey (*Meleagris gallopavo*), which contribute millions of dollars annually to California's economy through revenues from recreational hunting. Furthermore, hardwood rangelands are important environments for large numbers of neotropical migratory birds such as flycatchers, vireos, and warblers, which are a wildlife group receiving considerable conservation emphasis because of large-scale population declines (U.S. Department of Agriculture, Forest Service 1994).

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Despite the value to wildlife and long-term, extensive, and continuing losses and modifications of hardwood rangelands, little information exists on impacts to wildlife from habitat loss or modification. Gathering meaningful data on wildlife impacts is hindered by several factors. First, cutting of trees such as blue oak and other hardwoods on private rangelands is not regulated by the State of California as is harvesting of softwoods such as coast redwood (*Sequoia sempervirens*), Douglas-fir (*Pseudotsuga menziesii*), and other conifers. Therefore, basic information on the harvest is not available, nor is environmental review by agencies such as the California Department of Fish and Game (CDFG).

Second, most hardwood rangelands are privately owned, and access for evaluation is restricted. Furthermore, many landowners do not generally empathize with the need for wildlife impact studies, particularly when their lands might be evaluated and government agencies such as CDFG are involved. Third, CDFG and other agencies have limited budgets and manpower, thereby restricting their ability to conduct impact assessments. Lastly, studies on the impact of wood cutting have focused primarily on wildlife on public lands, such as National Forests, because of the multiple-use mandates and environmental regulations of state and federal agencies.

With this foundation, this study used data from a larger study of blue oak sprouting (Standiford and others 1996) to assess the impacts to wildlife from wood cutting in blue oak woodlands. This is a post-hoc analysis because we used lands where wood cutting had already occurred, and we could not gather pre- and post-harvest wildlife information from field inventories. Our objectives were to: (1) quantify baseline wildlife habitat characteristics of lands where wood had been cut; (2) determine wildlife species that might be most indicative of impacts from wood cutting; and (3) estimate habitat impacts for these species using existing models of habitat relationships.

Study Area

This study was conducted on 19 individual private ranches in Shasta and Tehama counties, California. The ranches were randomly selected from a larger pool of ranches where wood had been cut over the past 10 years. Twelve ranches were located in Tehama County, and seven ranches were located in Shasta County. These ranches were representative of the conditions on privately owned blue oak-dominated hardwood rangelands in the northern Sacramento Valley.

Dominant trees on these ranches are blue oak, foothill pine (*Pinus sabiniana*), and interior live oak (*Q. wislizenii*). Shrub layer vegetation includes poison-oak (*Toxicodendron diversilobum*), manzanita (*Arctostaphylos* spp.), and *Ceanothus* spp. Herbaceous layer plants are dominated by exotic annual grasses. Elevations were 500-2,000 feet above sea level, and topography was generally flat with steeper areas along watercourses. Ranches were equally distributed on the west and east sides of the northern Sacramento Valley.

Methods

Vegetation Measurements

On each ranch, 5-7 0.1-acre circular plots were randomly located within harvested areas. Only plots with one or more stumps from harvested trees were sampled. Within each plot, diameter, height, and species of all stumps were recorded. Height of the tallest stump sprout, if any, was measured. Diameter at breast height (DBH), height, canopy diameter, and species were recorded from all residual trees in the plot. The number and diameter of all snags >4 inches DBH and acorn storage (granary) trees used by acorn woodpecker (*Melanerpes* *formicivorus*) were also recorded. A 0.01-acre belt transect (4.4 feet x 100 feet) was randomly located through the plot center to measure woody debris (downed logs ≥3 inches diameter at large end) and brushpiles. Management information on herbicide use, prescribed burning, and acreage harvested was collected from interviews with ranch owners and/or managers.

Vegetation Growth Projections

From these data, pre-cut tree DBH and height conditions of uncut stands were estimated from relationships derived from uncut trees. Pre- and post-cut stand structures were applied to a statewide growth and yield model of individual blue oaks (Standiford 1995) to estimate stand growth with and without wood cutting over a 50-year period. Average stem diameter (quadratic mean) of all woody stems ≥5 inches DBH and canopy cover were estimated using the same growth model for cut and uncut conditions. Growth for cut and uncut conditions were individually projected for the 19 ranches.

With these projections for cut and uncut conditions, wildlife impacts were assessed for (1) all 19 ranches combined (see below) and (2) four individual ranches selected to represent a range of harvest conditions and 50-year growth projections. The 19 ranches combined had a total of 13,200 acres of harvested habitat for the wildlife impact assessment, while the harvest size on the four ranches selected for impact analysis ranged from 40 to 1,400 acres (*table 1*).

Table 1—Baseline vegetation characteristics (mean ± std) from blue oak woodlands where wood cutting occurred on four selected ranches and 19 ranches combined in blue oak woodlands of Shasta and Tehama counties, California.

Vegetation variables	Ranches 1 (*n*=6)	2 (*n*=6)	3 (*n*=5)	4 (*n*=6)	All (*n*=19)
Woody debris (*ft³/acre*)	83±180	247±503	444±722	34±64	120±115
Pct brushpile	9.0±5.9	2.7±4.4	12.4±17.6	1.3±3.0	5.1±5.6
Snag basal area (*ft²/acre*)	0.0±0.0	0.4±0.8	6.7±13.3	0.0±0.0	1.6±2.5
Snag density (*number/acre*)	0.0±0.0	1.7±3.7	2.0±4.0	0.0±0.0	3.0±4.4
Acorn woodpecker granary density (*no./acre*)	0.0±0.0	0.0±0.0	20.0±26.7	2.1±4.6	1.5±4.5
Pct shrub cover	0.0±0.0	3.5±5.0	0.0±0.0	0.0±0.0	1.9±3.3
Pct oak sprout cover	6.0±3.7	4.7±6.6	0.0±0.0	0.0±0.0	2.5±2.5
Oak sprout age (*years*)	8	9	7	7	4.6±2.5

For comparative purposes, individual ranch averages were used to determine average values for the entire study area. However, for the wildlife impact analysis (see below), weighted average stem diameter and canopy cover for the 50-year period were calculated for the 19 combined ranches using the size of the individual ranch harvest unit as the weighting factor. For each ranch, harvest unit size was multiplied by the average stem diameter and average canopy cover. These values were summed across all 19 ranches, and the total was divided by 13,200 acres to calculate the weighted average. A weighted average was preferable to an unweighted average because of the wide range of harvest sizes (40-7,000 acres). Weighted averages were similarly calculated for downed woody debris, snag and granary densities and basal areas, and percent brushpiles, oak sprout cover, and shrub cover. Simple arithmetic averages of the plot data were calculated for the four individual ranches.

Average stem diameter and canopy cover for cut and uncut conditions for the 50-year period were combined with baseline vegetation species composition to determine the appropriate habitat type and tree size/canopy cover class from the CWHR habitat classification system (Mayer and Laudenslayer 1988) (*table 2*). These CWHR habitat types and classes were used to generate a list of wildlife species predicted to occur in the study area (see below).

***Table 2**—Mean tree diameter at breast height (DBH), percent canopy cover, and California Wildlife Habitat Relationships (CWHR) habitat type and stage for cut and uncut conditions from blue oak woodlands over a 50-year period where wood cutting occurred on four selected ranches and 19 combined ranches in Shasta and Tehama counties, California.*

	Ranch 1		Ranch 2		Ranch 3		Ranch 4		All Ranches	
	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut	Cut	Uncut
Year 0										
DBH [1]	<5.0	8.7	<5.0	9.6	10.8	10.0	7.9	10.5	9.0	9.0
Pct canopy cover	0	51	0	41	22	65	7	26	16	53
CWHR habitat type and stage	[2]AG2D	BO3M	AG2M	BO3M	BO3S	BO3D	AG1P	BO3P	BO3S	BO3M
Year 10										
DBH	<5.0	9.2	5.4	10.1	11.3	10.4	8.4	11.0	9.5	9.5
Pct canopy cover	11	55	2	45	30	70	11	29	22	57
CWHR habitat type and stage	BO2S	BO3M	AG2M	BO3M	BO4P	BO3D	BO3S	BO4P	BO3S	BO3M
Year 20										
DBH	<5.0	9.7	6.7	10.6	11.9	10.9	9.1	11.5	10.3	10.1
Pct canopy cover	13	58	3	47	32	74	12	31	25	61
CWHR habitat type and stage	BO2S	BO3M	AG2M	BO3M	BO4P	BO3D	BO3S	BO4P	BO3P	BO3D
Year 30										
DBH	<5.0	10.2	7.7	11.1	12.4	11.4	9.6	12.1	11.0	10.6
Pct canopy cover	15	61	4	50	35	78	13	33	28	64
CWHR habitat type and stage	BO2S	BO3D	AG2M	BO4M	BO4P	BO4D	BO3S	BO4P	BO4P	BO3D
Year 40										
DBH	<5.0	10.7	8.7	11.6	13.0	11.9	10.2	12.6	11.8	11.1
Pct canopy cover	18	64	6	52	38	82	15	36	31	67
CWHR habitat type and stage	BO2S	BO3D	AG2M	BO4M	BO4P	BO4D	BO3S	BO4P	BO4P	BO4D
Year 50										
DBH	<5.0	11.2	9.6	12.1	13.6	12.4	10.7	13.1	12.5	11.6
Pct canopy cover	20	66	6	54	38	84	15	38	34	70
CWHR habitat type and stage	BO2S	BO4D	AG2M	BO4M	BO4P	BO4D	BO3S	BO4P	BO4P	BO4D

[1]Average stem diameter (quadratic average) of all woody stems ≥5.0 inches diameter at breast height (DBH).

[2]Habitat types from the California Wildlife Habitat Relationships (CWHR) System are: AG = Annual Grassland; and BO = Blue Oak Woodland. CWHR habitat stages for AG are: 1 = height ≤12.0 inches; 2 = height >12.0 inches; P = 10.0-39.9 percent vegetation cover; M = 40.0-59.9 percent cover; and D = 60.0-100.0 percent cover. CWHR habitat stages for BO are: 2 = DBH 1.0-5.9 inches; 3 = DBH 6.0-10.9 inches; 4 = DBH 11.0-23.9 inches; S = 10.0-23.9 percent vegetation cover; P = 24.0-39.9 percent cover; M = 40.0-59.9 percent cover; and D = 60.0-100.0 percent cover.

Wildlife Impact Assessment

Selecting Evaluation Species

Impacts from wood cutting were assessed by selecting wildlife species to represent a range of habitat needs and use patterns so that a variety of impacts (i.e., positive, negative, unaffected) could be determined. The CWHR habitat types and classes determined with the vegetation modeling were used with CWHR Version 5.2 (Timossi and others 1994) to generate a list of wildlife species predicted to occur in all 17 possible size/cover classes of blue oak woodland habitat in Shasta and Tehama counties. The CWHR query included species occurring any time of the year. Twenty-nine habitat elements were determined to be absent from the study areas, and these elements included those primarily associated with marine and developed agricultural and human habitats. Absent elements excluded wildlife species for which the elements were predicted by CWHR to be essential for their occurrence. From this query, 213 species of amphibians, reptiles, birds, and mammals were initially predicted for the study area.

Our purpose was to estimate impacts to wildlife species primarily associated with the hardwood tree component of blue oak woodlands in the northern Sacramento Valley. Therefore, the initial CWHR list of 213 species was further reduced by eliminating species meeting one or more of the following five criteria: (1) species primarily associated with aquatic habitats; (2) species primarily associated with conifer-dominated habitats; (3) species whose geographic distribution did not include the study area; (4) non-native species primarily associated with human habitation; or (5) species *without* arithmetic average habitat suitabilities ≥0.66 (Medium habitat suitability) for at least one of the 17 tree size/cover class combinations for blue oak woodland habitat. A total of 143 species remained after eliminating 70 species on the basis of the five criteria.

A scoring system using five additional criteria was used to rank the 143 species for their applicability in evaluating impacts of wood cutting. The criteria included: (1) CWHR-predicted sensitivity to differences in canopy cover (see below); (2) overlap of geographic distribution with the range of blue oak woodlands in California (1 = no or low overlap; 2 = moderate overlap; 3 = high overlap); (3) a subjective confidence rating for CWHR model accuracy (1 = no or low confidence; 2 = moderate; 3 = high); (4) whether or not the species breed in oak woodlands (0 = no; 1 = yes); and (5) whether or not the species has a special legal status, such as harvest, threatened, endangered, or special concern (0 = none; 1 = yes). A maximum score of 11 was possible, but scores ranged from 4 to 10. The wild pig (*Sus scrofa*) was the only species with the highest score of 10.

Sensitivity for Criterion 1 was determined using the difference in CWHR-predicted, arithmetic-average habitat suitability values between blue oak woodland habitat stages with <40 percent canopy cover (open canopies) and stages with ≥40 percent canopy cover (closed canopies). Species received a score of 3 (high sensitivity) with habitat suitability differences of ≥2 CWHR suitability index classes (e.g., High for open canopies and Low for closed canopies). Species with differences of one suitability index class were given a score of 2 (moderate sensitivity), while species with differences of less than one class were given a score of 1. Species with scores of 2 or 3 were categorized as preferring open or closed canopy conditions depending on which cover condition had the greatest average suitability value. Species with a score of 1 were categorized as having no preference (*table 3*).

From this ranking, a preliminary score threshold of ≥7 was used to further reduce the list and select evaluation species. Fifty-six species met this threshold as potential evaluation species. A score of 7 was selected as a threshold because approximately one-third of the ranked species met or exceeded that score.

Guilds based on primary breeding substrates and primary food habits were developed, and the 56 species were placed in appropriate guild cells. The absence or low number of species for several important guild cells necessitated adding species with scores of 5 to 6 to those cells. In most cases, the species with the highest score within a cell was selected as an evaluation species. However, five species with lower scores were chosen because we were more confident that the species actually occurred in the study area. Finally, 21 species were selected for evaluation which we felt were the most appropriate for assessing impacts from wood cutting because of the wide range of habitat conditions represented and possible predicted impacts (*table 3*).

Table 3—Rating scores, canopy cover preferences, and resource use patterns for 21 wildlife species used for a post-hoc assessment of habitat impacts from wood cutting in blue oak woodlands in Shasta and Tehama counties, California.

Common name	Scientific name	Rating score[1]	Cover sensitivity score[2]	Preferred canopy cover	Primary breeding substrates	Primary feeding habits
Ensatina	*Ensatina eschscholtzii*	7	2	Closed	Subsurface	Invertebrates
Cooper's hawk	*Accipiter cooperii*	8	2	Closed	Trees	Vertebrates
Red-tailed hawk	*Buteo jamaicensis*	7	1	None	Trees, cliffs	Vertebrates
Wild turkey	*Meleagris gallopavo*	9	1	None	Surface	Invertebrates, seeds, acorns, plants
Mourning dove	*Zenaida macroura*	9	2	Open	Trees	Seeds
Western screech-owl	*Otus kennicottii*	6	1	None	Tree cavities	Invertebrates, vertebrates
Acorn woodpecker	*Melanerpes formicivorus*	9	2	Open	Tree cavities	Acorns, fruits, invertebrates
Pacific-slope flycatcher	*Empidonax difficilis*	7	2	Closed	Trees	Invertebrates
Ash-throated flycatcher	*Myiarchus cinerascens*	7	2	Open	Tree cavities	Invertebrates
Western scrub-jay	*Aphelocoma californica*	7	1	None	Trees, shrubs	Acorns, fruits, invertebrates
Bushtit	*Psaltriparus minimus*	6	1	None	Trees, shrubs	Invertebrates, seeds, fruits
White-breasted nuthatch	*Sitta carolinensis*	7	1	None	Tree cavities	Invertebrates, seeds, fruits
Western bluebird	*Sialia mexicana*	7	2	Open	Tree cavities	Invertebrates, fruits
Western meadowlark	*Sturnella neglecta*	7	3	Open	Surface	Invertebrates, seeds
California ground squirrel	*Spermophilus beecheyi*	6	2	Open	Subsurface	Invertebrates, seeds
Western gray squirrel	*Sciurus griseus*	7	1	None	Trees	Acorns, nuts, seeds, fruits
Dusky-footed woodrat	*Neotoma fuscipes*	7	1	None	Surface	Plants, acorns, fruits
Gray fox	*Urocyon cinereoargenteus*	7	2	Open	Tree cavities, cliffs, rocks	Invertebrates, vertebrates, fruits
Mule deer	*Odocoileus heminous*	8	2	Open	Surface	Plants, acorns, fruits
Western fence lizard	*Sceloporus occidentalis*	5	1	None	Surface	Invertebrates
Gopher snake	*Pituophis melanoleucus*	6	2	Open	Subsurface	Vertebrates

[1]Results of numeric ratings for five criteria, including cover sensitivity score.
[2]Numeric rating for CWHR-predicted sensitivity to differences in blue oak tree canopy cover (1 = no difference, 2 = difference of 1 CWHR rating class, 3 = difference of ≥2 rating classes).

Evaluating Impacts

Habitat suitability index values (HSI) from the CWHR system for the 21 species were used in a Habitat Evaluation Procedures (HEP) analysis (U.S. Department of Interior, Fish and Wildlife Service, 1980) to quantify impacts from wood cutting. HEP is a standardized impact assessment method used to quantify impacts to wildlife habitat from land use activities (Doering and Armijo 1986, Williams 1988). HSI values were the arithmetic averages of suitability values for reproduction, cover, and feeding calculated by CWHR for the appropriate habitat type and stage. Six target years (0, 10, 20, 30, 40, and 50) were used for the 50-year impact assessment period (*table 2*), and HSI values were generated for each ranch scenario/target year combination. A Lotus 123® spreadsheet was used to calculate changes in HSI values and habitat units (HU) (HU = HSI value × study area acreage) over the 50-year period according to HEP guidelines. Species-specific CWHR-predicted HSI values = 0.0 were raised to 0.01 to minimize unreasonably large HU changes for the 50-year period, and recognize the likelihood of some habitat value existing in CWHR-predicted unsuitable habitats.

Impacts were determined by averaging changes in HUs for the 6 target years. These averages are known as Average Annual Habitat Units (AAHU), and AAHUs were calculated for the future-with-project (cut condition) and future-without-project (uncut condition) scenarios according to HEP guidelines. Garrison (1992) found it appropriate to quantify CWHR-predicted habitat changes between two conditions using future-with-project versus future-without-project scenarios.

Impacts were compared between evaluation species and among ranch scenarios by calculating percent change in AAHUs from the cut condition to uncut condition (*table 4*). Percent change was calculated using the following equation:

$$\left(\frac{F_{wo} - F_w}{F_{wo}}\right) \times 100 = \text{Percent Change}$$

where F_{wo} = future-without-project AAHUs and F_w = future-with-project AAHUs.

Using percent change standardized impacts among ranch scenarios because AAHUs are greatly influenced by project area size, which varied greatly among the five ranch scenarios (40-13,200 acres) (*table 4*). Determining biological significance of CWHR predictions is tenuous for many reasons (Garrison 1994); therefore, we selected an AAHU percent change of +50 percent as the significant impact threshold. This level represents a relatively conservative threshold because a 50 percent change means that average habitat suitabilities differed by one or more rating classes between the cut and uncut conditions.

Results

Vegetation

Substantial variation existed among the individual ranches in baseline vegetation characteristics on the harvested areas (*table 1*). This variation was masked when vegetation characteristics were averaged for the entire study area. For example, snags were lacking for two of the four (50 percent) individual ranches in *table 1*, and eight of the 19 (42 percent) ranches in the study. Furthermore, average snag density and average snag basal area for the entire study area exceeded that of 14 (74 percent) and 15 (79 percent), respectively, of the 19 ranches. Percent cover by oak sprouts, an index to oak recruitment in harvested areas, averaged 2.5 percent for all ranches combined, but only eight of the 19 (42 percent) ranches had sprout cover exceeding the combined ranch average. Similar relationships were found

Table 4—Percent change in Average Annual Habitat Units (AAHU) for 21 wildlife species from blue oak woodlands over a 50-year period where wood cutting occurred on four selected ranches and 19 combined ranches in Shasta and Tehama counties, California.

	Ranches and harvest size				
	1	2	3	4	All
Wildlife species	1,400 ac	300 ac	40 ac	500 ac	13,200 ac
Ensatina	-17.9	-97.7	-33.3	-10.0	-23.1
Cooper's hawk	-58.2	-78.0	-34.2	-17.5	-41.4
Red-tailed hawk	-12.4	-24.6	46.9	-19.7	28.7
Wild turkey	-26.6	0.0	12.4	-4.5	8.3
Mourning dove	-17.3	-45.0	196.1	-19.7	59.3
Western screech-owl	-54.6	-67.0	12.4	-6.7	8.3
Acorn woodpecker	-51.1	-98.6	77.6	-25.5	44.4
Pacific-slope flycatcher	-80.1	-99.0	-47.2	-42.4	-56.0
Ash-throated flycatcher	28.8	-98.5	199.7	-17.1	113.7
Western scrub-jay	-60.3	-99.0	-2.3	-25.5	-15.4
Bushtit	-50.4	-99.0	-2.3	-25.5	-15.4
White-breasted nuthatch	-52.5	-98.7	4.5	-27.5	-11.9
Western bluebird	-30.0	-29.0	189.4	-43.3	135.5
Western meadowlark	9,900.0	9,900.0	5,850.0	77.6	6,750.0
California ground squirrel	113.0	203.0	110.3	5.2	103.0
Western gray squirrel	-85.8	-98.5	-16.4	-54.8	-26.1
Dusky-footed woodrat	80.3	-97.0	-9.7	80.3	30.9
Gray fox	5.6	-44.2	122.8	-28.5	59.4
Mule deer	27.1	-43.4	40.0	-12.7	33.1
Western fence lizard	11.7	-67.0	51.5	-6.7	30.0
Gopher snake	4.4	0.0	203.0	0.0	88.3
No. significant differences[1]					
Positive	3	2	9	2	7
Negative	8	12	0	1	1
Unaffected	10	7	12	18	13

[1]Significant differences defined as percent change ± 50 percent between the cut and uncut conditions.

between the study area average and individual ranch averages for other vegetation variables (*table 1*).

Considerable differences existed between average stem diameter and average tree canopy cover between the cut and uncut conditions over the 50-year period (*table 2*). As expected, uncut conditions had the greatest amount of canopy cover, averaging 2-3 times more tree canopy than cut conditions. Average stem diameters, however, were almost identical for the cut and uncut condition for the entire study area.

Ranch 3 and All Ranches had the most similar stem diameters and canopy cover among the five scenarios. Similar stem diameters may indicate that harvesting was proportionately directed at all tree sizes. The most substantial differences in stem diameters were with Ranches 1 and 2, indicating a harvest directed at the larger trees. Because of the similarities in stem diameters and canopy covers, CWHR habitat types and stages were relatively similar to those of Ranch 3 and All Ranches.

Ranches 1, 2, and 4 had been harvested such that post-cut habitat conditions did not meet the criterion of 10 percent tree canopy cover for a tree-dominated CWHR habitat type (Mayer and Laudenslayer 1988) (*table 2*). These three ranches were typed as Annual Grassland habitats for Target Year 0, and Ranch 2 remained Annual Grassland habitat over the entire 50-year period because initial harvesting was so substantial that tree canopy cover never was ≥10 percent. Ranches 1 and 4 grew into blue oak woodland habitat by Target Year 10. For Ranches 3 and 4 and All Ranches, cut and uncut canopy cover classes differed by 1-2 classes (i.e., S [Sparse 10.0-23.9 percent] for cut and P [Open 24.0-39.9 percent] for uncut).

Wildlife

The 21 evaluation species included one amphibian, two reptiles, 13 birds, and five mammals (*table 3*). The western fence lizard (see *table 3* for scientific names) had the lowest score (5), while the wild turkey, mourning dove, and acorn woodpecker had the highest scores (9). The wild pig had the greatest score of all potential evaluation species, but it was not chosen because of controversy over its desirability as an occupant of California's oak woodlands. These evaluation species are representative of wildlife communities found in similar oak woodlands in California (Block and others 1991, Wilson and others 1991). A wide variety of breeding substrates and feeding habits are used by the evaluation species. In particular, trees and/or tree cavity breeding substrates were used by 13 species. At least six species used acorns as a primary food source.

Three species (ensatina, Cooper's hawk, Pacific-slope flycatcher) were predicted by CWHR to prefer blue oak woodlands with ≥40.0 percent tree canopy (closed canopies). CWHR predicted that nine species (mourning dove, acorn woodpecker, ash-throated flycatcher, western bluebird, western meadowlark, California ground squirrel, gray fox, mule deer, gopher snake) preferred open canopied (10-39.9 percent) blue oak woodlands. The remaining nine species had similar CWHR-predicted suitability values and were categorized as having no preference.

Patterns of AAHU percent change was relatively consistent among the five ranch scenarios (*table 4*). Using the 50 percent change significance threshold, the Cooper's hawk, western screech-owl, acorn woodpecker, Pacific-slope flycatcher, western scrub-jay, bushtit, white-breasted nuthatch, and western gray squirrel appeared to be the most negatively affected by wood cutting because they exceeded the negative threshold for two or more scenarios. Conversely, the mourning dove, ash-throated flycatcher, western bluebird, western meadowlark, California ground squirrel, dusky-footed woodrat, gray fox, and gopher snake were the most positively affected because they exceeded the positive threshold for two or more scenarios. The acorn woodpecker, ash-throated flycatcher, dusky-footed woodrat, and western fence lizard had negative changes for one or more ranches (Ranches 1 and/or 2) and positive changes for another ranch (Ranches 1 or 3 and/or All Ranches) (*table 4*).

Of the five scenarios, Ranch 4 had the least significant impacts. Ranches 1 and 2 had the greatest number of species negatively affected, while Ranch 3 and All Ranches had the greatest number of species positively affected. Ranches 1 and 2 had the greatest numbers of species positively and negatively affected.

Discussion

Differences in habitat conditions between cut and uncut conditions were plainly evident. Wood cutting resulted in substantially lower amounts of canopy cover. Stem densities were variously affected depending on the tree diameters selected during the harvest.

Wildlife were variously affected depending on the CWHR-predicted habitat suitabilities for each species. Generally, species favoring closed-canopy conditions with larger diameter trees, such as the Cooper's hawk and Pacific-slope flycatcher, were negatively affected when cutting resulted in grasslands or oak woodlands with small diameter trees and open canopies. Conversely, species favoring grasslands or very open woodlands, such as the western meadowlark, California ground squirrel, and gopher snake, were positively affected.

Some species favoring tree habitats with open canopies, such as the mourning dove, ash-throated flycatcher, western bluebird, gray fox, and mule deer, were predicted to be positively affected or unaffected on the basis of the magnitude of the tree cutting. The western screech owl, acorn woodpecker, western scrub-jay, bushtit, white-breasted nuthatch, and western gray squirrel were significantly negatively affected only when substantial differences occurred between the cut and uncut conditions. The ensatina, red-tailed hawk, wild turkey, mule deer, and western fence lizard were relatively unaffected by the cutting, despite varying degrees of canopy cover preference.

Substantial positive changes in AAHUs were calculated for the western meadowlark and California ground squirrel because CWHR predicted blue oak woodland habitats with even moderate amounts of tree canopy cover as unsuitable (HSI = 0.0). It is likely that CWHR underestimated the habitat value to these species, and some habitat value exists. AAHU changes would have been less if suitability values had existed for those habitat conditions.

Clearly, the magnitude of tree cutting influenced wildlife impacts. Ranch 3 and All Ranches had relatively minor amounts of tree cutting, and impacts were either positive (Ranch 3: nine species; All Ranches: seven species) or not significant (Ranch 3: 12 species; All Ranches: 13 species). The harvesting at Ranch 3 and All Ranches actually resulted in woodlands with larger diameter trees and more open canopy conditions than the uncut condition. Ranches 1 and 2 had relatively large amounts of tree cutting, and their impacts were mostly negative (Ranch 1: eight species; Ranch 2: 12 species). Ranch 4 had relatively similar canopy cover levels for the cut and uncut woodland conditions, and relatively few species were affected (one and two species negatively and positively affected, respectively).

It was difficult to assess the importance of habitat elements, such as snags, woody debris, and shrubs, in causing or minimizing wildlife habitat impacts. Differences in elements among ranches could be due to variable harvesting activities and/or natural resources. Either way, these habitat elements play major roles in supporting wildlife communities. Absence of key elements may mean absence of dependent wildlife species. Land use activities that maintain and recruit important elements, such as snags, granaries, woody debris, shrubs, and brushpiles, likely will minimize adverse impacts to wildlife. For example, the dusky-footed woodrat requires shrubs for habitat occupancy according to CWHR habitat models.

Hardwood habitat management guidelines employed by CDFG (California Department of Fish and Game 1989) establish *minimum* retention standards for several of these elements as well as canopy cover. Ranches 1 and 4 did not meet CDFG's blue oak habitat snag retention standard of 1 blue oak snag/5 acres (0.20 snags/acre), and eight of the 19 (42 percent) ranches did not meet the snag guideline. CDFG standards of 40 percent for tree canopy cover retention were not met by four of the five (80 percent) ranch scenarios in *table 2*, nor by 14 of the 15 (93 percent) ranches with baseline uncut canopy covers ≥40 percent.

Our results using CWHR and blue oak growth models indicate that over a relatively long time period (50 years in this case), the magnitude of wildlife impacts from tree cutting in blue oak woodlands varies by species. Effects of tree canopy cover are important when average tree diameters are similar between cut and uncut conditions. To minimize negative impacts and have some positive impacts, cutting should be proportionately directed at trees of all sizes or disproportionately more large trees should be left such that average tree diameter changes relatively little or slightly increases, respectively. Immediate post-harvest retention of tree canopy cover should be between 25 and 40 percent. Land management practices should allow for tree recruitment through stump sprouting, acorn germination, and retention of smaller, presumably younger, trees. Furthermore, snags, shrubs, downed woody debris, acorn-producing trees, brushpiles, and other habitat elements should remain or be enhanced.

CWHR models have inaccuracies as Block and others (1994) demonstrated for predictions from California oak woodlands. Therefore, our results should be cautiously interpreted and applied only to the 21 evaluation species. Furthermore, any management decisions or generalizations about impacts of wood cutting to wildlife communities in blue oak woodlands throughout California should be tempered. This post-hoc impact assessment used models of habitat relationships based on varying amounts of scientific information; on-site wildlife inventories were not done, and models were not tested. Also, impacts were evaluated over a 50-year period, and immediate impacts from tree cutting were not explicitly discussed, although they were accounted for with the HEP analysis.

We think that some inaccuracies have been minimized to the largest extent possible through the process of selecting evaluation species. This process resulted in use of 21 evaluation species that, we are relatively confident, occur in the study area and indicate blue oak woodland conditions. Nevertheless, the biological significance of CWHR-predicted impacts must be cautiously interpreted as Block and others (1994) and Garrison (1994) suggest.

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References

Block, William M.; Morrison, Michael L. 1991. **Influence of scale on the management of wildlife in California oak woodlands**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management. 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-GTR-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 96-104.

Block, William M.; Morrison, Michael L.; Verner, Jared; Manley, Patricia. 1994. **Assessing wildlife-habitat-relationships models: a case study with California oak woodlands.** Wildlife Society Bulletin 22(4): 549-561.

Bolsinger, Charles, L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas.** Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

California Department of Fish and Game. 1989. **Interim wildlife/hardwood management guidelines.** Sacramento, CA: Wildlife Management Division, Department of Fish and Game. 12 p.

Doering, John, P., III; Armijo, Mariann B. 1986. **Habitat evaluation procedures as a method of assessing timber-sale impacts.** In: Verner, Jared; Morrison, Michael L.; Ralph, C. John, eds. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Madison: The University of Wisconsin Press; 407-410.

Garrison, Barrett A. 1992. **Biodiversity of wildlife in a coast redwood forest: an analysis using the California Wildlife Habitat Relationships System.** In: Proceedings of the symposium on biodiversity of northwestern California; 1991 October 28-30; Santa Rosa, CA. Report 29. Berkeley, CA: Wildland Resources Center, University of California; 175-181.

Garrison, Barrett A. 1994. **Determining the biological significance of changes in predicted habitat values from the California Wildlife Habitat Relationships System.** California Fish and Game 80(4): 150-160.

Garrison, Barrett A. 1996. **Appendix A: vertebrate wildlife species and habitat associations.** Guidelines to managing California's hardwood rangelands; In: Standiford, Richard B., technical coordinator. Guidelines for managing California's hardwood rangelands. Berkeley: University of California; 120-145.

Mayer, Kenneth E.; Laudenslayer, William F., Jr., eds. 1988. **A guide to wildlife habitats of California.** Sacramento: The Resources Agency, California Department of Forestry and Fire Protection; 166 p. Available from California Department of Fish and Game, Wildlife Management Division, 1416 Ninth Street, Sacramento, CA 95814.

Mayer, Kenneth E.; Passof, Peter C.; Bolsinger, Charles L.; Grenfell, William E., Jr.; Slack, Harold. 1986. **Status of the hardwood resource of California: a report to the Board of Forestry.** Sacramento: California Board of Forestry; 126 p.

Pavlik, Bruce M.; Muick, Pamela C.; Johnson, Sharon G.; Popper, Marjorie. 1991. **Oaks of California.** Los Olivos, CA: Cachuma Press; 184 p.

Standiford, Richard B. 1995. **Growth of blue oak on California's hardwood rangelands.** Unpublished draft supplied by author.

Standiford, Richard B.; McCreary, Douglas; Barry, Sheila; Forero, Larry; Knight, Ron. 1996. **Impact of firewood harvesting on hardwood rangelands varies with region.** California Agriculture 50(2): 7-12.

Timossi, Irene; Sweet, Ann; Dedon, Mark; Barrett, Reginald. 1994. **User's manual for the California Wildlife Habitat Relationships microcomputer database.** Berkeley: The University of California, Department of Environmental Science, Policy, and Management; 77 p. Available from: California Department of Fish and Game, Wildlife Management Division, 1416 Ninth Street, Sacramento, CA 95814.

U.S. Department of Agriculture, Forest Service. 1994. **Neotropical migratory bird reference book.** San Francisco, CA: Forest Service, U.S. Department of Agriculture.

U.S. Department of Interior, Fish and Wildlife Service. 1980. **Habitat evaluation procedures (HEP).** 102-ESM-1. Washington, DC: U.S. Fish and Wildlife Service, Department of Interior.

Williams, Gary L. 1988. **An assessment of HEP (Habitat Evaluation Procedures) applications to Bureau of Reclamation projects.** Wildlife Society Bulletin 16(4): 437-447.

Wilson, Randolph A.; Manley, Patricia; Noon, Barry R. 1991. **Covariance patterns among birds and vegetation in a California oak woodland.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management. 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-GTR-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 126-135.

Contribution of Downed Woody Material by Blue, Valley, and Coast Live Oaks in Central California[1]

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Abstract**:** *Information on downed woody material (DWM) is necessary to produce guidelines to manage and maintain faunal diversity in California oak (*Quercus *spp.) woodlands. We sampled DWM within circular plots, one each centered on 122 blue (*Quercus douglasii*), 112 coast live (*Q. agrifolia*), and 74 valley (*Q. lobata*) oak trees in central California. Most DWM pieces that occurred within plots were small. Of large (≥25 cm diameter) pieces, 83 percent occurred under coast live (40 percent) and valley (43 percent) oaks. Mean diameter, length, number, and volume of pieces of DWM under blue, coast live, and valley oaks were not statistically different across the three tree species (all* P *>0.10). However, for each variable, mean values of pieces were lower under blue oaks versus under coast live and valley oaks. Approximately 50 percent of the pieces under each species were moderately decayed, compared to approximately 25 percent either sound or soft. Management practices in oak woodland may alter the abundance and distribution of DWM. Therefore, emphasis should be given to maintenance of DWM for vertebrate and invertebrate wildlife.*

Downed woody material (DWM) (defined herein as the dead branches, stems, and boles of trees that have fallen and lie on or above the ground [Brown 1974]) is an important component of wildlife habitat in California's 3.1 million ha of oak (*Quercus* spp.) woodlands. A query we conducted of version 5.0 of the California Wildlife Habitat Relationships (CWHR) System (Timossi and others 1994) produced a list of 278 terrestrial vertebrates that use oak woodlands. Of these, 28 percent (80; 15 of 22 amphibian species, 23 of 38 reptile species, 13 of 144 bird species, and 29 of 78 mammal species) use DWM for feeding, reproduction, or cover (Timossi and others 1994). Downed wood also functions as a moisture and nutrient reserve and perhaps as natural protection for emerging oak seedlings (Barnhart and others 1991)

Studies in forests of the Pacific Northwest show that the size (Ruben 1976), amount, distribution (Winn 1976), and state of decay of DWM influence wildlife use. Management practices in California oak woodlands and changing land-use patterns can alter the characteristics and distribution of DWM, thereby affecting dependent wildlife species. Baseline knowledge of DWM in oak woodlands is required to manage this important resource

The objectives of this study were to determine the relative contribution of DWM by the three predominant oak species (blue oak [*Quercus douglasii*], coast live oak [*Q. agrifolia*], and valley oak [*Q. lobata*]) in oak woodlands of central California. Study results will provide information for management of DWM and will be used by others for input to the CWHR System, a computerized wildlife information system used by many natural resource managers (Airola 1988).

Study Area

During summer and fall 1995, we sampled DWM in oak woodlands on 11 livestock ranches in central California (*fig. 1*). The ranches were chosen primarily for the existence of an active livestock production enterprise on the ranch, our

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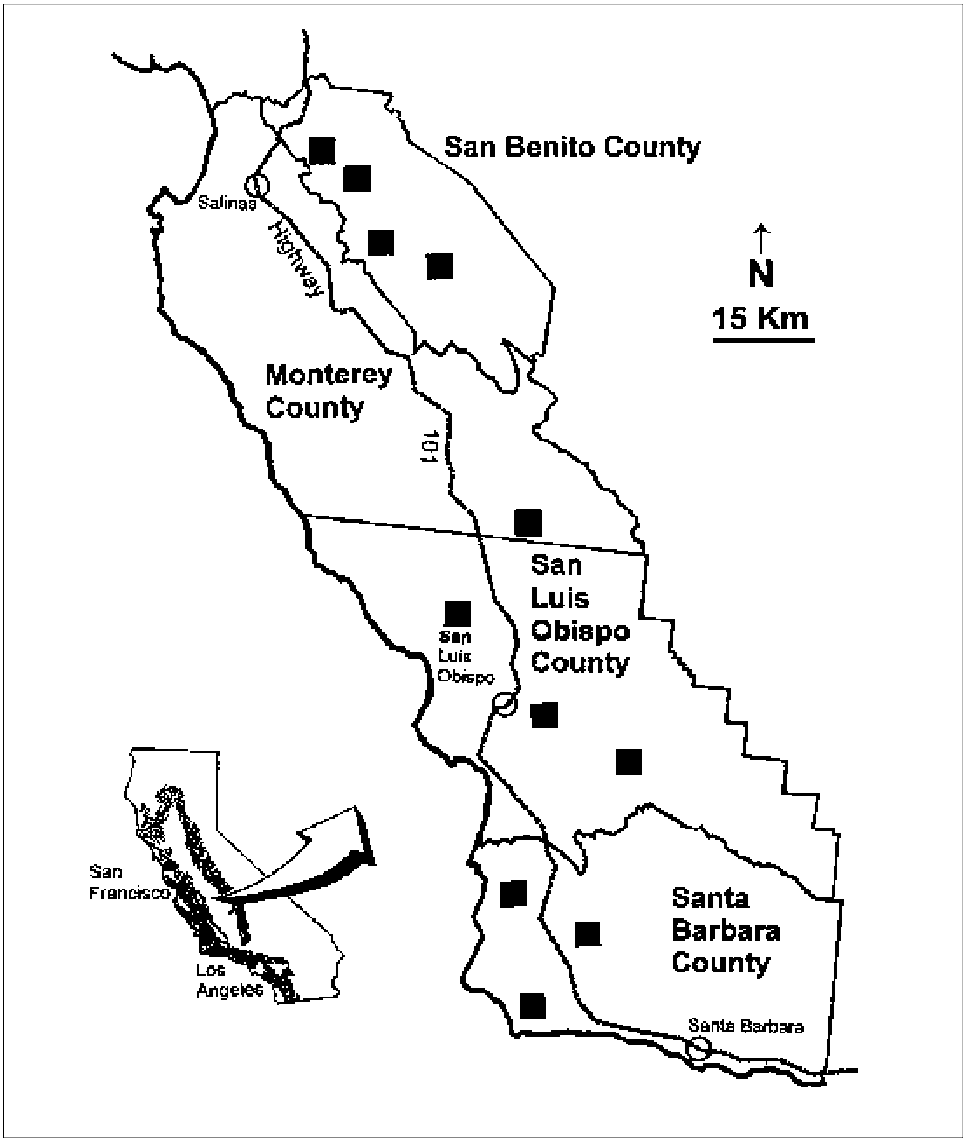

Figure 1—Ranch locations in coastal California in which downed woody material was sampled on 308 0.01-ha plots in oak woodlands, 1995. The inset map shows the composite distribution of blue, coast live, and valley oak trees in California (after Griffin and Critchfield 1976).

ability to gain access, and their somewhat even spacing from south Santa Barbara County to north San Benito County. These ranches are typical of central California oak woodlands and represent a continuum of stand densities and tree species compositions. Topography on the 11 ranches is generally hilly. Climate of the area is Mediterranean, characterized by warm, dry summers and cool, wet winters. Typically, all precipitation occurs during October to May

Blue oaks and coast live oaks predominate in the woodlands we sampled. Valley oaks occur as scattered individuals or in small groups in valley bottoms. Western sycamore (*Platanus racemosa*) and cottonwood (*Populus* spp.) predominate in intermittent and perennial riparian zones. Chaparral, dominated by chamise (*Adenostoma* spp.), occupies many south-facing slopes. When present, understories of the oak woodlands consist mostly of toyon (*Heteromeles arbutifolia*), California coffeeberry (*Rhamnus californica*), poison oak (*Toxicodendron diversilobum*), and deerweed (*Lotus scoparius*). Wild oats (*Avena* spp.), bromes (*Bromus* spp.), and fescues (*Festuca* spp.) predominate on woodland floors.

Methods

Field

On each ranch, the ranch headquarters or a ranch gate formed a starting point for selecting oak stands at regular intervals (0.5 km) along access roads on alternate sides. We paced 50 m off the road along a line approximately perpendicular to the road. In like manner to the point-centered quarter method (Cottam and Curtis 1956), the end formed a sampling point. The nearest living tree 10 cm diameter at breast high (dbh; 1.4 m above the ground) within each quadrant (NE, SE, SW, and NW) around the sampling point was termed a "mother tree" under which we measured DWM.

We measured the dbh of each mother tree with a Biltmore stick; height (m) was measured with a clinometer. We measured DWM within a 6-m radius sampling plot (0.01-ha circular plot) centered on each mother tree. In four instances where circular plots around two mother trees intersected, overlap was eliminated by selecting the next nearest tree of ≥10 cm dbh. The length (cm), widest diameter (cm), and decay state of all DWM ≥5 cm diameter were recorded. For DWM that intersected the plot perimeter, we measured DWM length only to its intersection. Volume of DWM was calculated as the volume for a cylinder using the length (cm) and largest diameter (cm) of pieces. Because DWM pieces were, on average, <1 m long (mean = 88.4 cm, n = 1,349, SE = 2.4 cm), disparity between largest and smallest diameters on individual pieces was likely not great and therefore represents only a potentially slight overestimate of volume. We based our classification of decay state on a system defined for Douglas-fir (*Pseudotsuga menziesii*) by Maser and others (1979) and modified by Bingham and Sawyer (1988). By this method, we placed downed oak wood into one of three decay classes: (1) sound wood or only slight surface breakdown, with bark and branches intact; (2) moderately decayed wood and small branches missing, but bark usually present; and (3) soft DWM, often too rotten to support its own weight.

Data Analysis

Because sample sizes were small, normality could not be assumed; therefore, we used Kruskall-Wallis non-parametric single-factor analyses of variance to assess differences among tree species. Chi-square was used to assess differing proportions of DWM by species in each of three decay states. Differences were considered significant when $P \leq 0.10$. Statistical procedures were conducted in PC-SAS (SAS Institute Inc. 1988).

Results

Mother Trees

We measured DWM in 308 0.01-ha circular plots centered on 74 valley, 112 coast live, and 122 blue oak trees located in four counties (Santa Barbara, San Luis Obispo, Monterey, and San Benito Counties on 76, 80, 68, and 84 plots, respectively). Most mother trees were large: 64 percent were 63 cm dbh (range 10-218 cm dbh). Seventy-one percent of coast live oak and 97 percent of valley oak mother trees were 63 cm dbh, compared to 38 percent of the blue oak trees (*fig. 2*).

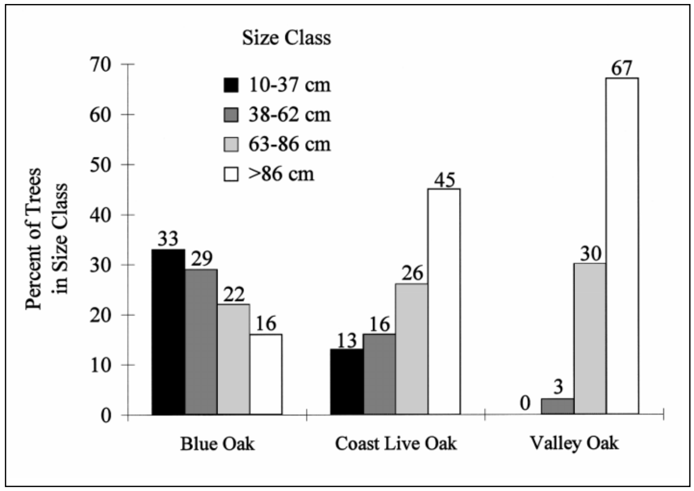

Figure 2—Size-class distribution by tree species of 308 blue, coast live, and valley oak trees in coastal California, 1995, under which downed woody material was sampled within a 0.01-ha plot centered on each tree.

Downed Wood

A total of 1,351 DWM pieces was sampled. Of the 308 plots, 79 percent had ≥1 piece of DWM ≥5 cm diameter. Categorizing DWM as small (5-14 cm diameter), medium (15-24 cm), or large (≥25 cm diameter), 88 percent of DWM pieces were small. Of 53 large pieces, 40 and 43 percent occurred under coast live and valley oaks, respectively (*table 1*).

Analysis among the three oak species of mean diameter and length of DWM pieces and mean number and volume of pieces under mother trees produced no statistically significant differences (all P>0.10, *table 2*). There was a notably consistent trend, however, of smaller average size and lesser average amount of DWM under blue oak mother trees compared to that under coast live and valley oaks: diameter = 8.3 ± 1.3 (mean ± SE) vs. 9.8 ± 0.9 and 9.3 ± 1.3 cm, respectively; length = 87.7 ± 7.4 vs. 117.9 ± 9.6 and 106.4 ± 19.3 cm, respectively; number = 3.7 ± 0.8 vs. 7.1 ± 1.8 and 5.6 ± 1.3, respectively; and volume = 0.04 ± 0.02 vs. 0.16 ± 0.07 and 0.11 ± 0.05 m^3/plot, respectively (*table 2*).

Among blue, coast live, and valley oaks, DWM exhibited a similar pattern of decay state: approximately 50 percent of the pieces under each species were moderately decayed (58, 51, and 50 percent, respectively), compared to approximately 25 percent either sound (15, 23, and 22 percent, respectively) or soft (27, 26, 28 percent, respectively). Within only the sound decay state, significantly more DWM under valley (22 percent) and coast live (23 percent) oaks was sound than under blue oak (15 percent) trees (χ^2 = 18.35, df = 2, $P \leq$ 0.0001) (*fig. 3*).

Discussion

Selection of mother trees using the quarter method (Cottam and Curtis 1956) may have resulted in autocorrelation among the four trees we selected within a point. Therefore, we did not treat these four trees as independent samples in our analyses. Rather, we generated mean values from the four trees within a point and then generated a mean for each species for each ranch. The fact that the 11 ranches had the same primary management practice (cattle grazing), were within the oak woodland type, had similar fire histories, and that samples within ranches were taken from stands on various aspects, slopes, and soils all indicate that ranches constituted independent replicates

Table 1—Number of pieces of downed woody material (DWM) in three diameter (cm) classes under three species of oaks on 11 ranches in central California oak woodlands, 1995.

Species	Trees with no DWM present	Piece size: Small (5-14 cm)	Medium (15-24 cm)	Large (≥25 cm)	Total pieces
Blue oak (*Quercus douglasii*)	36	373	22	9	404
Coast live oak (*Quercus agrifolia*)	21	448	45	21	514
Valley oak (*Quercus lobata*)	8	369	41	23	433
Total	65	1,190	108	53	1,351

Table 2—Characteristics of downed woody material (DWM) on 11 ranches in central California, 1995.

	Piece diameter	Piece length	Pieces per tree	Volume per tree
	cm	*cm*	*no.*	m^3
Blue oak ($n = 7$)[1]				
mean	8.3	87.7	3.7	0.04
SE	1.3	7.4	0.8	0.02
Coast live oak ($n = 11$)				
mean	9.8	117.9	7.1	0.16
SE	0.9	9.6	1.8	0.07
Valley oak ($n = 9$)				
mean	9.3	106.4	5.6	0.11
SE	1.3	19.3	1.3	0.05
χ^2 (Approximation)	1.2030	3.7094	2.8649	3.9494
df	2	2	2	2
P (Kruskal-Wallis χ^2 approximation)	0.5480	0.1565	0.2387	0.1388

[1]Over 1,350 pieces were observed on 308 0.01-ha plots centered on 74 valley, 112 coast live, and 122 blue oak trees. Samples were considered independent only at the ranch level: means represent values averaged (piece diameter and length) or summed (volume/tree and number of pieces/tree) by tree, averaged across trees of the same species within sample points, then averaged across points within ranches. Sample sizes (*n*) are the number of ranches on which that species occurred.

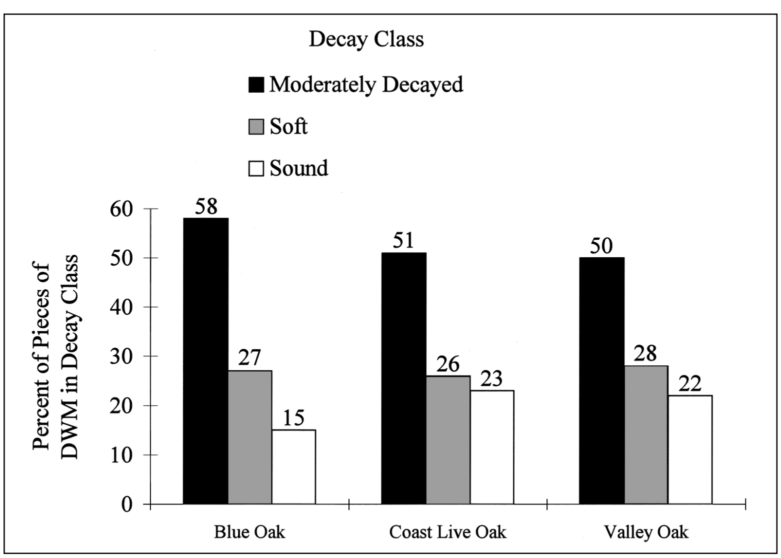

Figure 3—Percent by decay class of 1,351 pieces of downed woody material (DWM) sampled in coastal California in 1995 on 308 0.01-ha plots under blue, coast live, and valley oak trees. Proportions of pieces exhibiting the three decay states differed significantly among the three species (χ^2 = 11.37, df = 4, P = 0.0227). Subdivided chi-square tests resulted in differences within all three species across decay states and within only the "sound" decay state across species.

Lack of statistically significant ($P \leq 0.10$) results using the ranches as replicates apparently was due to the relatively high variability of the DWM data within and among ranches compared to among oak species. If we could justifiably have used individual trees as replicates and thereby discounted within- and among-ranch variability, perhaps the subsequent analysis would have substantiated the consistent trends apparent in our results and demonstrated that DWM was more numerous and larger (diameter, length, and volume) for coast live and valley oaks compared to blue oak. This difference, if real, could be attributed to the larger size of the coast live and valley oak trees we sampled, in conjunction with the tendency of valley oak to drop limbs. Limb dropping apparently results from increased brittleness after rehydration on hot days (Dias 1989). Our sampling of predominantly large valley and coast live oak trees was not an artifact of the sampling design. Rather, it likely represents the actual size-class distribution of these species in oak woodland: trees 74 cm dbh and larger account for 12 and 40 percent of the standing volume of coast live and valley oak, respectively, in California oak woodland compared to only 3 percent for blue oak (Bolsinger 1988)

We recognize that there is some bias in our data which complicates interpretation and limits application of the results. Sampling under trees rather than across woodlands precludes extrapolating DWM to area estimates across woodlands. The 0.01-ha plot of fixed radius (6 m) probably captured most DWM under blue oak trees, but may have been too small to do the same for many valley and coast live oaks under which we sampled. Because we measured DWM only to the plot intersection, mean length measurements are an index of piece length, not an absolute length of DWM. Nonetheless, this study is one of the first to characterize and quantify DWM in oak woodlands. Although many studies on DWM have been conducted in western North America in conifer-dominated habitats (Graham and Cromack 1982, Harmon and others 1987, Larson 1992, Maser and others 1979), other than Borchert and others (1993), no information exists on DWM presence and characteristics in oak woodland. In two blue oak stands in San Luis Obispo County, Borchert and others (1993) found an average of 6.2 and 3.5 pieces/ha of small DWM and 2.0 and 3.5 pieces/ha of large DWM. They defined "small" as 8-20 cm diameter and ≥0.9 m long and "large" as >20 cm diameter and ≥0.9 m long.

Management Implications

This study demonstrates the substantial contribution of DWM by large valley and coast live oak trees, and probably in lesser amount, blue oak, in central California oak woodlands. However, current information indicates that larger trees are sometimes cut for firewood (Standiford 1996). If firewood must be cut, we recommend leaving some slash piles and some larger pieces of wood to mitigate the removal of DWM. Further concern about the long-term presence of DWM arises from the prevalent notion that it provides habitat for rodent and snake pests. Downed wood is also used for firewood, and its removal is sometimes encouraged for aesthetic reasons. Naturally occurring DWM (i.e., fallen limbs and fallen snags) should be left in place.

Downed wood is an important habitat component for at least 80 of the 278 wildlife species predicted by our CWHR query to occur in oak woodlands, so it is important for maintaining faunal diversity. We cannot yet make prescriptions for the amount of DWM necessary to maintain wildlife values. At this time, however, we recommend that landowners and managers maintain DWM wherever possible.

Acknowledgments

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References

Airola, Daniel A. 1988. **Guide to the California wildlife habitat relationships system**. Prepared for the State of California Resources Agency, Dept. of Fish and Game, Sacramento, CA; 74 p

Barnhart, Stephen J.; McBride, Joe R.; Warner, Peter. 1991. **Oak seedling establishment in relation to environmental factors at Annadel State Park**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-GTR-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 25-30

Bingham, Bruce B.; Sawyer, John O. 1988. **Volume and mass of decaying logs in an upland old-growth redwood forest**. Canadian Journal of Forest Research 18: 1649-1651

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas**. Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p

Borchert, Mark I.; Cunha, Nancy D.; Krosse, Patricia C.; Lawrence, Marcee L. 1993. **Blue oak plant communities of Southern San Luis Obispo and Northern Santa Barbara Counties, California**. Gen. Tech. Rep. PSW-139. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 49 p

Brown, James K. 1974. **Handbook for inventorying downed woody material**. Gen. Tech. Rep. INT-16. Ogden, UT: Intermountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 24 p

Cottam, Grant; Curtis, John T. 1956. **The use of distance measures in phytosociological sampling**. Ecology 37: 451-460

Dias, Stephanie. 1989. **Valley oaknative of the central coast**. In: Tietje, William D., ed. Hardwood habitats: notes for central coast resource management, Vol. 2 (1). San Luis Obispo, CA: University of California Cooperative Extension; 5-6.

Graham, Robin L.; Cromack, Kermit, Jr. 1982. **Mass, nutrient content, and decay rate of dead boles in rain forests of Olympic National Park**. Canadian Journal of Forest Research 12: 511-521

Griffin, James R.; Critchfield, William B. 1976. **The distribution of forest trees in California**. Res. Paper PSW-82. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 114 p.

Harmon, Mark E.; Cromack, Kermit, Jr.; Smith, Brian G. 1987. **Coarse woody debris in mixed-conifer forests, Sequoia National Park, California**. Canadian Journal of Forest Research 17: 559-564.

Larson, Frederic R. 1992. **Downed woody material in southeast Alaska forest stands**. Res. Paper PNW-RP-452. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 12 p.

Maser, Chris; Anderson, Ralph G.; Cromack, Kermit, Jr.; Williams, Jerry T.; Martin, Robert E. 1979. **Dead and down woody material**. In: Thomas, Jack W., ed. Wildlife habitats in managed foreststhe Blue Mountains of Oregon and Washington. Agric. Handb. 553. Washington, D.C.: U.S. Deptartment of Agriculture, Forest Service; 78-95.

Ruben, John A. 1976. **Reduced nocturnal heat loss associated with ground litter burrowing by the California red-sided garter snake *Thamnophis sirtalis infernalis***. Herpetologica 32: 323-325.

SAS Institute Inc. **SAS/STAT** [Computer program]. 1988. Cary, NC: SAS Institute Inc.; 1028 p.

Standiford, Richard B., Forest Management Specialist, University of California at Berkeley. (Telephone conversation with Douglas D. McCreary). 4 January 1996.

Timossi, Irene; Sweet, Ann; Dedon, Mark F.; Barrett, Reginald H. 1994. **User's manual for the California Wildlife Habitat Relationships Microcomputer Database**. (Computerized information system, Version 5.0). California Department of Fish and Game, Sacramento, CA; 77 p.

Winn, David S. 1976. **Terrestrial vertebrate fauna and selected coniferous forest habitat types on the north slope of the Unita Mountains**. Salt Lake City, UT: Wasatch National Forest, Forest Service, U.S. Department of Agriculture; 145 p.

Design Recommendations for Point Counts of Birds in California Oak-Pine Woodlands: Power, Sample Size, and Count Stations Versus Visits[1]

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Abstract: *We used point count data from a 3-year experiment measuring the impact of firewood cutting on an oak woodland bird community to recommend a sampling design for detecting environmental impacts on bird population trends. The optimal allocation of sampling effort to count stations and visits varied from two to seven visits per station depending on the bird species. When the number of count stations was constrained by logistics, additional visits increased statistical power to detect an effect to acceptable levels (>0.5) for some species. Depending on the species, 14 to 920 count stations per treatment level were necessary to detect a 50 percent difference in the mean number of birds counted with power = 0.8.*

As California's oak (*Quercus* spp.) woodlands come under increasing pressure from human activities, so increases the need for the reliable detection of impacts on wildlife. In an experimental framework, the challenge is to isolate the effects of interest from natural spatial and temporal variability using an appropriate statistical test (Osenberg and others 1994). The power of a statistical test is the probability that it will find an effect of a specified size to be significant (Cohen 1988). Thus, power is critical in studies evaluating the impacts of environmental disturbances. These studies must be designed with adequate statistical power to detect biologically important changes in the population parameters of interest (e.g., density or reproductive success of a species). A possible result of failing to detect such changes may be the adoption or continuation of detrimental management practices, and perhaps extinction for some species.

In designing experiments, sample size is often seen as the primary means to control power. Certainly, sample size must be adequate to meet minimum power requirements, but in practice it is always subject to constraints. A fixed budget is a universal constraint on sample size, but logistical constraints, such as a small study area or limited potential for experimental treatments, may also exist.

Often overlooked is that, given a fixed budget, the statistical power of a study can be optimized by design. That is, different study designs of equal cost will have different power, and the researcher should select the optimal design. Such optimization requires information on the variance components of the population under study. The information may come from pilot studies or from previous experiments using similar populations. Thus, evaluating the efficiency of completed studies is a necessary first step toward maximizing the efficiency of future ones.

In woodland vegetation types, point counts have become a standard method for monitoring population trends in landbirds (Ralph and others 1993). Point counts are conducted by recording the number of individuals of target species detected from a counting station within a specified time interval. Frequently, stations are visited several times during a season to obtain an average index of population size. Although many studies have used point counts to detect the effect of environmental impacts on bird densities (deCalesta 1994, Wilson and others 1995), few have evaluated design efficiency once variance components are

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[1] An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, Calif.

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known. At least two studies have investigated the optimum allocation of sampling effort between count stations and visits (Buskirk and McDonald 1995, Smith and others 1995). However, because these optima are likely to be specific to particular vegetation types and bird species, further studies are needed to evaluate design efficiency in a variety of areas and vegetation types.

Here, we use point count data from a 3-year experimental study of the impact of firewood cutting on an oak woodland bird community in California to make specific recommendations about sample sizes necessary to meet power requirements and how to optimize the allocation of sampling effort to count stations and visits. Specifically, we address the following questions: (1) Assuming a fixed budget, what number of count stations and visits maximizes power to detect a specified difference between two group means (treatment and control)? (2) Assuming that the number of count stations is limited by logistical constraints, how does power increase with added visits? (3) Under the optimal allocation in (1), what sample sizes are necessary to detect biologically meaningful effects with reasonable power?

Study Area

We conducted field work at the University of California, Sierra Foothill Research and Extension Center, Yuba County, California, in the foothills of the northern Sierra Nevada mountains about 25 km east of Marysville. Elevation on the 2,300-ha Center ranged from 75 to 625 m with a general west to northwest aspect. Dominant trees were blue oak (*Quercus douglasii*), interior live oak (*Q. wislizenii*), and foothill pine (*Pinus sabiniana*), with fewer black oak (*Q. kelloggii*), valley oak (*Q. lobata*), ponderosa pine (*P. ponderosa*), and California buckeye (*Aesculus californicus*). Most stands contained mixtures of the three dominant species, although some pure stands of blue oak or live oak were present. Dominant shrubs were poison oak (*Toxicodendron diversilobum*), coffeeberry (*Rhamnus californica*), toyon (*Heteromeles arbutifolia*), and buckbrush (*Ceanothus cuneatus*). An herbaceous understory consisted of annual and perennial grasses and forbs.

Methods

Experimental Design and Field Methods

We used a completely randomized experimental design (Neter and others 1990:36-37) with a treatment and control replicated 30 times. The treatment consisted of a reduction of approximately 20 to 25 percent of total tree basal area, achieved by uniformly thinning commercial-grade (minimum 15-cm base diameter) blue oak and live oak. This level of thinning was chosen to represent a light firewood harvest. Experimental units were approximately 3.1-ha, circular plots centered on a single bird counting station. In a previous study, Block (1989) established 105 counting stations at 300-m intervals along linear transects (900 to 4,200 m) using a systematic random-sampling design (Thompson 1992). Of these, we selected 60 that were suitable for cutting for use in this experiment. Suitable plots were contained entirely on Center property, did not overlap with other researchers' plots, occurred mostly on slopes of less than 30 percent, and were accessible by vehicle. Cutting occurred on 30 of these from mid-August 1993 to early-March 1994.

We used a fixed-radius, circular-plot technique (Verner 1985) to count birds during the breeding season before (1993) and two breeding seasons after (1994 and 1995) cutting. Each count station was visited 10 times during a season at approximately regular intervals between late-March and mid-July. Observers recorded all birds detected by sight and sound within a 100-m (328-foot) radius of the counting station during a 5-minute period. Aigner (1996) describes the selection of experimental units and counting procedures in detail.

Power Analysis

We selected 10 bird species, five residents and five breeding migrants, for our power analysis (*table 1*). Species were selected to represent a range of mean densities, as well as spatial and temporal variances in occurrence, although no extremely rare species were included.

Sample Size Limited by Cost

For the fixed budget optimization we used the procedure described by Neter and others (1990:992) for a completely randomized single-factor study with

Table 1—Standard deviations in population trend[1] among visits ($\hat{\sigma}_s$) and count stations ($\hat{\sigma}_s$), and optimal numbers of visits (m_{opt}) to minimize the variance of the treatment mean population trend for birds at Sierra Foothill Research and Extension Center, California.

Species	$\hat{\sigma}_s$	$\hat{\sigma}_u$	m_{opt}
Residents:			
Acorn woodpecker (*Melanerpes formicivorus*)	24.4	6.5	4
Plain titmouse (*Parus inornatus*)	24.0	3.7	7
Bewick's wren (*Thryomanes bewickii*)	14.6	3.6	4
Hutton's vireo (*Vireo huttoni*)	8.1	-	[2]-
Rufous-crowned sparrow (*Aimophila ruficeps*)	12.4	3.1	4
Breeding Migrants:			
Western kingbird (*Tyrannus verticalis*)	10.9	3.6	3
Ash-throated flycatcher (*Myiarchus cinerascens*)	15.6	-	[2]-
House wren (*Troglodytes aedon*)	10.6	4.6	2
Blue-gray gnatcatcher (*Polioptila caerulea*)	8.6	2.7	3
Orange-crowned warbler (*Vermivora celata*)	10.8	1.7	6
Σ All species:	44.2	11.0	4

[1] Population trend for a species is the mean difference between the number of birds counted in the season before cutting and each of the two seasons after cutting.

[2] Subsampling error > experimental error, so no estimates of σ_u or m_{opt} could be derived.

subsampling. Under this model, visits (m) are considered subsamples, and sample size (n) is equal to the number of count stations. For each species, our parameter of interest was the population trend, defined as the mean difference between the number of birds counted in the season before cutting and each of the two seasons after cutting. The procedure minimizes the variance of the treatment mean, subject to the cost constraint equation:

$$C = c_o + an(c_u + mc_s) \qquad (1)$$

where C is total cost, c_o is any fixed cost, c_u is the cost of establishing a count station, c_s is the cost of visiting a count station, and a is the number of treatments. The resulting expression for the optimal number of visits is:

$$m_{\text{opt}} = \frac{\sigma_s}{\sigma_u}\sqrt{\frac{c_u}{c_s}} \qquad (2)$$

where σ_s is the standard deviation in population trend among visits and σ_u is the standard deviation among count stations. From our experience, we estimated that the cost of visiting a count station is the same as establishing one, thus $c_s = c_u$, and equation (2) reduces to the ratio σ_s/σ_u. This estimate ignores the cost of applying a treatment. When a treatment must be applied, c_u will probably be much greater than c_s.

In equation (2), note that the optimal number of visits does not depend on total cost. Once m_{opt} has been calculated, only n is determined by total cost in equation (1). Thus, the calculation of the optimal number of visits does not require specifying a total cost, only the relative costs of establishing and visiting a station. For generality, we did not set a particular total cost and consequently computed only m_{opt} and not n.

When n is approximately >20 and the desired significance criterion is in the range 0.05 to 0.1, minimizing the variance of the treatment mean is approximately equivalent to maximizing power to detect a treatment effect. When n is small, maximum power may occur with n higher, and m lower than the optimal values to minimize the variance of the treatment mean. This is because when n is small, the increase in power from additional error degrees of freedom may outweigh the loss of power from having a larger variance.

Sample Size Limited by Logistical Constraints

To investigate how power improves with added visits when the number of count stations is fixed by constraints other than cost, we ran 10 separate power analyses for each bird species using data from all 60 count stations. We began by using data from a single visit and incrementally selected more visits with each subsequent analysis. Visits selected for each analysis were uniformly distributed across the breeding season, or as close as possible. In each case, we computed power to detect the effect of thinning on population trend in a single-factor analysis of covariance model (ANCOVA, Norušis 1992:35-54). Although this method of resampling was subjective and may have resulted in somewhat biased power estimates, it was adequate for our goal of obtaining a rough idea of how power improves with added visits.

Precutting count was used as a covariate in the model as a variance reduction technique. We observed an inherent tendency for points with high precutting counts to have negative population trends, and points with low or zero precutting counts to have positive trends.

In the power analyses, we set the effect size at 50 percent of the mean precutting count and used a significance criterion of 0.05. We chose 50 percent as the minimum biologically important effect size because many species had large among-year variation in total count. For example, we had 38 percent fewer detections of acorn woodpeckers in 1995 than in 1993 (Aigner, unpublished data).[5] We reasoned that thinning effects, to be biologically important, should exceed among-year variation in bird counts.

[5] Unpublished data on file at Rocky Mountain Research Station, Southwest Forestry Complex, 2500 South Pine Knoll Drive, Flagstaff, AZ 86001.

Power calculations were made using the computer program STPLAN (University of Texas System Cancer Center 1986). Because this program does not specifically provide for the use of a covariate, actual error degrees of freedom were one less than those used in the power calculations. Consequently, our power estimates are slightly liberal, although the difference should be insignificant.

Sample Size to Meet Power Requirements

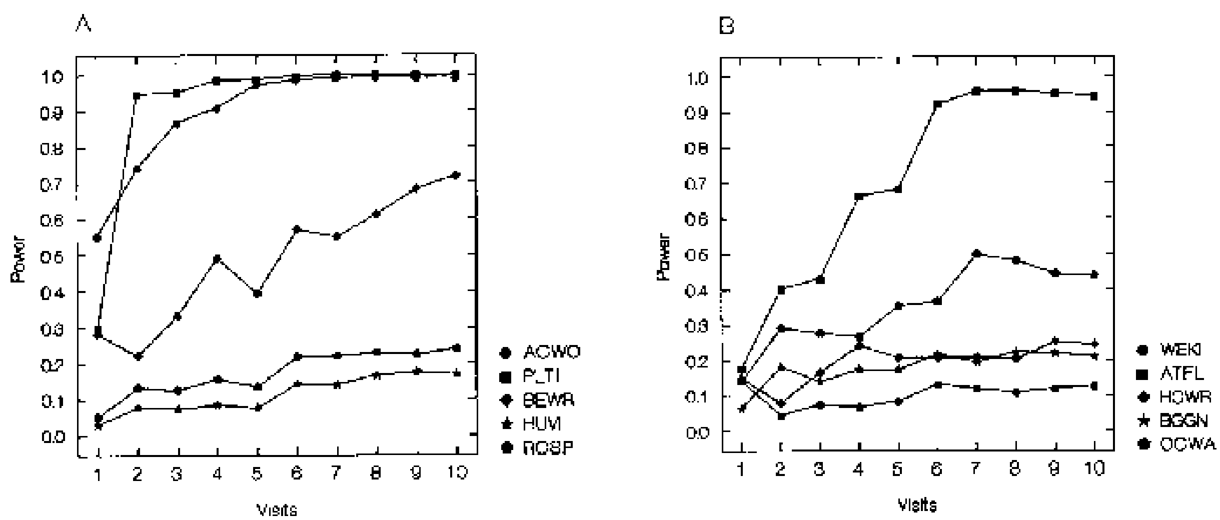
For each species, we calculated sample sizes necessary to meet power requirements for the design described above. Because most studies are likely to target several bird species, in these calculations we used a value for m to minimize the sum of the variance of the treatment mean for all 10 species. We computed sample sizes necessary to achieve power of 0.6, 0.7, and 0.8, with significance criteria of 0.05, 0.1, and 0.2 and an effect size equal to 50 percent of the mean precutting count. Sample size calculations were made using the computer program PC-SIZE (Dallal 1986). As with STPLAN, actual error degrees of freedom were one less than those used in the power calculations. Consequently, necessary sample sizes were slightly underestimated. The difference should be insignificant when the sample size per treatment level is >15.

Results

The optimal numbers of visits (m_{opt}) to minimize the variance of the treatment mean population trend ranged from two for the house wren to 7 for the plain titmouse (*table 1*). Four visits minimized the sum of the variances across all species excluding the Hutton's vireo and ash-throated flycatcher. We were unable to calculate m_{opt} for the Hutton's vireo and ash-throated flycatcher because subsampling error exceeded experimental error, so no estimates of σ_u could be derived (Neter and others 1990:997-998). This indicates that σ_s was large relative to σ_u, and m_{opt} would be large for these species if it could be estimated. Our estimates of m_{opt} can be easily modified for different cost structures by substituting appropriate values of c_s and c_u into equation (2) and using estimates of σ_s and σ_u from *table 1*.

When we fixed the number of count stations at 30 per treatment level, the increase in power associated with added visits varied among species (*fig. 1*). With only one visit, power was <0.6 for all species. For the acorn woodpecker, plain titmouse, and ash-throated flycatcher, increasing visits to 7 raised power to >0.9. In contrast, increasing visits did nothing to improve power for the western kingbird; power was greatest with only one visit. For the Hutton's vireo, rufous-

Figure 1—The effect of increasing visits on the statistical power to detect an effect of firewood cutting on population trends of five resident (A) and five breeding migrant (B) bird species at Sierra Foothill Research and Extension Center, California, when the number of count stations is fixed at 30 per treatment group. Effect size is 50 percent of the mean precutting count, and significance criterion is 0.05. Acronyms for species are ACWO = acorn woodpecker, PLTI = plain titmouse, BEWR = Bewick's wren, HUVI = Hutton's vireo, RCSP = rufous-crowned sparrow, WEKI = western kingbird, ATFL = ash-throated flycatcher, HOWR = house wren, BGGN = blue-gray gnatcatcher, and OCWA = orange-crowned warbler.



crowned sparrow, house wren, and blue-gray gnatcatcher, power increased slightly with increased visits, but was <0.3 even with 10 visits. The Bewick's wren and orange-crowned warbler showed intermediate increases in power. For all species, except the Bewick's wren, that showed increased power with increased visits, the increase in power leveled off after the sixth or seventh visit. For the Bewick's wren, power continued to increase almost linearly up to the 10th visit.

The number of count stations necessary to meet the specified power requirement varied among species by a factor of one-thousand (*table 2*). Sample sizes per treatment group necessary to achieve power = 0.8 to detect a 50 percent cutting effect with a significance criterion of 0.05 ranged from 14 for the plain titmouse to 920 for the western kingbird.

These sample-size requirements are for a two-tailed test of effects in a two-group comparison with a relatively stringent significance criterion. In *table 2*,

Table 2—Count stations per treatment group necessary to meet power requirements to detect the effect of thinning on bird population trends[1] at Sierra Foothill Research and Extension Center, California.

		Two-tailed significance criterion[2]		
Species (effect, S.D.)[3]	Power	0.05	0.1	0.2
Residents:				
Acorn woodpecker (46, 51)	0.6	16	12	8
	0.7	20	15	10
	0.8	24	19	14
Plain titmouse (68, 60)	0.6	9	7	5
	0.7	11	9	6
	0.8	14	11	8
Bewick's wren (22, 41)	0.6	36	27	18
	0.7	46	35	24
	0.8	58	45	33
Hutton's vireo (4, 28)	0.6	402	296	192
	0.7	510	386	267
	0.8	650	510	369
Rufous-crowned sparrow (12, 47)	0.6	143	105	69
	0.7	180	137	95
	0.8	229	180	131
Breeding Migrants:				
Western kingbird (6, 43)	0.6	580	420	273
	0.7	720	550	379
	0.8	920	730	530
Ash-throated flycatcher (26, 41)	0.6	26	19	13
	0.7	32	25	17
	0.8	41	32	23
House wren (11, 34)	0.6	93	69	45
	0.7	117	89	62
	0.8	148	117	85
Blue-gray gnatcatcher (7, 27)	0.6	132	97	63
	0.7	165	126	87
	0.8	210	165	121
Orange-crowned warbler (13, 37)	0.6	81	60	39
	0.7	102	78	54
	0.8	129	102	74

[1]Population trend defined in *table 1*.
[2]For a significance criterion of 0.05 in a one-tailed test, use the 0.1 column; for a significance criterion of 0.1 in a one-tailed test, use the 0.2 column.
[3]Effect is 50 percent of the mean precutting count. Units are birds counted per 100 count stations.

sample sizes for one-tailed tests with significance criteria of 0.05 and 0.1 are equivalent to the two-tailed results with significance criteria of 0.1 and 0.2, respectively. For all species, sample size to achieve power = 0.8 in a one-tailed test with a significance criterion of 0.1 is approximately half of that required in a two-tailed test with a significance criterion of 0.05.

Discussion

Our estimates of the optimal allocation of sampling effort to count stations and visits varied greatly among species. The biological factors underlying this variation are probably complex. For a given cost structure, m_{opt} is determined by the ratio of within-season temporal (σ_s) to spatial (σ_u) variability in population trend. Temporal and spatial variability in population trend are not correlated with temporal and spatial variability in occurrence. For example, the blue-gray gnatcatcher is a species with high spatial variability in occurrence, and it tends to reoccupy the same sites year after year. Occupied and unoccupied sites have zero or near-zero changes in count among years, and consequently the spatial variability in population trend is low. In general, such site fidelity in species should contribute to reducing σ_u and increasing m_{opt}.

For migrant breeders, within-season temporal variability in population trend could be affected by among-year differences in arrival times. Consider, for example, a migratory species that arrived and left earlier in each of the two seasons postcutting than in the precutting season. Even if overall numbers remained constant, the population trend would be positive early in the season and negative later in the season. Population trend, although variable in time, would be uniform over all count stations. In this way, temporal variability would be exaggerated relative to spatial variability.

Despite these sources of variability, m_{opt} for all species was ≥ 2. Ralph and others (1993) recommended sampling a count station only once during a season, pointing out that if one is to make a fixed *nm* observations in a specified period, it is better statistically to count at *nm* stations than to visit *n* stations *m* times (where $m \geq 2$). Although this observation is true, it is misleading because it fails to consider cost. Unless there is no cost associated with establishing a count station, perhaps possible only if count stations have been established in a previous study, visiting 15 count stations twice will be cheaper than visiting 30 count stations once. When the cost of establishing a count station is high, as where an experimental treatment must be applied, the statistical benefit of making more visits at fewer count stations grows. Furthermore, when the number of count stations is constrained by logistics or limited potential for experimental treatments, increasing the number of visits can increase power to acceptable levels.

Buskirk and McDonald (1995), using data from point counts in a deciduous woodland in Indiana, and Smith and others (1995), using data from bottomland hardwood forests in the Mississippi alluvial valley, came to identical conclusions that three or fewer visits per season should maximize the efficiency of point counts. Using a bootstrap, the authors selected these optima to maximize the cumulative number of species detected or the cumulative number of individuals detected. Although their recommendations are similar to our overall m_{opt} of four, the agreement seems largely coincidental. Both recommendations were based on an implicit assumption that no cost was associated with establishing a count station. Furthermore, maximizing the cumulative number of species or individuals detected should have little relationship to maximizing the power to detect a specified effect on population trend for a particular species.

For a two-tailed test with a significance criterion of 0.05, sample sizes necessary to attain power = 0.8 were prohibitively large for nearly half the species in our study. Few studies that we are aware of have had anywhere near 210 to 920 count stations per treatment level. Required sample sizes were largest for the most uncommon species. This is particularly problematic, as some of these species were uncommon because they were habitat specialists. Given that habitat specialists may be more sensitive to environmental change than habitat generalists (Tellería and Santos 1995), experiments to detect environmental impacts on birds will have most difficulty meeting power requirements for species most likely to be affected.

When only declines in density are of concern, necessary sample size may be reduced by using one-tailed tests for effects. This may be appropriate when a study is focussed on only one or two sensitive species. However, if an entire avifauna is under study, both declines and increases in density are likely to be of interest. For exotic species, like the European starling (*Sturnus vulgaris*), or brood parasites, like the brown-headed cowbird (*Molothrus ater*), increases in density are as important as decreases. Required sample sizes may also be reduced by relaxing significance criteria. In conservation biology, where the cost of failing to detect an effect may be the extinction of the species in question, 0.1 may replace 0.05 as a generally accepted significance criterion.

Required sample sizes may be further reduced by accepting a lower probability of rejecting the null hypothesis when it is false (i.e., lessening power). Currently, there is no generally accepted level for the power of a test. Clearly, there is no justification for proceeding with a study if power <0.5, but at what value power becomes acceptable is unclear.

We emphasize that investigators must clearly define study goals and parameters of interest to be able to optimize design and meet power requirements. Sample sizes to meet power requirements and optimal allocation of sampling effort vary widely among species. Most studies of impacts on birds in oak woodlands will probably focus on several species, if not the entire avifauna. This complicates the optimization of sampling effort and determination of sample size. At a minimum, investigators must select a sample size that will provide adequate power for most of the species of interest. Furthermore, power analysis and optimization of sampling effort require that the investigator has defined a parameter of interest. Clearly, it is not enough to specify that counts of birds are of interest. Optimization of sampling effort will undoubtedly vary depending on whether the population parameter is the cumulative number of species detected, the number of individuals counted of a particular species, or the difference in a count between time periods. Thus, optimization of study design requires that specific parameters of interest and statistical hypothesis tests are clearly defined.

Ideally, investigators should conduct pilot studies in order to obtain the variance components necessary for preliminary power analyses. However, for almost any study it would be prohibitively expensive to collect the information necessary to evaluate the full range of possible study designs. For this reason, we think that great benefit would come from more regular publication of design evaluations after studies are completed. At least cursory design evaluations should be included in all published studies that use statistical hypothesis tests.

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References

Aigner, Paul A. 1996. **Effects of firewood harvesting on avian abundance and guild structure in a California oak-pine woodland**. Flagstaff: Northern Arizona University; 117 p. M.S. thesis.

Block, William M. 1989. **Spatial and temporal patterns of resource use by birds in California oak woodlands**. Berkeley: University of California; 364 p. Ph.D. dissertation.

Buskirk, William H.; McDonald, Jennifer L. 1995. **Comparison of point count sampling regimes for monitoring forest birds**. In: Ralph, C. John; Sauer, John R.; Droege, Sam, technical editors. Monitoring bird populations by point counts. Gen. Tech. Rep. PSW-GTR-149. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 25-34.

Cohen, Jacob. 1988. **Statistical power analysis for the behavioral sciences**. 2d ed. Hillsdale, NJ: Lawrence Erlbaum Associates; 567 p.

Dallal, Gerard E. **PC-SIZE: A program for sample size determinations** [Computer program]. 1986. 53 Beltran St., Malden, MA 02148.

deCalesta, David S. 1994. **Effect of white-tailed deer on songbirds within managed forests in Pennsylvania**. Journal of Wildlife Management 58(4): 711- 718.

Neter, John; Wasserman, William; Kutner, Michael H. 1990. **Applied linear statistical models: regression, analysis of variance, and experimental designs**. 3d ed. Homewood, IL: Irwin; 1181 p.

Norušis, Marija J. 1992. **SPSS/PC+, Advanced Statistics, Version 5.0**. Chicago, IL: SPSS Inc.; 481 p.

Osenberg, Craig W.; Schmitt, Russell J.; Holbrook, Sally J.; Kahlil, E. Abu-Saba; Flegal, A. Russell. 1994. **Detection of environmental impacts: natural variability, effect size, and power analysis**. Ecological Applications 4(1): 16-30.

Ralph, C. John; Geupel, Geoffrey R.; Pyle, Peter; Martin, Thomas E.; DeSante, David F. 1993. **Handbook of field methods for monitoring landbirds**. Gen. Tech. Rep. PSW-GTR-144. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 41 p.

Smith, Winston P.; Twedt, Daniel J.; Cooper, Robert J.; Wiedenfeld, David A.; Hamel, Paul B.; Ford, Robert P. 1995. **Sample size and allocation of effort in point count sampling of birds in bottomland hardwood forests**. In: Ralph, C. John; Sauer, John R.; Droege, Sam, technical editors. Monitoring bird populations by point counts. Gen. Tech. Rep. PSW-GTR-149. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 7-17.

Tellería, J.L.; Santos, T. 1995. **Effects of forest fragmentation on a guild of wintering passerines: the role of habitat selection**. Biological Conservation 71(1): 61-67.

Thompson, Steven K. 1992. **Sampling**. New York: John Wiley & Sons; 343 p.

University of Texas System Cancer Center. **STPLAN** [Computer program]. 1986. M.D. Anderson Hospital and Tumor Institute, Department of Biometrics, Box 237, 1515 Holcombe Blvd., Houston, TX 77030.

Verner, Jared. 1985. **Assessment of counting techniques**. Current Ornithology 2: 247-302.

Wilson, Christopher W.; Masters, Ronald E.; Bukenhofer, George A. 1995. **Breeding bird response to pine-grassland community restoration for red-cockaded woodpeckers**. Journal of Wildlife Management 59(1): 56-67.

WOOD PRODUCTS AND UTILIZATION

V

Wood Products and Utilization[1]

John R. Shelly[2]

Forests are obviously a very important asset to California, and their economic and social value to the state is well documented. Wood is perhaps one of the world's most environmentally friendly raw materials. Besides being renewable, it does not require extensive cultivation and extraction methods, and it uses less manmade energy to manufacture finished goods than most other raw materials. The timberland regions of California supply nearly 20 percent of the nation's lumber needs and are also an important supplier of pulp and composite chips. In addition, these trees are a vital component of wildlife and plant ecosystems, water quality, recreation, and esthetic needs of the state.

Not only is California a major timber-producing state, it is also the nation's leading consumer of forest products. The population, which is approaching 35 million, creates a huge demand for residential housing, furnishings, paper, and a myriad of other products made from wood. Although in the past, California produced more timber than the state needed to provide these needs, California is now a net importer of wood. Although demand is increasing, supply is decreasing. The economic conditions and timber availability concerns in the 1990's have resulted in a down-sizing of the forest products industry in California. The pressures of balancing environmental concerns with consumer needs and demands are creating a need to consider alternate sources for products. Many of these issues are found in the oak-woodland/urban-interface regions.

The trees found in woodland areas are not normally considered a viable raw material for wood products. However, trees are continually being removed from these regions and winding up in landfills or as a low-value wood product such as firewood or compost. Urban expansion and firewood harvesting are two activities that consume large quantities of wood from oak woodlands. Finding higher-value uses for these species has the potential to reduce the volume of firewood removals and provide an economic incentive to manage the woodlands for the benefit of the environmental health as well as the income needs of landowners.

In addition to the oak woodlands, there are also large quantities of wood found in the urban forests and the woody component of the urban waste stream. These have the potential to provide at least part of the raw material needs for many consumer products. This session was designed to examine what role these resources might play in the forest products industry of California.

The utilization potential of various woodland species is evaluated in two of the papers presented in the utilization session. The underlying premise of the paper by Shelly was that if trees are being harvested from woodland regions, the wood should go to the highest-value use. Utilization recommendations are provided on the basis of what is known about wood characteristics and manufacturing criteria. The concept of processing grade lumber from California black oak was further discussed in the paper by Lowell and Plank. Lumber recovery results from a portable sawmill and an intermediate-size softwood sawmill provide some of the preliminary information needed to evaluate the economic viability of processing California hardwoods.

[1] Presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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The importance of considering the urban wood components as a resource rather than as a disposal problem is opening many utilization opportunities. The paper by Pillsbury and Reimer provides a method for inventorying urban forests that will give urban communities a tool for collecting tree volume information that will aid in utilization decisions. The paper by O'Keefe reviews some of the utilization possibilities, illustrated with examples of successful ventures, and it also emphasizes the importance of technology assistance and education to achieving the goal of efficient and profitable utilization of urban residues.

Rounding out the overview of the utilization possibilities of the woodland and urban resources was a discussion of an example of managing a woodland resource for a product. The paper by Brooks provided an overview of the historical efforts of providing a domestic cork production through the cultivation of the exotic species *Quercus subra*.

In closing, the panel of speakers addressed the concerns that promoting utilization in woodland and urban environments could lead to the wholesale harvesting of trees from sensitive regions. The panel emphasized that, in many cases, utilization can be a healthy component of any resource management plan and that it is important to balance consumer needs with environmental concerns. The removal of woodland and urban trees and the volume of woody material in the urban waste stream should be considered a resource and not a disposal problem. A common goal that everyone can agree with is that any utilization of these materials should be an efficient process that aims for the highest-value use.

An Examination of the Oak Woodland as a Potential Resource for Higher-Value Wood Products[1]

John R. Shelly[2]

Abstract: *California is a leading consumer of hardwood lumber and goods manufactured from hardwoods, but less than 5 percent of the hardwood lumber used by California manufacturers is produced in California. A preliminary survey of the California hardwood lumber industry revealed a fragmented industry with many sole proprietorships and a raw-material mix ranging from timberland species to exotic trees in the urban landscape. In certain situations woodland hardwoods may be a viable resource for local needs or specialty products. On the basis of wood properties and the experience of local artisans and woodworkers, successful markets for high-value wood products are deemed possible, but special manufacturing techniques and innovative marketing strategies may be required to do it economically. A review of the available information on physical and mechanical properties of some woodland species indicates a potential for niche marketing for various wood and wood-based products.*

California, as the most populous state in the country, is a major consumer market for wood products. This market, combined with the substantial forest resource in the state, has contributed to the development of a major wood products manufacturing industry. A few recent reports give an indication of the vast size of this industry. In 1990, California manufacturers used an estimated $2.5 billion worth of wood (US Department of Commerce 1993). A 1993 survey identified 860 furniture manufacturers in California (Cohen and Goudie 1995). In 1989, an estimated 108 million board feet of hardwood lumber, or about 5 percent of the national consumption, was used by West Coast furniture manufacturers (Meyer and others 1992).

The forest resource in California is usually characterized by the 46 billion cubic feet of merchantable coniferous forests (growing stock volume) (Waddell and others 1989). However, forest inventories also reveal a sizable hardwood resource of approximately 12.5 billion cubic feet, of which approximately 29 percent is of commercial timber size (Bolsinger 1988). The combination of a large demand for hardwood lumber and a substantial hardwood resource should result in a healthy, thriving hardwood lumber industry in the state; however, it has not worked out that way. According to USDA Forest Service estimates, approximately 500,000 board feet of hardwood lumber were produced from the California hardwood resource in 1992 (Ward 1995). That is only about 0.5 percent of the manufacturing demand in the state. Clearly there is a potential for increased hardwood lumber production.

Sixty percent of the state's hardwood resource occurs in timberland regions (Bolsinger 1988). The major timberland hardwood species will undoubtedly provide most of the growth in hardwood lumber production. The remaining 40 percent of the hardwood resource occurs in the non-timberland (woodland) regions of California. In this paper the woodland species are defined as those which occur on land not capable of producing 20 cubic feet per acre per year of commercial timber (*table 1*).

[1] An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Table 1—Hardwood species commonly found in the timberland and woodland regions of California, listed by estimated volume of growing stock.[1]

Common name	Scientific name	Volume in million cubic feet: Timberland	Volume in million cubic feet: Woodland
Alder, red and white	*Alnus rubra, A. rhombifolia*	163	4
Ash, Oregon	*Fraxinus latifolia*	<1	nf[2]
Aspen	*Populus tremuloides*	20	9
Buckeye, California	*Aesculus californica*	1	24
Chinkapin, giant	*Castanopsis chrysophylla*	50	nf
Eucalyptus	*Eucalyptus* spp.	10	221
Laurel, California bay	*Umbellularia californica*	273	154
Maple, bigleaf	*Acer macrophyllum*	150	6
Madrone, pacific	*Arbutus menziesii*	1116	401
Oak, blue	*Quercus douglasii*	1	1112
Oak, California black	*Quercus kelloggii*	2254	277
Oak, California white (valley)	*Quercus lobata*	34	164
Oak, canyon live	*Quercus chrysolepis*	1302	731
Oak, coast live	*Quercus agrifolia*	126	755
Oak, interior live	*Quercus wislizeni*	45	508
Oak, engelmann	*Quercus engelmannii*	nf	10
Oak, Oregon white	*Quercus garryana*	211	389
Poplar/cottonwood	*Populus* spp.	10	32
Sycamore, western	*Platanus racemosa*	nf	<1
Tanoak	*Lithocarpus densiflorus*	1887	51
Walnut, California black	*Juglans hindsii*	1	<1
Willow	*Salix* spp.	7	6

[1] Source: *The hardwoods of California's timberlands, woodlands, and savannas* (Bolsinger 1988)
[2] nf = not normally found

The purpose of this paper is to examine the utilization potential of the woodland species.[3] Information is provided on the structure of the hardwood industry as well as the basic wood properties and manufacturing characteristics of various woodland species. An understanding of the hardwood industry in California provides the framework for analyzing the utilization potential for woodland hardwood species. Knowledge of the basic wood properties and manufacturing characteristics provides the criteria to evaluate the utilization potential of woodland species.

There is no doubt that these woodland species can be used to make a wide variety of wood products; our indigenous cultures proved that centuries ago. The ultimate question, as to whether woodland hardwoods can be used on a commercial scale, both economically and without unacceptable environmental damage to wildlife habitat and woodland ecosystems, is beyond the scope of this paper, but has been discussed by others (McDonald and Huber 1995).

[3] Portions of this discussion also appear in Shelly and others (1996).

California Hardwood Industry

The California hardwood industry consists of producers (primary manufacturers), suppliers, and secondary manufacturers of finished goods. A survey of these segments revealed a small, fragmented primary industry but mature, well-defined supplier and secondary manufacturing segments (Shelly 1996).

The producers are concentrated in northern California near the timberland hardwood resource, but 59 percent of the 22 producers surveyed also manufacture lumber from woodland species, and 5 of these mills exclusively use woodland species (*fig. 1*). The current total estimated annual production of 2 million board feet and the maximum drying capacity of 1.3 million board feet distributed amongst 22 independent producers are likely too small to compete in the West Coast hardwood commodity market of more than 100 million board feet.

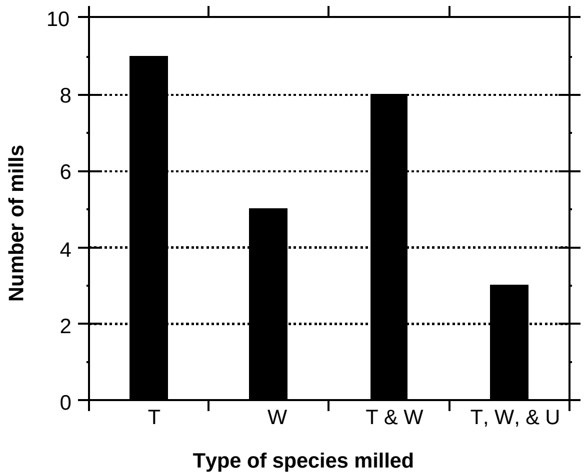

Figure 1—Type of wood processed by California hardwood sawmills. T = timberland, W = woodland, U = urban

The 25 suppliers that are familiar with native hardwood species and the 429 manufacturers in California that use hardwoods form a large commodity network that is centered around the major population centers of the San Francisco Bay Area and the Los Angeles/San Diego region (Lubin and Shelly 1995).

Potential Markets for Woodland Species

The above discussion of the hardwood resource and the industry profile indicate a sizable, underutilized hardwood resource; a large hardwood demand; and a network of hardwood lumber producers and suppliers. The question remaining is whether the 40 percent of the hardwood resource found in woodlands can be used to meet some of the demand for hardwood products. Historically, woodland species, if used at all, were used for low-value products such as firewood and fence posts (Barger and Ffolliott 1972).

Higher value uses of hardwood lumber include furniture, flooring, cabinetry, or various architectural and artistic products. Within each of these categories there is a commodity market and a niche market (Riley 1994). The commodity market demands large volumes of lumber, readily available at a competitive price and manufactured to existing industry standards as defined by the National Hardwood Lumber Association. In contrast, the niche market is more flexible because a specific product or customer is targeted and the product is tailored to the customer's needs. The demands of the commodity market effectively eliminate the possibility of any woodland species being considered. However, the flexibility of the niche market holds promise for many of the woodland species if lumber of acceptable quality can be produced.

In addition to the classic commodity and niche markets, the emerging market for products produced from wood harvested from forests certified as practicing environmentally acceptable, sustainable management has potential for California's hardwoods. Recent surveys indicate that consumers would like to be able to buy products made from wood obtained from certified, sustainably managed forests (Mater and others 1992). However, the message is mixed; it is not clear whether consumers are willing to pay more for these products.

Utilization Characteristics of Woodland Species

Tall, straight trees with few branches on the main stem are the ideal lumber tree. This description does not represent most woodland hardwood species. The spreading, highly branched tree form of most rangeland hardwoods creates numerous grain deviations, making them a low-quality timber tree by standard log- and lumber-grading rules. Grain deviations in wood, such as spiral grain, diagonal grain, or the deviation of grain around knots, are a leading cause of warped lumber. The low proportion of stem to branch wood results in a low yield of usable material. Although many of these branches may be large enough to produce lumber, branches produce poor-quality lumber. Branch wood has a high percentage of reaction wood which is highly susceptible to severe warp and collapse (Zoebel and van Buijtenen 1989).

Very little scientific research has been performed on the wood properties of most California hardwood species because of the lack of a strong commercial interest. The exceptions are California black oak (*Quercus kelloggii*), tanoak (*Lithocarpus densiflorus*), and madrone (*Arbutus menziesii*) (Niemiec and others 1995). These are primarily timberland species, but they can also be found in some woodland regions. Of all California hardwoods, these three species have the greatest utilization potential. What is known about the other woodland species is that the inherent variation in properties and the high density of most of them will make processing difficult.

Because of the limited information and the undocumented performance of wood products made from woodland species, it is difficult to predict product performance. Although machining studies have not been performed on most of these species, machining information on similar species suggests that the higher-density, fine-textured woodland species, such as the live oaks and California white oak, will machine well (Davis 1962). However, the higher frequency of knots and grain deviations in these woodland species may result in a higher percentage of surface defects than found in timberland species. Sometimes the best information available is that passed down by local woodworkers and crafts people who have experience working with these woods, and generally their comments support the contention that the higher-density hardwoods work well. The limitations discussed above do not mean that valuable products are unattainable, but rather that extra processing steps and great care are necessary.

Potential Products

While most manufactured wooden products could be made from the woodland hardwoods, some species are particularly suited for specialty products. For example, wine barrels and implement handles have very special property requirements that can be met with some of these woods. Wine barrels require an impermeable wood with tylosis in hardwood vessels and flavor components compatible with wine, features found in both California white oak or valley oak (*Quercus lobata*) and Oregon white oak (*Quercus garryana*). Implement handles require species with straight grain, high-impact bending and toughness strength properties. The required bending and toughness properties are common in most high-density rangeland hardwoods, especially the oaks. Although woodland hardwoods are generally not straight-grained, straight-grain pieces can be achieved in short lengths.

Based on wood property considerations, other categories of potential wood products can be identified. *Table 2* presents a partial list of potential products and material property requirements which can serve as a guide for identifying potential uses for woodland hardwoods. Trees can be used to make solid wood products where the wood grain and texture qualities are readily apparent, or the wood can be broken down into particles or fibers and used in this form or reconstituted into a composite product. These products have been grouped on the basis of the potential value for the raw material.

Table 2—Preferred wood characteristics important for various products.

Products	Properties
High-Value Products	
Furniture lumber	Good machining and finishing characteristics, attractive appearance
Flooring	Good machining and finishing characteristics, high hardness, dimensionally stable
Custom/artistic	Good machining and finishing characteristics, attractive appearance, interesting character
Cooperage	Low permeability, favorable flavor characteristics
Implement handles	High density and impact strength, knot free, straight grain
Moderate-Value Products	
Non-grade lumber	Moderate to high density, good machining characteristics
Landscape timbers	Natural decay resistance
Pulp or composite panels	Clean, dry chips
Chemical feedstock	Clean, dry chips
Animal bedding	Low density, clean chips
Excelsior	Low density
Cooking/flavor enhancers	Interesting aroma or flavor
Charcoal	High density
Densified fuel	Low ash content
Low-Value Products	
Firewood	High density, air-dried
Hogged fuel	No special requirements
Mulch or compost	No special requirements

Based on the information summarized in *table 2* and a knowledge of basic wood properties, it is possible to identify some possible uses for woodland species. *Table 3* is a compilation of the best available information for some woodland species, tempered by the experience of past and present woodworkers. The information in this table should be considered only a starting point for determining the viability of using particular woods for various products. Because of the inherent variation in wood properties and the small sample sizes used in many of the studies referenced, the properties may be noticeably different from location to location. When considering this information for developing new enterprises, it is important to remember that species can be matched to products on the basis of material property criteria, but the limiting factors are usually availability, size, and quality of the resource.

Manufacturing Considerations

All of the major lumber-processing steps (harvesting, milling, and drying) are important, but drying is the most critical step in producing quality hardwood lumber (Quarles 1986, Shelly 1995). As a general rule, the higher-density California hardwoods present more manufacturing difficulties than the low-density hardwoods. These difficulties must be considered in processing the

Table 3—Selected physical and mechanical properties of some California hardwoods.

Common name	Density[1] at 12 pct moisture content	Hardness[1]	Shrinkage[1]		Machinability[1]	Ease of drying[2]
			tang	radial		
	g/cm³	*lb*	*pct*			
Alder, red	0.43	620	7.3	4.4	Good	Easy
Ash, Oregon	0.61	1160	8.1	4.1	Good	Moderate
Buckeye, California[3]	<0.5	?	?	?	Fair	Easy
Chinkapin	0.50	780	7.4	4.6	Good	Easy
Eucalyptus, blue gum[4]	0.8	?	11	5	Good	Difficult
Laurel, California bay	0.62	1270	8.1	2.8	Good	Easy
Madrone	0.68	1530	11.9	5.4	Excellent	Difficult
Maple, bigleaf	0.48	850	7.1	3.7	Good	Easy
Oak, blue[3]	>0.6	?	?	?	?	Difficult
Oak, California black	0.60	1080	6.6	3.6	Good	Moderate
Oak, Calif. white (valley)[5]	0.68	1570	?	?	Good	Moderate
Oak, Engelmann[6]	>0.6	?	?	?	?	?
Oak, live [2]	>0.6	2420	9.5	5.4	?	Difficult
Oak, Oregon white	0.74	1780	9.0	4.2	Good	Difficult
Poplar/cottonwood[3]	0.38	390	8.6	3.6	Poor	Easy
Sycamore, western [3]	0.58	?	?	?	Poor	Moderate
Tanoak	0.67	1450	10.0	5.5	Good	Difficult
Walnut, California black[6]	>0.5	?	?	?	Good	Moderate
Willow[3]	0.48	?	?	?	Good	Easy

[1]Information compiled from the following references: Niemiec and others (1995); Markwardt and Wilson (1935); Davis (1962); and Schniewind (1960 a,b,c).

[2]Assessment based on information in the reference noted in footnote 1 above plus the anecdotal comments of practitioners.

[3]Estimates based on characteristics of similar species (same genus) which are reported in Markwardt and Wilson (1935), and Davis (1962).

[4] Estimated from information reported in the Australian literature, as summarized in Shelly (1991).

[5] Assessment based on information reported by Schniewind (1959).

[6] Estimated from comments in Harrar (1957).

higher-value, solid wood products. In most situations the extra effort and care required to deal with these difficulties will not pay off for most of the low- and moderate-value products. The following discussion refers specifically to high-value uses, but many of the same ideas can be applied to the lower-value uses.

The hardwood industry in the United States developed around the large diameter, high-quality trees of the Northeast and a minimum log length of 8 feet. The decreasing quality of the available resource has led to innovations in processing aimed at maximizing quality lumber production from small-diameter, low-grade trees. A basic knowledge of wood behavior and processing techniques is important to minimize the problems associated with lumber production from high-density California hardwoods.

Harvesting

It is important to recognize the utilization potential of trees before they are cut. Some trees will have very little potential and should be left in the forest or removed as firewood or other low-value product. Of the trees that are selected for removal to be processed as lumber, it is important to cut log lengths that maximize the highest quality lumber. This means cutting to lengths that maximize straight grain and minimize the presence of knots or other defects such as decay or insect damage. For woodland hardwoods this often means short log lengths of 6 feet or, if the sawmill can handle it, even 4 feet.

Milling

The goal of any sawmilling operation is to produce rectangular boards from round logs with as little waste as possible. Some of the sawing philosophies to accomplish this are discussed in this section. Although there are some major differences between these methods, two basic decisions common to all of them are a selection of a green board thickness and the grain orientation of the wide face of the board.

To maximize yield it is important to carefully select a rough/green thickness and to remove as little as possible when squaring up the round log. The rough/green thickness must take into account the amount of thickness reduction due to planing (about 0.19 inches) and the loss to shrinkage when the board is dried (about 5 percent of the green dimension). As an example, to produce a surfaced, 1-inch thick, kiln-dried board the rough/green thickness should be 1.25 inches (0.19 inches planing allowance + 0.06 inches shrinkage allowance).

Another important milling decision is to decide whether to maximize flat-sawn or quarter-sawn boards. Quarter-sawn boards are generally considered a more dimensionally stable product because they exhibit less dimensional change (shrinking or swelling) across the wide face of the board than flat-sawn boards exhibit. This is due to the fact that wood shrinks or swells about twice as much in the direction tangent to the growth rings (tangential) than it does in the direction perpendicular to the growth rings (radial). Flat-sawn boards are generally considered to exhibit a more interesting appearance than quarter-sawn boards because of the exposed grain patterns exhibited on the wide face of the board.

For certain uses, quarter-sawn material is desired. For example, in hardwood flooring, quarter-sawn stock is often desired as it will be less sensitive to dimensional changes resulting from the relative humidity fluctuations that occur in many structures. Another example is barrel staves for tight cooperage. Quarter-sawn material is less permeable because the permeable ray cells are oriented parallel to the surface of the stave and thus are not a conduit for fluid flow across the thickness of the stave.

Once a thickness and preferred grain orientation are determined, it is helpful to visualize how the boards can be cut from a log before sawing it into lumber. This is often interpreted as finding the greatest number (maximum yield) of uniformly thick, high-quality boards possible in each log. Over the years, numerous methods were developed for sawing hardwood logs, often using computer simulations (Richards and others 1980). In practice, most hardwood sawyers obtain the highest quality boards by positioning the log in such a manner that the knots will tend to be located near the edges of a board. These edge defects can then be removed by edging the lumber, resulting in a higher-quality board (Malcolm 1965). However, attempting to produce the highest lumber grades may not be the best approach. Recent studies indicate that sawing hardwood logs into three or four large cants which are then sawn into lumber results in improved recovery (less waste) (Lunstrum 1994). This lumber can be further processed by crosscutting and ripping to produce custom sizes for niche market customers, or into small clear sections that can be edge-glued into standardized furniture blanks (Reynolds and Araman 1983).

Drying

California hardwoods have a reputation for being hard to dry. However, with the proper care, good results can be obtained. Knowledge of physical properties provides a basis for predicting how wood will dry and how it will perform in service. Density is a good predictor of the ease of drying, and relative amounts of dimensional change in response to changes in wood moisture content is a good predictor of the potential for warp. Wood with a density, at 12 percent moisture content, higher than 30 lb/ft^3 is generally more difficult to dry and less dimensionally stable than wood with a lower density.

Most of the problems encountered in drying are related to stresses that develop during drying. For example, the stresses that cause lumber to warp are a direct result of the differential shrinkage in wood between the tangential (tangent to the growth rings) and radial directions (parallel to the rays). The drying defects of surface checking, collapse, honeycomb, and casehardening are also related to drying stresses.

A contributing factor to warp is the variation in the direction of the grain within a board (grain deviation). These grain deviations can be growth related, such as spiral or interlocked grain (common in many eucalyptus trees); a result of the sawing method, especially in crooked logs; or, due to the presence of knots. The high degree of grain deviation expected in most woodland hardwoods suggests that lumber cut from them would have a tendency to warp. Warp can be minimized by drying lumber in thicker dimensions and then re-sawing it, or by placing restraint on the boards to keep them flat during drying. The disadvantage of drying thicker lumber is that the technique lengthens the time to dry the lumber and increases the chance of developing other drying defects such as surface checking, collapse, honeycomb, and casehardening. If time is not a concern, this method has great potential for producing high-quality lumber. However, if time is an important consideration in the optimization of the drying process, the risk of incurring other drying defects is too great in the higher-density California hardwood species. Restraining the lumber from warping is the preferred method. Two methods for restraining the lumber are to place a 50- to 100-lb/ft^2 uniform load on the top of the lumber stack, or to keep a continuous force (equivalent to the 50- to 100-lb/ft^2 load) on the stack by using adjustable, non-metal straps (McMillen and Wengert 1978).

Collapse, honeycomb, and casehardening are drying defects that occur because stresses are created in the wood as the water leaves and the wood shrinks. Although these defects are not apparent until the wood is nearly dry, they actually begin developing very early in drying. Surface checking is a stress-related defect that actually occurs early in drying. Because these defects are developed early in drying, drying wood when the moisture content is more than 25 percent is considered the critical stage of drying. Once the average moisture content reaches about 25 percent, then more severe drying conditions can be used safely.

With a knowledge of drying principles and adequate control over the drying conditions, quality dry lumber can be produced with any drying method. If long drying times are not a concern, air drying can be an effective method for the critical drying stage, but even in an air yard the drying conditions can be too severe. Avoiding direct sun exposure on the wood and positioning lumber stacks (relative to wind direction) to increase or decrease the amount of air that passes through the lumber stack are ways to gain some control over nature's drying conditions. Ideally, the drying method should be capable of drying wood to 8 percent moisture content, achieving a temperature of 160 °F (the temperature required to sterilize insect-infested wood), and having a method to reintroduce moisture at the end of drying so that casehardened lumber can be conditioned to relieve the drying stresses. A kiln is needed to accomplish these goals.

The cost of drying is an important consideration. There are many types of drying methods available for drying wood, including air drying, solar kilns, dehumidification kilns, radio frequency units, vacuum kilns, and conventional steam-heated kilns. The equipment costs for each type of method vary greatly with radio frequency and vacuum methods generally being the most expensive. However, these units are capable of drying wood much faster than the other methods and are very effective in drying short lengths and thick stock. A thorough analysis of drying cost on an annual production basis is beyond the scope of this paper. However, in general, on a comparable volume basis, a passive solar kiln is the least expensive kiln method, but it is difficult to achieve the recommended 160 ˚F and to condition the lumber without auxiliary equipment. A dehumidification kiln is generally less expensive than a steam-heated kiln, unless an inexpensive steam source is available. Some dehumidification units have a maximum operating temperature of only 120 ˚F, but units are available that can reach 160 ˚F. A small steam generator should be added to a dehumidification kiln in order to have the ability to condition the lumber and minimize the problem of casehardened lumber. A steam-heated kiln gives you the most control over the drying conditions, but it is also the most expensive unit to purchase.

Concluding Remarks

As discussed above, on the basis of their physical and mechanical properties, many of the common hardwood consumer goods could be manufactured from woodland hardwoods. Obviously, some woods are better suited for particular products than other woods. Also, factors such as ecology concerns, resource availability, cost of production, and quality of the end product are important in determining the long-term utilization potential of woodland hardwoods.

Niche markets hold the most promise for a woodland hardwood enterprise. The commodity lumber markets demand large volumes of lumber, readily available at a competitive price and manufactured to existing industry standards. In contrast, the niche market is more flexible because a specific product or customer is targeted and the product is tailored to the customer's needs.

A key to the success of any processing enterprise is to produce products of consistent quality. For wood product operations using woodland hardwoods targeted to niche markets, this usually means that product quality needs to be defined. Once product quality is defined, in terms of moisture content, size tolerances, surface quality, etc., a method of measuring quality parameters during production should be created. Any materials not meeting the quality standards should be reprocessed to achieve desired quality or marketed as a below-grade product.

Although there are exceptions to all the above factors, availability of the resource and the associated cost of transportation are often the limiting factors, particularly for the low- and moderate-value products listed in *table 2*. Woodland hardwoods are not concentrated in high-density stands the way hardwoods are in the timberland regions which means that hauling distance to obtain an adequate supply may be too large to justify the relatively low value. A careful assessment of the resource availability and the cost of production is needed to determine the feasibility of processing woodland hardwoods.

Throughout history woodland hardwoods provided a resource for local needs. In certain situations woodland hardwoods may still be a viable resource for these local needs or specialty products. Availability and quality concerns make it unlikely that any woodland hardwoods could supply a commodity market; however, based on the properties and characteristics of the wood successful niche markets are possible. Local products made by artisans, woodworkers, and hobbyists prove that high-value products can be made. In fact, value-added products can be produced from any type of wood, but special manufacturing techniques and innovative marketing strategies may be required to do so economically.

References

Barger, R.L.; Ffolliott, P.F. 1972. **Physical characteristics and utilization of major woodland tree species in Arizona**. Res. Paper RM-83. Fort Collins, CO: Rocky Mountain Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 80 p.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas**. Resource Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Cohen, David H.; Goudie, Derek. 1995. **Profile of the California furniture industry: structure, product types, and wood use**. Forest Products Journal 45(6): 31-37.

Davis, E.M. 1962. **Machining and related characteristics of United States hardwoods**. Technical Bulletin No. 1267. Washington, DC: Forest Service, U.S. Department of Agriculture; 68 p.

Harrar, E.S. 1957. **Hough's encyclopaedia of American woods**. New York: Robert Speller and Sons.

Lubin, Dorothy Mockus; Shelly, John. 1995. **California hardwoods and non-timber forest products directory of producers and suppliers**. Richmond, CA: University of California Forest Products Laboratory; 69 p.

Lunstrum, Stanford J. 1994. **Improving recovery in sawing logs of the future**. Madison WI: Forest Products Conservation & Recycling Technology Marketing Unit, State and Private Forestry, Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 20 p.

Malcolm, F.B. 1965. **A simplified procedure for developing grade lumber from hardwood logs**. Res. Note FPL-098. Madison, WI: Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 13 p.

Markwardt, L.J.; Wilson, T.R.C. 1935. **Strength and related properties of woods grown in the United States**. Technical Bulletin No. 479. Washington, DC: Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 99 p.

Mater, J.; Mater, M. Scott; Mater, Catherine M. 1992. **Marketing forest products—gaining the competitive edge**. San Francisco: Miller Freeman, Inc.

McDonald, Philip M.; Huber, Dean W. 1995. **California's hardwood resource: managing for wildlife, water, pleasing scenery, and wood products**. Gen. Tech. Rep. PSW-GTR-154. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 23 p.

McMillen, John M.; Wengert, Eugene M. 1978. **Drying eastern hardwood lumber**. Agriculture Handbook No. 528. Washington, DC: Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 104 p.

Meyer, Christopher J.; Michael, Judd H.; Sinclair, Steven A.; Luppold, William G. 1992. **Wood material use in the U.S. wood furniture industry**. Forest Products Journal 42(5): 28-30.

Niemiec, Stanley S.; Ahrens, G.R.; Willits; S.; Hibbs; D.E. 1995. **Hardwoods of the Pacific Northwest**. Research Contribution 8. Corvallis, OR: Forest Research Laboratory, Oregon State University; 115 p.

Quarles, Stephen L. 1986. **Overview of the hardwood utilization problem**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 233-236.

Reynolds, Hugh W.; Araman, Philip A. 1983. **System 6: making frame-quality blanks from white oak thinnings**. Resource Paper NE-520. Broomall, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 9 p.

Richards, D.B.; Adkins, W.K.; Hallock, H.; Bulgrin, E.H. 1980. **Lumber values from computerized simulation of hardwood log sawing**. Res. Paper FPL-356. Madison, WI: Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 28 p.

Riley, Betty, ed. 1994. **Markets analysis and marketing strategy for California hardwoods**. Auburn, CA: Sierra Economic Development District.

Schniewind, Arno; P. Bryan, Eugene L. 1959. **Some strength and related properties of California white oak**. California Forestry and Forest Products, No. 13. Berkeley: University of California, Agriculture Experiment Station; 5 p.

Schniewind, Arno P. 1960a. **The strength and related properties of Pacific madrone, II: shrinkage and strength properties in the air-dry condition**. California Forestry and Forest Products, No. 20. Berkeley: University of California, Agriculture Experiment Station; 4 p.

Schniewind, Arno P. 1960b. **The strength and related properties of California black oak, II: shrinkage and strength properties in the air-dry condition**. California Forestry and Forest Products, No. 21. Berkeley: University of California, Agriculture Experiment Station; 4 p.

Schniewind, Arno P. 1960c. **The strength and related properties of tanoak II: shrinkage and strength in the air-dry condition**. California Forestry and Forest Products, No. 22. Berkeley: University of California, Agriculture Experiment Station; 4 p.

Shelly, John R. 1991. **Utilization of California's eucalypts**. In: Proceedings of the 1991 future of eucalyptus in California workshop; 1991 May 9; Sacramento, CA. Davis, CA: Eucalyptus Improvement Association.

Shelly, John R. 1995. **Quality processing of California's hardwoods**. In: Gray, Deborah; Lang, M.G., editors. Starting a cooperative for hardwoods and special forest products. Davis, CA. Center for Cooperatives, University of California; 32-38.

Shelly, John R. 1996. **Profile of the California hardwood lumber industry**. [These proceedings]

Shelly, John R.; Tietje, William; McCreary, Doug. 1996. **Resource evaluation for forest products.** In: Guidelines for managing California's hardwood rangelands. Publication 3368. Oakland: University of California Division of Agriculture & Natural Resources; 82-97.

U.S. Department of Commerce. 1993. **1991 annual survey of manufacturers**. Statistics for industry groups and industries, Series M91(AS)-1. Washington, DC: U.S. Department of Commerce.

Waddell, Karen L.; Oswald, Daniel D.; Powell, Douglas S. 1989. **Forest statistics of the United States, 1987**. Resource Bull. PNW-RB-168. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 106 p.

Ward, Franklin R. 1995. **California's forest products industry: 1992**. Resource Bull. PNW-RB-206. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 68 p.

Zobel, Bruce J.; van Buijtenen, J.P. 1989. **Wood variation: its causes and control**. New York: Springer-Verlag; 363 p.

California Black Oak—From Firewood to Lumber, the Lumber Recovery Story[1]

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Abstract: *Interest in use of local western hardwoods is increasing, especially among secondary manufacturers. In the case of black oak, trees have traditionally been sold for firewood, but a better economic use of this material would be to manufacture products such as furniture or flooring. Questions regarding the quality of black oak (*Quercus kelloggii*) for these products have been raised. This study sampled 140 black oak trees to determine lumber volume recovery and value recovery by tree and log grade. Two types of mills, a portable sawmill and a mill that typically saws softwoods, manufactured the lumber for this study. Volume recovery differed between mills, and differences were found between both tree and log grades in terms of value.*

As opportunities for the commercial use of the softwood resource in California become limited because of environmental pressures and land-use restrictions, there is an increased interest in the utilization potential of hardwoods. Much hardwood lumber from the eastern United States is used by manufacturers producing value-added products. Questions and concerns about the quantity of hardwoods in California and their quality for wood products have been raised. Answers to these questions are critical to developing a hardwood industry in California.

A combined effort of state and local agencies to evaluate the hardwood resource in five counties (Amador, El Dorado, Nevada, Placer, and Sierra Counties) was undertaken in 1989. The resulting publication, *Hardwood Resource, Assessment, and Management* (McCaskill 1990), examined the hardwood resources on private land in the five counties and developed a tree-grading system to describe the quality of the hardwood resource. It is estimated that the five counties contain approximately 548,000 acres of hardwood woodland or commercial timberland outside National Forests (Bolsinger 1988) and that California harvests less than 5 percent of the annual hardwood growth (Smith 1986). At that level of harvest, the volume of hardwood resource will increase, with much of the small amounts harvested going primarily for firewood, an underutilization of its economic potential.

The High Sierra Resource Conservation and Development Area Council (High Sierra RC&D) wanted to supplement this inventory information with product recovery information. Their primary interest is in California black oak (*Quercus kelloggii*) which grows abundantly on the west side of the Sierra Nevada. It is also found in the northern Coast Range of California. This species grows in a wide elevation range (400-7000 feet) and is associated with six forest cover types. Black oak is primarily found in mixed conifer stands and is not a major component of the Canyon Live Oak Type (Burns and Honkala 1990) or other oak types found at low elevations.

Godden, Stanley, and Huber (1993) selected black oak trees from one site in the Sierra Nevada and performed a lumber recovery study on logs from these trees using a portable (Mobile Dimension) sawmill. The USDA Forest Service Pacific Northwest Research Station (PNW) Timber Quality Research (TQR) Team was contacted by the High Sierra RC&D to conduct a larger scale study using trees from a broader geographic area and to observe differences in lumber

[1] An abbreviated form of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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recovery between a portable mill and a conventional sawmill. In addition to the High Sierra RC&D and PNW, cooperators for this study included USDA Forest Service Region 5, California Department of Forestry and Fire Protection, University of California Blodgett Research Forest, Sierra Pacific Industries, California Hardwood Producers Co-op, Inc. and Willits Redwood.

This study was designed to provide baseline lumber volume recovery of black oak by log diameter, analyze differences in value between tree grades, and note differences between two different types of sawmill operations.

Methods

Sample

To determine baseline recovery for black oak, the sample was designed to cover the diameter and quality (tree grade) range of merchantable black oak trees. The sampling matrix was 2-inch dbh (diameter at breast height) class (10 to 36+ inches, a total of 14 classes) by tree grades (grades 1, 2, and 3). Trees were graded according to eastern hardwood tree grades developed by Hanks (1976). A target of seven trees for each dbh class/tree grade combination was set, resulting in a desired sample size of 294 trees for the study. Limitations in the available sample made it impossible to fill all combinations. Finding large-diameter trees of lower grades proved difficult because quality of the butt log generally increases as tree diameter increases. Conversely, locating high-grade, small-diameter trees was not always possible. Minimum log diameters established by the grading rules also prevented filling some of the high-grade, small-diameter sample cells. Personnel with some experience in hardwood tree grading were asked to assist during the sampling phase of the study. The final sample included 140 trees distributed by tree grade and processing site (*table 1*).

Table 1—Tree grade and dbh (diameter at breast height) summary of the black oak study trees

	Softwood mill			Hardwood mill		
		Diameter breast height			Diameter breast height	
Tree grade	No. of trees	Range	Mean[1]	No. of trees	Range	Mean[1]
		inches			*inches*	
1	14	16 - 40	26 (1.9)	7	17 - 36	27 (2.8)
2	38	15 - 36	24 (0.9)	20	14 - 38	24 (1.5)
3	41	12 - 42	23 (1.2)	20	14 - 41	24 (1.7)

[1]Numbers in parentheses are standard errors of the mean.

Trees were sought from many ownerships whose managers were interested in the project and willing to cooperate by donating trees. Although much of the hardwood resource is found on private lands, logistics (e.g., few and scattered trees in an area or inaccessibility leading to increased harvesting and transportation costs) favored sampling from the public domain. The final sampling areas included National Forest (NF) lands (Plumas NF, Six Rivers NF, Eldorado NF), University of California Blodgett Research Forest, and Sierra Pacific Industry lands (*fig. 1*).

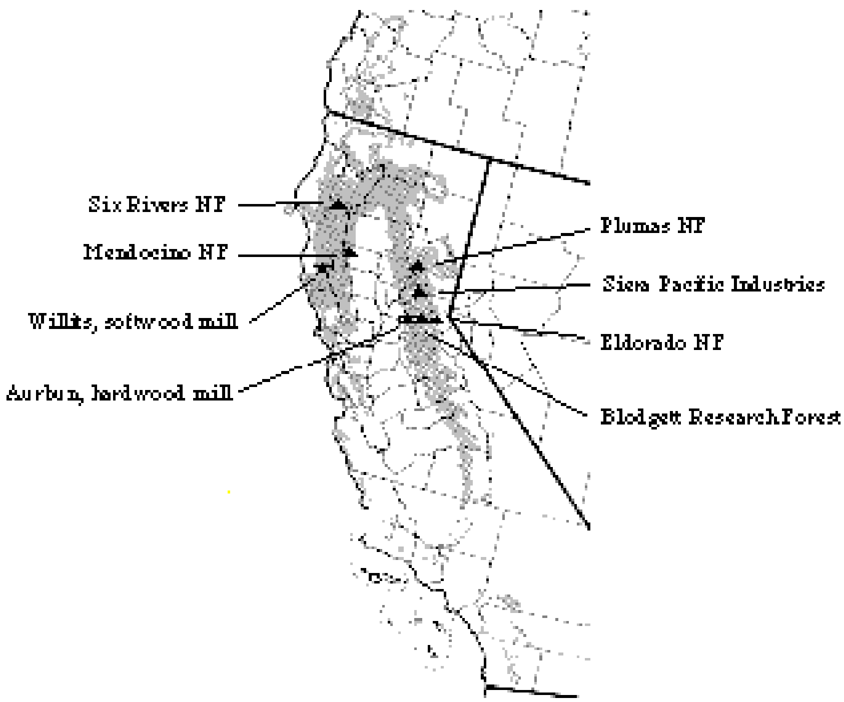

Figure 1—Geographic range of black oak with sample and mill locations identified.

Areas with large concentrations of black oak were identified by local personnel having knowledge of the resource (e.g., District timber staff, company foresters). The sample selection team visited all candidate areas recommended and then chose those that would best fill the sampling matrix. No cell in the sampling matrix was filled with trees from a single area.

Logging, Log Scaling, and Log Grading

Felling black oak requires care to minimize splits in the butt logs. Bucking decisions also influence the value of the end product (Fobes 1960). A bucking consultant worked with the loggers for 1 day to familiarize them with hardwood bucking decisions. Woods-length logs varied from tree length (for hauling purposes) to a minimum of 8 feet. Minimum top diameter was 8 inches. Each log was tagged with a number identifying the tree and its position within the tree.

Logs were hauled to the cooperating mills to be roll-out scaled (individually scaled in the mill yard) by Forest Service scalers. The official rules for the study were cubic (USDA Forest Service 1991) and eastside Scribner (USDA Forest Service 1985). Woods-length logs were bucked in the mill yard and rescaled. Mill-length logs were graded using USDA Forest Service standard grades for hardwood factory lumber logs (Rast and others 1973). *Table 2* shows grades and volumes of the final log sample. Cull logs were removed from the data set and not analyzed separately even though, in most cases, lumber was produced from them.

One-inch, random-width lumber was produced. A random sample of green lumber thicknesses and widths (to the nearest 0.001 inch) was taken. Green lumber thickness averaged 1.174 inches at the softwood mill and 1.147 inches at the hardwood mill. Widths ranged from 2 to 12 inches. Each piece of lumber was labeled to track the tree and log it was cut from. Equipment at the softwood mill included a horizontal band headrig saw, an edger, and a resaw. The hardwood mill consisted of two Wood Mizers, one Mobile Dimension saw for primary breakdown for logs larger than 30-inches, two edgers, and one resaw.

Table 2—Mill-length log sample summarizing final tally of log grades, log volume, and percent defect

Grade	No. of logs	Diameter		Gross volume	Cubic defect
		Range	Mean[1]		
		------------- *in.* --------------		*ft*^{3}	*pct*
1	20	14-32	22.4 (1.2)	685.6	13
2	113	9-37	19.9 (0.5)	3374.4	14
3	356	8-34	15.5 (0.3)	5740.9	16
Construction	36	8-29	11.8 (0.6)	321.9	29
Local use	20	7-19	10.8 (0.8)	119.1	27
Cull[2]	43	8-29	15.4 (0.9)		

[1]Numbers in parentheses are standard errors of the mean.

[2] Cull defined by Scribner Eastside rules as being less than 2/3 sound. These logs were removed from the analysis data set.

Lumber from both mills was air-dried at least 3 months to a target moisture content of 20 percent before kiln-drying. All lumber was surfaced on two sides to a thickness of 0.938 inches. Pallet stock was tallied rough green. The grade, length, and width of all other lumber were tallied after planing. Lumber was graded according to National Hardwood Lumber Association (NHLA) grading rules by an NHLA hardwood lumber grader who was hired to assist in this phase of the study.

Results

Lumber Volume Recovery

One objective of this study was to determine baseline lumber recovery volume of black oak by log diameter. Regression analysis was used to develop a model predicting volume recovery of black oak by log small-end diameter (or some transformation of diameter). The best fitting model for each set of data was selected on the basis of coefficient of determination (R^2) and standard error of the estimate. All tests were done at the 0.05 probability level.

The average cubic recovery (cubic volume of green lumber/gross cubic log volume) was the same at both the hardwood and the softwood mill, about 55 percent. However, lumber accounts for only a portion of what is produced when a log is sawn. Chips, sawdust from the headrig and edgers, and shavings from the planer are also produced. Shrinkage in drying also needs to be accounted for in recoverable volume. Cubic recovery (percent volume of components from the total volume of log) is one measure of volume recovery and is shown in *fig. 2* for the softwood mill. A statistical comparison of lumber recovery from the two mills is not possible because the same set of logs cannot be sawn at both mills. Therefore, recovery data for each mill was analyzed separately. Recovery increased with log diameter at the softwood mill (*fig. 2*) but remained constant at the hardwood mill where surfaced, dry lumber accounted for 42 percent of the volume of a log; planer shavings and shrinkage, 14 percent; sawdust, 8 percent; and chips, 36 percent.

Both mills produced boards and low-quality center cants. In addition, the softwood mill produced some double 4/4 pieces which were further broken down on their resaw. All center cants were resawn at the hardwood mill. Only 20 percent of the lumber produced at the softwood mill was in uneven widths compared to 46 percent uneven-width lumber sawn at the hardwood mill.

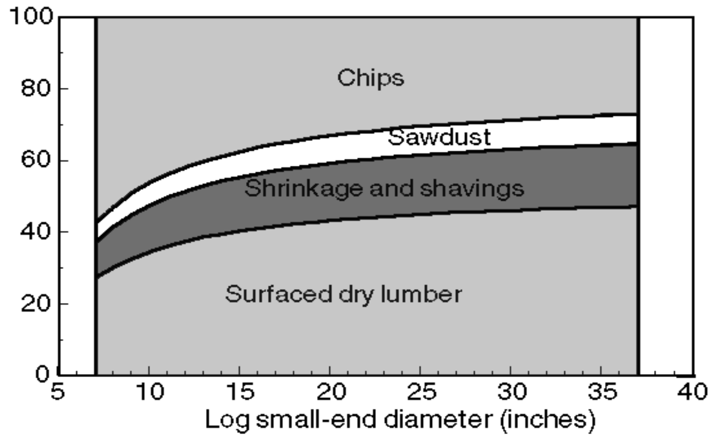

Figure 2—Regression models for cubic volume of products resulting from manufacture of lumber at the softwood mill based on log small-end diameter.

Lumber Value Recovery

Probably of most interest to landowners is not what a black oak log is worth, but rather what the value of their tree(s) is. The following value and lumber grade recovery data are presented based on tree dbh, rather than on log small-end diameter. The lumber sawn at the softwood mill was not promptly stickered and suffered some degrade from stain. Because the final lumber grade tally reflected this loss, only the sample from the hardwood mill was used to examine differences in lumber value and lumber grade recovery among tree grades.

Dollars per thousand board feet lumber tally ($/MLT) is the most meaningful monetary measure in evaluating differences in tree (or log) grades because it is the average value of all lumber produced from a tree (or log) and does not include any bias from defect estimation. The lumber volume of all logs (to a small diameter of 8 inches) from a tree was added together to get total volume of lumber sawn from each tree. Dollars per thousand board feet lumber tally is calculated by multiplying the volume in a lumber grade group by its price, summing them, and dividing the total value by the total volume of lumber produced from each tree. Results are strongly tied to the prices used (*table 3*); any change in price relation among grades would influence the results. Value is highly correlated with tree dbh because tree quality tends to increase with tree size and does not include any bias from defect estimation.

Table 3—Lumber grades and prices used in analysis

Lumber grade	Price[1]
	$/MBF[2]
Select and better	1,285
#1 Common	815
#2 Common	560
#3 Common	385

[1]Prices from Hardwood Lumber Producers Coop, Inc., Auburn, CA.
[2]$/MBF = dollars per thousand board feet

A model predicting $/MLT based on tree dbh was developed for each tree grade. A comparison of regression lines (testing for differences in slopes and intercepts) was used to determine whether there was a significant difference ($P \leq 0.05$) in value among tree grades. Resulting regression statistics are summarized in *table 4*.

Table 4—Regression equations and statistics for figures 2-5

Dependent variable	Equation[1, 2]	*P*	R^2
Cubic recovery (pct)—softwood mill	R_1 = 52.1 - (170.96 * 1/SD)	0.0001	.14
Surfaced dry lumber + shrinkage and shavings	R_2 = 71.28 - (234.03 * 1/SD)	0.0001	.14
Surfaced dry lumber + shrinkage and shavings + sawdust	R_3 = 80.44 - (262.04 * 1/SD)	0.0001	.14
Chips	R_4 = 100 - R_3		
$/MLT[3]—hardwood mill			
Tree grade 1	$/MLT = 410.24 + (12.42 * DBH)	0.0026	.86
Tree grades 2 & 3	$/MLT = 383.28 + (10.64 * DBH)	0.0001	.58
Lumber grade recovery (pct) from grade 1 trees—hardwood mill			
3 Common	R_5 = 56.85 - (1.15 * DBH)	0.0101	.76
2 Common	R_6 = 99.15 - (1.69 * DBH) - R_5	0.0032	.85
1 Common	R_7 = 111.16 - (1.30 * DBH) - R_6	0.0123	.75
Select	R_8 = 119.44 - (1.08 * DBH) - R_7	0.0161	.72
FAS[4]	R_9 = 100-R_8		
Lumber grade recovery (pct) from grade 2 and 3 trees—hardwood mill			
3 Common	R_{10} = 75.53 - (1.66 * DBH)	0.0001	.56
2 Common	R_{11} = 101.55 - (1.44 * DBH) - R_{10}	0.0001	.55
1 Common	R_{12} = 108.63 - (.87 * DBH) - R_{11}	0.0001	.46
Select	R_{13} = 108.07 - (.51 * DBH) - R_{12}	0.0001	.44
FAS[4]	R_{14} = 100 - R_{13}		

[1] SD = log small-end diameter in inches
[2] DBH = diameter breast height in inches
[3]$/MLT = dollars per thousand board feet of lumber tally
[4]FAS = First and Seconds

The effect of tree grade and dbh is shown in *fig. 3*. Diameter was significant (*table 4*) for all tree grades. There was no significant difference in the value of lumber produced from trees graded 2 and 3 as is shown by the single regression line in *fig. 3*. The value of grade 1 trees differed significantly from those graded 2 or 3.

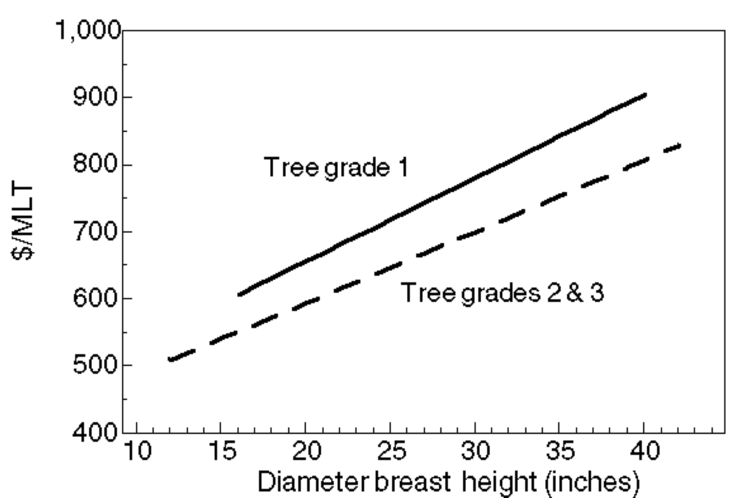

Figure 3—Difference in dollars per thousand board feet lumber tally ($/MLT) among tree grades as a function of tree diameter at breast height from the hardwood lumber mill.

Lumber Grade Recovery

Of the total 59,500 board feet of lumber sawn, 34 percent (20,000 board feet) was produced at the hardwood mill. *Figures 4* and *5* show the amount of lumber recovered in each lumber grade group. Larger amounts of higher-grade lumber come from larger-diameter trees while smaller-diameter trees tend to yield more lower-grade lumber. For Grade 1 trees (*fig. 4, table 4*), the Select and Better lumber produced ranged from about 9 percent for a 15-inch dbh tree to 36 percent in a 36-inch dbh tree. The amount of higher-grade lumber drops off in tree grades 2 and 3 (*fig. 5, table 4*) to 4 percent Select and Better in a 15-inch tree and to 25 percent in a 36-inch tree. This is the reason the value differed among tree grades.

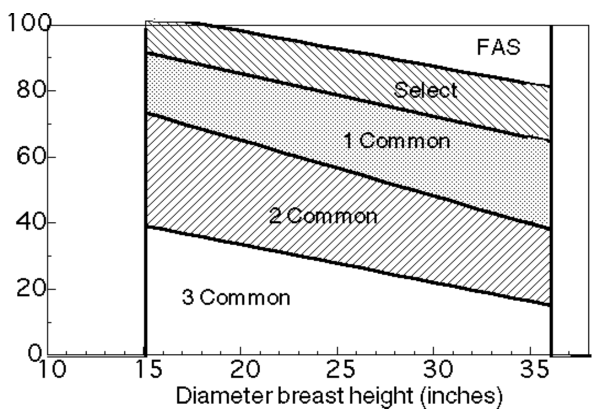

Figure 4—Cumulative percent of lumber grade recovery from the hardwood mill for tree grade 1. FAS is lumber grades First and Seconds.

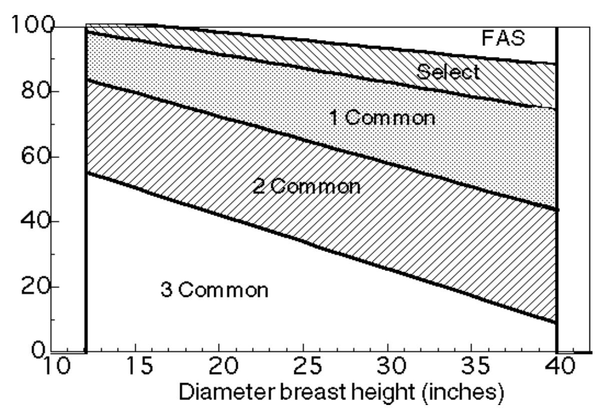

Figure 5—Cumulative percent of lumber grade recovery from the hardwood mill for trees graded 2 and 3. FAS is lumber grades First and Seconds.

Conclusions

Portable sawmills, such as the Wood Mizer, tend to be more efficient in cubic volume recovery of small-diameter logs (< 15 inches). Recovery from the larger-diameter logs appears to be similar at both types of sawmills. Average lumber volume recovery for both mills was essentially the same; however, distribution of recovery over log diameter differs.

Tree grading rules for eastern hardwood species differentiate the best trees while not seeming to make much distinction between tree grades 2 and 3 in terms of value or lumber grade recovery for the sample sawn at the hardwood mill.

Results from this study provide necessary volume and value recovery data for current and potential hardwood lumber producers such as portable sawmills or small softwood mills looking for an opportunity to diversify their product line. These data provide a basis for evaluating opportunities by small-scale operations to use a local resource, thereby enhancing the economic base of local communities.

References

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savanna.** Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Burns, Russell M.; Honkala, Barbara H., technical coordinators. 1990. **Silvics of North America.** Volume 2. Hardwoods. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture; 673 p.

Fobes, E.W. 1960. **Quality-controlled log bucking.** Forest Products Journal. 10(8): 415-418.

Godden, Randall L.; Stanley, Mark; Huber, Dean. 1993. **California black oak lumber recovery study.** Final report. 17 p. Available from: High Sierra Resource Conservation and Development Area, 251 Auburn Ravine #201, Auburn, CA.

Hanks, Leland F. 1976. **Hardwood tree grades for factory lumber.** Res. Paper NE-333. Broomall, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 81 p.

McCaskill, George L. 1990. **Hardwood resource assessment and management.** Sierra Economic Development District EDA Technical Assistance Project Number 07-06-03059; 116 p.

Rast, Everette D.; Sonderman, David L.; Gammon, Glen L. 1973. **A guide to hardwood log grading (revised).** Gen. Tech. Rep. NE-1. Upper Darby, PA: Northeastern Forest Experiment Station, Forest Service, U.S. Department of Agriculture; 31 p.

Smith, Z.G. 1986. **California hardwoods: a professional challenge to the resource community**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 1-4.

U.S. Department of Agriculture, Forest Service. 1991. **National Forest cubic scaling handbook**. FSH 2409.11a. Amend. 2409.11a-91-1. Washington, DC: U.S. Department of Agriculture, Forest Service.

U.S. Department of Agriculture, Forest Service. 1985. **National Forest log scaling handbook.** FSH 2409.11. Amend. 6. Washington, DC: U.S. Department of Agriculture, Forest Service.

Tree Volume Equations for 10 Urban Species in California[1]

Norman H. Pillsbury[2]   Jeffrey L. Reimer[2]

Abstract: *This study is the first phase of a three-phase urban forest utilization project at California Polytechnic State University, San Luis Obispo. Selected samples of 10 urban species were carefully measured in order to develop tree volume equations. These species include Chinese elm, holly oak, camphor tree, jacaranda, American sweet gum, Monterey pine, blue gum, Monterey cypress, acacia (golden wattle), and carob. Equations for species in three regions of California will ultimately be developed. The results of two regions are completed and reported here. Local and standard volume equations were developed for use by urban foresters needing to calculate tree volumes.*

Cities throughout California are facing tremendous challenges in funding and sustaining urban forestry programs. Some of the costliest operations are tree care and removal, and disposal of wood residues. Urban foresters can no longer afford to operate in a manner that treats urban forest wood residues as a costly disposal problem. Recycled uses for these wood residues could generate significant savings in handling and landfill costs, costs that are growing rapidly. Even more attractive is the prospect that these wood residues could actually generate net revenues if markets for energy and high-quality woods could be identified and developed.

In order to move urban forestry programs from the costly status quo to a more sustainable state, where wood residues are valued, a more comprehensive inventory of the urban forest is required. Many communities have developed a "street tree inventory" which typically describes the location and health condition of trees by species. Such an inventory is an important first step in understanding the composition of the urban forest. However, much more information is needed to begin managing the urban forest in a sustainable fashion.

For an inventory to serve as a management tool, it should describe the structure, composition and "volumes" of the urban forest with reasonable accuracy. To achieve these results, data must be collected on tree size (i.e., diameter at breast height and total height), and age (date planted) in addition to species, location, and health or damage rating. Data on maintenance activities, costs, and timing would make the inventory even more useful. Because developing such comprehensive inventories requires a considerable investment in time and resources, standardized methods are needed to assist urban foresters in data collection, analysis, and inventory assessment.

Overview of Goals of the Urban Forest Utilization Project

This section is presented for the reader to understand how this study fits into the multi-year Urban Forest Utilization project and its role in enhancing the sustainability of urban forests. The goal of this project is to conduct a series of volume and utilization studies of the major urban forest species to further the

[1]A modified version of this paper was presented as a video ("Cal Poly Urban Forest Utilization Project") at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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development of management inventories in each California city for the purpose of promoting sustainable urban forests. To accomplish this goal, the project has been broken down into three phases:

- **Phase I** - Development of Tree Volume Predictions - The first phase involves biometric studies to enable the urban forester to predict the volume of various tree species for the future sustainable urban forests (Pillsbury and Thompson 1995). Detailed measurements are made of sample trees in order to create a statistical model for each predetermined species. Volume prediction equations are developed. It is this phase that is presented in this report. Results of Phases II and III will be reported separately.

- **Phase II** - Development of Community Forest Inventories - Using the prediction models from Phase I, cities can expand their current *street tree inventory* and begin to create a *management inventory*. Collecting data on tree diameter in addition to data on species, location, planting date, and tree condition is all that is necessary for estimating total inventory. Other data on maintenance activities, tree heights, useful life, growth rate, value, and product utilization are needed to create a *comprehensive inventory*. A comprehensive inventory can be used to manage by rotation and develop product and sustainable budgets (see Phase III).

- **Phase III** - Information Management for Budgeting and Product Development - As urban forest management inventories are established, a whole range of management functions can be enhanced and new opportunities explored. Cities can use such inventories to design the urban forest to normalize its species composition and structure; better plan and organize planting, care, trimming and removal activities; and establish new uses and markets for the regularized flows of wood residues. Combined with a GIS database, new ways of integrating the urban forest into the city infrastructure and interacting with the public can be developed.

Study Design and Criteria

As discussed earlier, the objective of this study is to develop equations that can be used to predict or estimate tree volume for urban forest species from various geographical regions and communities in California. The following sampling design was used to develop prediction equations for urban forest species in California.

Selecting Communities with Urban Forestry Programs

California was first divided into three broad geographic regions: Southland, Coastal, and the Central Valley (*fig. 1*). The rationale for this initial stratification is to ensure that species selected represent major climatic conditions found in the State.

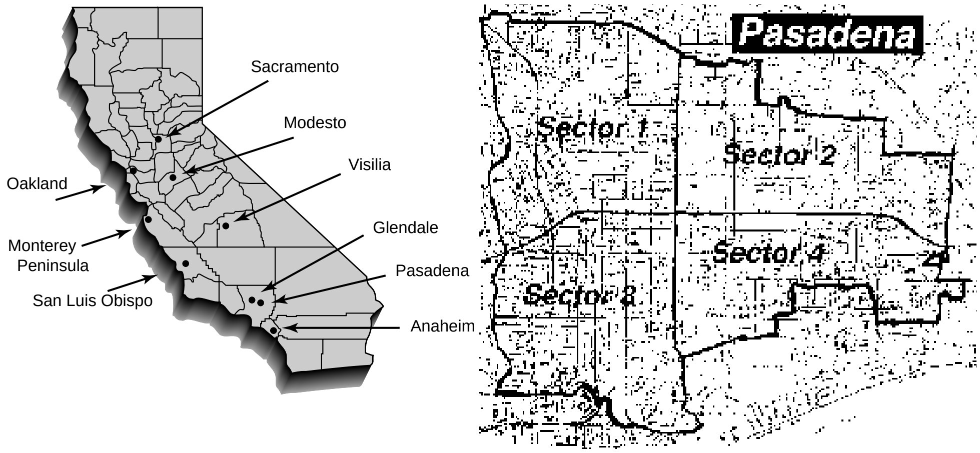

Figure 1—Cities studied for volume table development of urban forest species.

Three communities in each geographic region were identified that could benefit from an evaluation of the volume potential of their urban forest. Communities were selected on the basis of the following criteria:

1. The community must have an active urban forestry program. The program must be prominently visible in the cities' organizational structure and have an identified urban forester in charge.
2. The urban forestry program must be able to demonstrate a commitment to long-term urban forest development and be on the road to sustainability. The four core elements of sustainability are: species selection and diversity, inventory and landscape planning, tree care and wood utilization, and public relations and support. For more information on sustainability, see *The Elements of Sustainability in Urban Forestry* by Thompson and others (1994).
3. The community must at least have the beginnings of a street tree inventory. The inventory must be computer-based and accessible for future studies discussed in Phase II, Development of Community Forest Inventories.
4. Within each geographic area of the State, urban foresters must agree on the species that will be sampled.
5. Communities having large, old trees that are facing removal in the next 5-10 years were favored because prediction equations would be more relevant in the near term.

Communities selected for study are shown below:

Region	*Community*	*Year of sample*
Southland	Anaheim	1994
	Glendale	1994
	Pasadena	1994
Coastal	San Luis Obispo	1995
	Monterey Peninsula	1995
	Oakland	1995
Central Valley	Modesto	1996
	Sacramento	1996
	Visalia	1996

Clearly many other communities could be included in the sample, and as the need and support arise, they can be added. The intent here is to provide specific information on selected communities from different parts of California rather than intensively sample in one or two cities. It is our hope that the value of these results will encourage equation development of additional species in the same or other communities. However, the information collected for the communities that were sampled will allow "preliminary" estimates of volume for other cities as well.

Species Selection

Five species in each geographic region were selected for study. Species were selected on the basis of the following criteria:

1. Species had to be well represented in each community of the geographic region. This was evaluated by urban foresters and from street tree inventories.
2. Trees marked for removal in the next decade were given higher priority. We decided that the prediction equations developed in this study should represent species most likely to be harvested in the near future, rather than species recently planted that will not be removed soon.
3. Species that attain larger sizes were favored in the selection process, as they provide greater volumes for use and represent greater savings of disposal costs.
4. Species were favored for selection that were of higher wood quality and value.
5. Five species were selected from each geographic region with the restriction that species not be duplicated among regions to increase the number of trees evaluated.
6. Species were ranked lower on the list if equations were available from other studies, even if the studies did not include trees from an urban environment. An example of this is coast live oak (*Quercus agrifolia*) which has been reported in several publications, including Pillsbury and Kirkley (1984).

The selection process involved much discussion among the authors and urban foresters from these communities, and many additional species were considered. The species selected, by geographic region, are as follows:

Region	*Species*	
Southland	Chinese elm	*Ulmus parvifolia chinensis*
	Holly oak	*Quercus ilex*
	Camphor tree	*Cinnamomum camphora*
	Jacaranda	*Jacaranda mimosifolia*
	American sweet gum	*Liquidambar styraciflua*
Coastal	Monterey pine	*Pinus radiata*
	Blue gum	*Eucalyptus globulus*
	Monterey cypress	*Cupressus macrocarpa*
	Acacia (golden wattle)	*Acacia longifolia*
	Carob	*Ceratonia siliqua*
Central Valley	Japanese zelkova	*Zelkova serrata*
	Southern magnolia	*Magnolia grandiflora*
	London plane	*Platanus acerifolia*
	Chinese pistache	*Pistacia chinensis*
	Modesto ash	*Fraxinus velutina* 'Modesto'

Procedures and Data Collection Methods

Sample Size

In similar volume studies [3] we found that a sample size of approximately 50 trees is the minimum number necessary to develop a statistically reliable estimate of the equation parameters. Based on these studies, a sample size of 50 trees per species was adopted.

[3]Full citations are provided in the References: Pillsbury 1994, Pillsbury and Pryor 1994, Pillsbury and Hermosilla 1993, Pillsbury and Pryor 1992, De Lasaux and Pillsbury 1988, Pillsbury and Pryor 1989, Pillsbury and others 1989, and Pillsbury and Kirkley 1984.

Geographic Stratification

Each geographic area is represented by three cities or communities, and the number of sample trees per species was proportioned among their urban forests. To further make certain that the sample design fully represents the geographic area, each community was stratified into three to five sectors of approximately equal area (in communities where species were widely spread), and trees were sampled equally among sectors. This design, illustrated in *fig. 1* for the City of Pasadena, ensured that all sectors were sampled with similar intensity.

Diameter Distribution

In addition to sample size and geographic stratification concerns, trees must be at least 5.0 inches dbh (diameter at breast height) and 15 feet tall to be included in the sample. Because volume is closely correlated to tree diameter, an accounting of diameters was kept. As trees were measured, their diameters were plotted on a d-line (diameter line). This was an easy method to be certain that the full range of tree sizes of each species was represented. In addition, we checked each sector carefully to be sure that representatives of the largest trees were included in the sample.

Tree Data Collected

The data collected for each sample tree are summarized in *table 1*. The variables collected are listed and discussed below.

Species

The common name was recorded on the data form. Trees having major defects, unusually large damaged areas, or that were abnormally shaped or pruned were not included in the sample.

Diameter at Breast Height

Diameters are used in volume equation development. Diameter at breast height outside bark (dbhob) was measured with a diameter tape at a point 4.5 feet above the ground on the uphill side. If the tree was leaning, the 4.5 feet were measured along the central stem axis. For trees that forked at breast height or lower, the tree was considered to be two trees; however, trees of this type were not included in the sample, unless otherwise noted. If forking occurred just above breast height, a single dbh measurement was made below joint swelling. This means that dbh measurements could vary anywhere from about 2 to 6 feet on the stem, although almost all measurements were at 4.5 feet. It is important that use of the equations presented later in this report follow these "rules" for greatest accuracy.

Diameter Outside Bark at 1 Foot

Diameter outside bark (dob) was also measured at 1 foot to compute the volume of the base segment. If butt swell was present, the measurement was taken where the tree taper was normal, usually no higher than 2 feet. A diameter tape was used.

Table 1—Data collected from urban tree species.

Characteristic	Units	Description	Used in development of equations by the authors	Data the urban forester will collect
A. Tree Information*:*				
Species	Code	A = Acacia (Golden wattle) BG = Blue gum C = Carob CA = Camphor CE = Chinese elm HO = Holly oak JA = Jacaranda LA = Liquidambar MC = Monterey cypress MP = Monterey pine M = Southern magnolia MA = Modesto ash CP = Chinese pistache LP = London plane Z = Japanese zelkova	Yes	Yes
Dbh	Inches	Diameter at breast height, to the nearest 0.1 inch.	Yes	Yes
Dob at 1 foot	Inches	Diameter to the nearest 0.1 inch.	Yes	No
Total height	Feet	Estimated total height to top of terminal leader.	Yes	Yes
Average crown diameter	Feet	Average of long and short axis, to the nearest foot.	Yes	No
Number and average length of terminal branches	No., Feet	Count of the number of terminal branches; average length determined by measuring a sample for average of long and short axis.	Yes	No
B. Tree Identification Information*:*				
Date	n/a	Date of field measurement.	Yes	Yes
Photo number	n/a	Roll number and photo number.	Yes	No
Tree location and tree number	n/a	Located by street address. If more than one tree at the same address, trees were numbered in the direction of increasing address numbers.	Yes	Yes

Total Height

Total tree height was measured from the tree base on the uphill side to the tip or tallest live portion of the crown. Heights of leaning trees were calculated using the vertical height to the tree tip and the angle of the bole. Heights are used in volume equation development. An example is shown in *figure 2a*.

Average Crown Diameter

Crown diameter was determined by averaging measurements of the long axis with a diameter taken at 90 degrees. Readings were taken with a 100-foot cloth tape. Data can be used to correlate with tree volume.

Number and Length of Terminal Branches

Terminal branches, 4 inches in diameter at the large end, were included in the calculation of tree volume. For each sample tree, 5 or 6 terminal branches were measured for length. In all cases, lengths were consistent within 2-3 feet, and an average was obtained. The total number of terminal branches was counted for each sample tree.

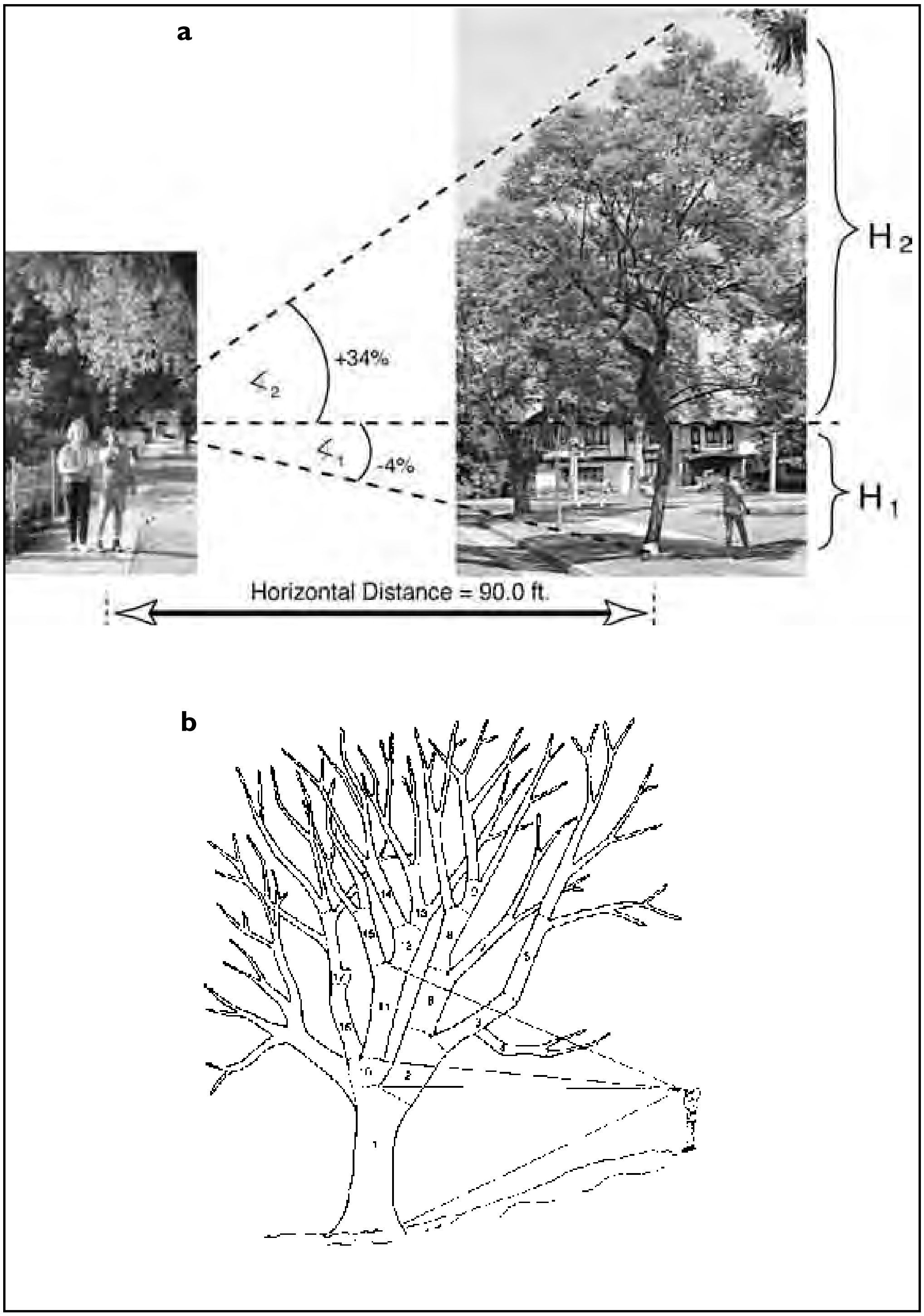

Figure 2—Tree height and segment measurement. (a) The use of Standard Volume equations (or tables) requires total tree height. A clinometer or abney can be used to measure the vertical angle to the tree top and base. For this example, total tree height ($H_1 + H_2$) is: ((4+34)x90)/100 = 34.2 ft. (b) Sample trees were measured on a segment-by-segment basis to determine volume. Numbers on tree indicate tree segments.

Tree Location and Number

Trees were located by house and street address. If more than one tree was growing at an address, the trees were numbered sequentially following the direction of house numbers.

Photo and Sketch

Each tree was photographed with a 35-mm camera using slide film. A placard was held to identify the tree. Also, as the segment data were collected, a sketch was drawn showing the relative location of each segment. This information was used for illustration and in a few cases when field notes were unclear.

Tree Volume Calculation

Any level of use or management involving the cutting and removal of urban trees requires that accurate volume prediction equations be used. Volume equations can be used to determine tree removal volume, inventory, and for growth and yield studies. Reliable estimates of urban tree volume depend, in part, on the accuracy of the equations developed. Also, they are more reliable within the geographic area from which the field data were collected; the greater the distance from the collection area, the less reliable.

For volume measurement, the branching pattern was defined on a segment basis. Segment length and the diameters at each end were measured using a Spiegel Relaskop (Pillsbury and Kirkley 1984). Segment length was determined from coordinates measured at both ends of each segment. Each tree was divided into segments based on four criteria:

1. Segments were defined as the distance from fork to fork in trees with very complex branching pattern, such as segment 11 in *fig. 2b*.
2. If a branch had a sweep or crook, segments were measured to obtain a straight log length such as in segments 3 and 5.
3. Segments were defined if abrupt changes in taper were apparent such as in segments 16 and 17.
4. If a tree had an excurrent growth form, such as liquidambar, the maximum segment length measured was approximately 10 feet.

If swelling was present on the stem, a common occurrence, relaskop diameter readings were taken slightly above or below the abnormality. A two-step process was used for branches not growing vertically. First the vertical distance between the ends was calculated on the basis of relaskop coordinates. Secondly, an angle, to the nearest 1 degree from horizontal, was measured with a clinometer, and segment length was computed. Segments growing less than 30 degrees from horizontal were measured by projecting their length to the ground and measuring it with a cloth tape held parallel to the branch angle.

Cubic foot volume was calculated for each tree using three equations for determining the cubic volume of a solid. The stump (base segment) was treated as a cylinder (equation 1), the tip was treated as a cone (equation 2), and the remaining segments were treated as a paraboloid frustrum, and Smalian's formula was used (equation 3).

$$V_1 = A_u L \quad [1]$$

$$V_2 = \frac{L}{3}\left(A_b\right) \quad [2]$$

$$V_3 = \frac{L}{2}\left(A_u + A_b\right) \quad [3]$$

where:
V = volume outside bark in cubic feet to 0-inch top,
A_b = cross-sectional area outside bark at base in square feet,
A_u = cross-sectional area outside bark at top in square feet, and,
L = length of segment in feet.

Utilization Standards

Total tree volume includes the volume of all stem segments from ground level including terminal branches and bark. It does not include the volume of roots and foliage. A spreadsheet formulated in Microsoft Excel®[4] was developed to calculate individual tree volumes using Equations 1-3. Because markets for urban wood are limited, it is not known what branch or stem size will be needed by existing and developing wood manufacturing industries. For example, some companies might be equipped to handle large diameter, 8-foot bolts, while others may operate in the small mulching market. In order to provide estimates for a variety of uses, the spreadsheet was created to calculate wood volume in the following diameter size classes: less than 4 inches, 4-8 inches, 8-12 inches, 12-16 inches, 16-20 inches, greater than 20 inches as well as total volume. The average diameter of each segment was used to determine its diameter class. Further, these size classes were set as variables and can be changed to obtain volume proportions based on different diameter groupings. For instance, if one were interested in firewood potential, the volumes of all segments in the 4- to 8-inch and 8- to 12-inch diameter classes would be combined. Based on field measurements, the average percent volume for the segment diameter classes discussed above are shown in *figure 3*.

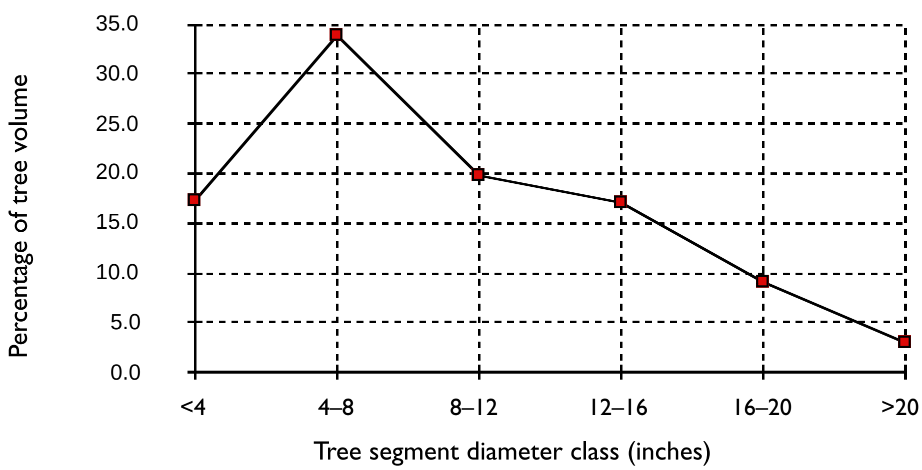

Figure 3—Approximate percentage of tree volume by diameter class for holly oak.

Volume Equations

Two types of equations are commonly used to predict tree volume, local and standard volume equations. Local volume equations use one variable, diameter at breast height (dbh), to estimate tree volume, while a standard volume equation uses both dbh and height. Including height in the equation generally provides a better estimate as it helps account for soil, climate, and some cultural variations. Because not all street tree inventories include height, both types of equations are presented here to provide flexibility for the user.

The relationship between volume and dbh and height is a power function that can be linearized as described by equations 4 and 5.

$$V = b_0 (\text{Dbh})^{b_1} \quad [4]$$

$$V = b_0 (\text{DBH})^{b_1} (\text{Ht.})^{b_2} \quad [5]$$

where:

V = volume outside bark in cubic ft,

Dbh = diameter outside bark at breast-height in inches,

Ht. = total tree height in feet, and,

b_i = regression coefficients.

Simple and multiple regression analysis (equations 4 and 5, respectively) were used to develop the volume prediction equations (*table 2*). A logarithmic transformation of volume, dbh, and height was used to linearize the data and to equalize the variation about the regression line. The data were converted to the logarithmic form to compute the regression coefficients b_0, b_1, and b_2. This is the normal procedure when fitting nonlinear tree volume equations because the logarithmic forms tend to reduce variance in homogeneous samples (Husch and others 1982).

Table 2—Local and standard volume equations for selected urban forest species

Species	Local Volume Equation	Adj. R^2	*n*	SE	Avg pct deviation	Pct aggregate difference
Blue gum	Vol (cf) = 0.055113 ($dbh^{2.436970}$)	0.968	50	1.27	18.6	0.6
Acacia	Vol (cf) = 0.048490 ($dbh^{2.347250}$)	0.938	50	1.24	15.8	-3.0
Monterey pine	Vol (cf) = 0.019874 ($dbh^{2.666079}$)	0.969	50	1.27	18.9	-1.7
Monterey cypress	Vol (cf) = 0.035598 ($dbh^{2.495263}$)	0.980	50	1.23	15.7	1.9
Carob	Vol (cf) = 0.066256 ($dbh^{2.128861}$)	0.910	50	1.29	18.9	-2.3
Camphor	Vol (cf) = 0.031449 ($dbh^{2.534660}$)	0.970	50	1.17	12.5	-1.2
Chinese elm	Vol (cf) = 0.028530 ($dbh^{2.639347}$)	0.903	50	1.22	16.6	-2.3
Holly oak	Vol (cf) = 0.025169 ($dbh^{2.607285}$)	0.938	50	1.24	17.0	-1.3
Jacaranda	Vol (cf) = 0.036147 ($dbh^{2.486248}$)	0.949	49	1.19	13.9	0.0
Liquidambar	Vol (cf) = 0.030684 ($dbh^{2.560469}$)	0.979	50	1.15	10.5	-0.5
Species	**Standard Volume Equation**	**Adj. R^2**	***n***	**SE**	**Avg pct deviation**	**Pct aggregate difference**
Blue gum	Vol (cf) =0.003089 ($dbh^{2.151822}$)($ht^{0.835731}$)	0.983	50	1.19	10.9	-1.0
Acacia	Vol (cf) = 0.014058 ($dbh^{2.186485}$)($ht^{0.467357}$)	0.976	50	1.14	14.5	-2.7
Monterey pine	Vol (cf) = 0.005325 ($dbh^{2.226808}$)($ht^{0.668993}$)	0.979	50	1.22	16.0	-1.1
Monterey cypress	Vol (cf) = 0.005764 ($dbh^{2.260353}$)($ht^{0.630129}$)	0.989	50	1.16	11.9	2.2
Carob	Vol (cf) = 0.008573 ($dbh^{1.795854}$)($ht^{0.926668}$)	0.933	50	1.24	17.8	-1.4
Camphor	Vol (cf) = 0.009817 ($dbh^{2.134803}$)($ht^{0.634042}$)	0.976	50	1.15	10.9	-1.3
Chinese elm	Vol (cf) = 0.010456 ($dbh^{2.324812}$)($ht^{0.493171}$)	0.915	50	1.21	14.8	-1.9
Holly oak	Vol (cf) = 0.004307 ($dbh^{1.821580}$)($ht^{1.062691}$)	0.976	50	1.15	10.4	0.3
Jacaranda	Vol (cf) = 0.011312 ($dbh^{2.185780}$)($ht^{0.548045}$)	0.956	49	1.17	12.7	0.1
Liquidambar	Vol (cf) = 0.011773 ($dbh^{2.315815}$)($ht^{0.415711}$)	0.982	50	1.13	9.2	-0.6

Note: For an explanation of terms used here, see the discussion in the text.

Tests of Equation Fit, Reliability, and Measures of Accuracy

There is no one measure of the adequacy of volume equations. We examined several of the more common tests to determine the overall fit and reliability of the equations. In *table 2*, several statistics are provided that help the reader understand the relative precision of the relationships that have been developed. *Standard Error of the Estimate* (SE) is the abbreviation used in these tables for this measure of reliability. The standard error of the estimate indicates, in volume units, the error associated with the mean volume of each species. *Average Percentage Deviation* measures the extent to which the individual observations of sample tree volume deviate from the regression surface. This percentage gives an idea of the amount by which any single calculated value (or value read from a volume table) will vary from the actual value. *Percent Aggregate Difference* is the percent difference between the sum of the predicted and the sum of the actual volumes for a given sample.

Error and Outlier Analysis

Concurrent with the development of the prediction equations, the data were carefully checked to determine whether measurement or recording errors were present. We developed computer programs to identify possible errors in diameter, height, and tree segment data. Tree volumes were checked by examining the standardized residual calculated for each tree. Even if a tree showed an unusual relationship between the dbh and height values and volume, the tree was checked against the sketch and photograph for legitimacy. After all checks were performed, only one tree was removed from the data set on the basis of these tests.

Other Measures

In addition to the reliability tests previously discussed, several other tests were conducted. These included analysis of the *F*-value, the root mean squared error (another measure of the residual variation), and plots of residuals to check for nonlinearity and nonconstant error variance. In no case did we find reason to believe a problem in the database existed.

Limitations of Equations

It must be emphasized that the measures of reliability and accuracy presented above pertain only to the accuracy of the equations in the context of the data used in their construction. Despite the efforts of the authors to develop and implement a sound sampling design and to carefully evaluate the results, there is still no guarantee that these equations and tables will always apply equally well to an independent sample. However, past experience has shown that equations developed by these rigorous measures will perform well, usually within 10-12 percent, if field procedures follow the methods outlined in this report. When a more accurate estimate is required, say in the case of sale or purchase of standing trees, the equations (or tables) should be checked against the measured volumes of a representative sample of trees obtained from the area of interest.

Volume equations will best represent the communities where the data were originally collected. To apply the equations in a different portion of the State runs the risk of unacceptable errors (Pillsbury and others 1995). The question of "how well will they do" in a new environment cannot be answered without additional study. Often equations are used out of their geographic area simply because they are the "best" equations available. Clearly the user takes the responsibility for the results.

Of the two types of equations presented, generally the standard volume equations (using both dbh and height) are considered more accurate, as the height variable adds more precision to the estimate. However, in the case of trees that have been recently topped, the correlation of dbh and height to volume will have been significantly altered. In this situation, the local volume equation (use of dbh only) may provide a better volume estimate.

Lastly, trees were not included in the sample when, through extensive trimming, the crown was virtually decimated or when trees were topped. Two options are possible for measuring trees cultured this way. First, the equations can be used, although error is introduced. Fortunately trees of this condition are infrequent and, if they are small, will represent little volume having little effect on the overall estimate. Secondly, the main stem diameter can be obtained by measuring what appears to be the average diameter. The stem height can be measured or approximated. To estimate its cubic-foot volume, use the equation [6] for a cylinder.

$$Volume = 0.005454D^2H \qquad [6]$$

where D is the average stem diameter in inches and H is the stem height (or length) in feet.

Application of Equations to an Independent Inventory

The following discussion outlines the steps necessary to conduct a field inventory for volume and an estimate for trees scheduled for removal from your urban forest.

Your field crews have input inventory data on street trees that show that 200 trees are scheduled for removal in the northeast part of your community during the next 3 years. The species involved are those for which equations have been developed.

Rather than cut and haul the wood to the landfill over a 3-year period, you decide to contact two area-wide hardwood manufacturers and obtain bids on the wood. This strategy, in addition to providing revenue for your urban forestry program, will also reduce the time frame to one summer and relieve the extra burden from your fully committed crews. You and the purchasers agree to sell the wood based on a measure of the cut trees; however, to provide a reasonable estimate of cubic foot quantity available for the bid, you perform the following steps.

1. Field verification: A quick verification of the information in your street tree inventory is needed. A crew is dispatched to check and update the database for location, species, and diameter, and if time is available, for total tree height. Field equipment needed are a diameter tape, clinometer, and a 100 foot tape. A written notice is left on the nearest premise advising residents of the project.
2. Diameter and height should be measured in accordance with the methods discussed in Procedures and Data Collection Methods section. The data should be kept separate by species.
3. Calculations: Use local or standard volume equations to estimate tree volumes. An example of how to obtain tree volume estimates for the equations and tables is presented here.

Use of Volume Equations

A holly oak was measured and found to have a 13.4-inch dbh and a total height of 30.5 feet. Substitute your data into the standard volume equation for holly oak from *table 2*, as follows:

1. Vol (cf) = $0.004307\ (dbh^{1.821580})\ \ (ht^{1.062691})$
2. Vol (cf) = $0.004307\ (13.4^{1.821580})\ (30.5^{1.062691})$ = 18.4 cubic feet

If height data were not collected, be sure to use the local volume equation (from *table* 2), as follows:

1. Vol (cf) = 0.025169 (dbh $^{2.607285}$)
2. Vol (cf) = 0.025169 (13.4 $^{2.607285}$) = 21.9 cubic feet.

This approach is greatly simplified by setting up a spreadsheet with the regression coefficients referenced as absolute and the tree data referenced as relative.

Use of Volume Tables

Volume tables are normally arranged in diameter classes of 1 or 2 inches and height classes of 5 or 10 feet. Two options are possible, depending on your need. To obtain a rough volume estimate, you can either round diameter and height data to the nearest diameter and height class, respectively, or double interpolate the table to eliminate rounding error. Regardless of the method used, the process is repeated for each tree until finished. Next, volume estimates are summed by species, and again for all species. The proportion of volume by segment diameter can be estimated. An example for holly oak is shown in *figure 3*.

Concluding Remarks

As communities strive for sustainability of their urban forestry programs, increased attention must be paid to the wood resource of the urban forest. To manage for these values, comprehensive inventories and databases are needed. A new level of sophistication and commitment is necessary to build these inventories and to make use of them to further the program's goals.

The urban forester must be capable of properly measuring specific characteristics of a tree such as diameter, height, and age in order to use them in calculating the typical managerial measures (e.g., basal area, volume, and growth rates). These measures can then be combined with other quantitative and qualitative measures such as species, location, health and vigor rating, expected life, and past treatments to establish a database which will form the foundation for wood marketing, policymaking, and public relations activities.

Practicing urban foresters may have already had education and training in forest inventory as part of their bachelor's degree. However, the nuances of measuring native and exotic species in open-grown settings influenced by urbanization require special knowledge and training that is not typical of most forest measurement and inventory course work. To acquire the field and analytical skills needed for this work, urban foresters may need to continue their education through short courses, workshops, and field demonstrations. These continuing education experiences will also facilitate better networking between practicing urban foresters on a broad range of issues, concerns, and potential solutions.

Although considerable resources must be committed to designing and maintaining these comprehensive urban forest inventories, long-term benefits including a healthy urban forest that is both biologically and economically sound will more than justify the expense through improved forest management, regular maintenance, and new funding sources. It is these types of outcomes that the urban forester can point to as evidence of sustainable management.

References

De Lasaux, M.J.; Pillsbury, N.H. 1988. **Young-growth sierra redwood volume equations for Mountain Home Demonstration State Forest.** San Luis Obispo, CA: Natural Resources Management Department, California Polytechnic State University; 77 p.

Husch, B.; Miller C.; Beers, T. 1982. **Forest mensuration.** 3d ed. New York: John Wiley and Sons; 402 p.

Pillsbury, N.H. 1994. **Aspen inventory, assessment, and management on the Kern Plateau, Sequoia National Forest.** (USDA-Forest Service, Porterville, CA.) San Luis Obispo, CA: Natural Resources Management Department, California Polytechnic State University; 551 p.

Pillsbury, N.H.; Hermosilla, D.R. 1993. **Biomass farm demonstration project; 1992 measurements.** San Luis Obispo, CA: Natural Resources Management Department, California Polytechnic State University; 230 p.

Pillsbury, N.H.; Kirkley, M.L. 1984. **Equations for total, wood, and saw-log volume for thirteen California hardwoods.** Res. Note PNW-414. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 52 p.

Pillsbury, N.; McDonald, P.; Simon, V. 1995. **Reliability of tanoak volume equations when applied to different areas.** Western Journal of Applied Forestry 10(2): 1-7.

Pillsbury, N.H.; Pryor, R.D. 1989. **Volume equations for young growth softwood and hardwood species at Boggs Mountain Demonstration State Forest.** San Luis Obispo, CA: Natural Resources Management Department, California Polytechnic State University; 100 p.

Pillsbury, N.H.; Pryor, R.D. 1992. **Volume equations for young growth softwood and hardwood species at Boggs Mountain Demonstration State Forest.** California State Forest Note. Sacramento: California Department of Forestry and Fire Protection; 8 p.

Pillsbury, N.H.; Pryor, R.D. 1994. **Volume equations for canyon live oak in the San Bernardino Mountains of southern California.** Western Journal of Applied Forestry 9(2): 46-51.

Pillsbury, N.H.; Standiford, R.; Costello, L.; Rhoades, T.; Regan (Banducci), P. 1989. **Wood volume equations for central coast blue gum (*Eucalyptus globulus*).** California Agriculture 43(6): 13-14.

Pillsbury, N.H.; Thompson, R, 1995. **Tree volume equations for fifteen urban species in California. Interim Report.** San Luis Obispo, CA: California Polytechnic State University, Urban Forest Ecosystems Institute; 45 p.

Thompson, R.; Pillsbury, N.; Hanna, J. 1994. **The elements of sustainability in urban forestry.** Tech. Rept. No. 1. San Luis Obispo, CA: California Polytechnic State University, Urban Forest Ecosystems Institute; 56 p.

A Literature Review of California Domestic Cork Production[1]

William H. Brooks[2]

Abstract: *As early as 1858 there were attempts by the federal government to assess the potential of developing domestic cork production in the United States. Between 1939 and 1949 cork oak (*Quercus suber *L.) seedlings were distributed to cooperators in more than 30 California counties to assess the possibility of relieving this nation's dependence on foreign production of the raw material. Information collected from earlier field trials supports the contention that this renewable raw material can be produced in California. This paper briefly reviews earlier work but concentrates on a more recent analysis of domestic cork development on the Central California Coast.*

During 1993, the Central Coast Resource Conservation and Development (RC&D) Council was awarded funds from USDA Soil Conservation Service (now Natural Resources Conservation Service) and the California Department of Forestry and Fire Protection (Rural Forest Improvement Program). These funds were targeted to further explore the literature and the potential of domestic production of cork from cork oak (*Quercus suber* L.). The RC&D Council contracted with Professor James E. Wilen, Department of Agricultural Economics, University of California, Davis. Dr. Wilen and his students conducted an extensive review of literature accessible through the University of California system. Except where otherwise noted, this review paper is largely abstracted from the study they conducted to examine factors that might determine the feasibility of culturing cork oak trees and products from cork oak.

Early Use of Cork

Cork has been a useful product for at least 2,000 years of written history. The Greek botanist Theophrastus referred to cork bark stripping in the fourth century B.C. Pliny, the Elder, in his *Naturales Historia* describes its bark as "extremely thick and which when cut grows again and is used chiefly for ships' anchor drag ropes and fishermen's drag nets and for the bungs of casks and also to make soles for women's winter shoes." Cork has been used as an insulating material for several centuries. According to Cooke (1961), early monasteries used cork on walls and ceilings to insulate from heat. Inhabitants of cork-growing regions used cork slabs for roofing materials.

The greatest stimulation to expansion of the cork industry began with the broad use of glass bottles in the 17th century. The widespread use of stoppers for glass bottles capitalized on cork's resistance to deterioration and its high coefficient of friction.

The botanist John Bartram observed a cork oak tree near Charleston, South Carolina in 1765, and Thomas Jefferson started plantings of cork oak in 1787. During 1858, the U.S. Patent Department bought a limited quantity of seed. From this effort some cork oak seedlings were started in the southeastern states and California. Most of these seedlings died from lack of proper care. In 1880, more acorns were obtained and distributed to many places in the southern states, Arizona, and California. From 1913 to 1931, the U.S. Bureau of Plant Industry distributed cork oak seedlings to selected locations in San Francisco and Central

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and Southern California. From 1930 to 1941, the average distribution was 260 trees per year to these locations. In 1941, Professor Woodbridge Metcalf (University of California) joined with Charles McManus (President, Crown Cork and Seal Company, Baltimore, Md.) in a project to develop plantations throughout California "to add to the natural resources of our country and to provide in the United States a source for at least a part of the nation's cork requirement."

Before World War II, all cork used in the United States was imported from Portugal, Spain, France, Italy, and northern Africa. Status of supplies, perilously close to the European conflict, were termed "critical." In 1941, 15,000 cork oak seedlings were planted by cooperators in 37 California counties. In 1942, 50,000 seedlings were planted. During 1943-44, in cooperation with the USDA Forest Service and the Spanish Ministry of Agriculture, cork oak acorns were imported from Spain, French Morocco, and Algiers and distributed in 20 states.

An important discovery in the early 1900's led to composition cork, a significant step toward the utilization of the large amount of waste byproduct which had begun to accumulate. Composition cork was first produced by grinding and screening cork pieces and then binding them together with small amounts of adhesive and heat. Such products include washers, gaskets, and oil seals.

Today, cork is still the only material used for high-quality champagne and wine bottle stoppers although the industry has been considering synthetic substitutes for years. The list of uses also includes insulation, sound absorption, sporting goods, and bottle caps.

Acorns are a source of nutrition for such wildlife species as bear (*Ursus americanus*), deer (*Odocoileus hemionus*), and quail (*Callipepla californica*) in California. In Portugal, as an agroforestry practice, the large cork oak acorns are fed to hogs and are available at a time when annual grasses are at their lowest nutritional value. Acorn-fed hogs are especially favored in Italy. The factors that made acorns a major source of food in California for indigenous peoples in the past make them attractive candidates for greater use in the future (Bainbridge 1987).

The evergreen foliage of the cork oak provides shade, and the tree has significant landscape and windbreak attributes. Pruned cork oak tree branches or bark also provide a highly desirable media for growing orchids and other epiphytes. Commercial orchid growers say it is possible to use a variety of tree barks or branches, but the most popular is cork bark. It has a rough, attractive appearance, the orchid roots can get a good grip, and it is long-lasting. Good prices are offered for cork oak prunings.

Developing Domestic Sources

Since the 1800's there has been periodic interest in developing domestic sources of cork in California. Cork oak trees are hardy in a wide range of Mediterranean conditions found in California, including land not well suited to other uses such as agriculture. The most important sources of literature in English on cork, with a focus on the United States, came out of the interest generated during World War II as part of the McManus Project mentioned earlier.

The McManus Project had several objectives:

1. To study growth characteristics of the tree and the quality of cork using existing trees in the United States. Results can be found in Metcalf's (1947) The *Cork Oak Tree in California.* Metcalf concluded that cork oak production was feasible in several locations with

Mediterranean climate and that the quality of North American grown cork was equal to that from Europe.

2. To examine areas of potential production feasibility in the U.S., Victor Ryan (1948), Crown Cork and Seal Co., studied the economic and geographic aspects of cork production. He concluded that conditions were close to the Mediterranean ideal in California and were generally favorable in parts of 27 other states.
3. To launch a planting project with the intent of increasing the potential cork production from domestic sources.

Historically and presently, the world's production of cork has been dominated by Spain and Portugal. In 1990, the two countries together produced 88 percent of the world's exports of natural cork. Cork oak makes up 22 percent of Portugal's forests (40 percent of the world's cork forests), 60 percent of the world's cork production, and 80 percent of the world's production of cork stoppers (Wilen 1993a). According to Lisbon's Agronomy Institute, the soil fungus *Phytophthora cinnamoni*, the blight which also attacks eucalyptus (*Eucalyptus* spp.) trees, has decimated up to 20 percent of Portugal's cork oaks, aided by years of "excessive bark stripping, neglect, poor forest management and prolonged drought" (Smith 1993).

Wilen (1993a) summarizes world production by stating that while both raw cork and the stopper business are still dominated by Portugal and Spain, important changes are occurring in both countries. He notes that while the value of Portugal's exports has doubled, its market share of total exports has dropped from 60 percent to 40 percent since 1970 (*table 1*). During the same period, Spain's exports of cork have risen 10 fold. This is explained in part by noting that Portugal has become a more important user of raw cork in bottle-stopper production and consequently imports more raw material from Spain. Another trend is towards modernization of a process which for many years discouraged good management practices by tenant farmers. This in turn means that Portugal and Spain are becoming more efficient and competitive in the world market, producing a product which is of better quality and probably cheaper in real terms. The price of raw cork has increased from the equivalent of about 9 cents a pound in 1982 to about 50 cents a pound in 1993 (Smith 1993). Smith also reported that as much as 30 percent of a $31 million reforestation program

Table 1—Imports and exports of cork as a percentage of the total world value.[1]

	Exports		Imports			
Year	Spain	Portugal	United States	Portugal	France	Italy
1990	48.4	39.5	7.4	35.6	9.5	10.2
1989	44.4	40.8	10.7	31.9	7.1	9.1
1988	47.0	39.8	10.8	31.6	7.6	10.8
1987	46.4	41.9	10.5	26.8	6.8	16.3
1986	38.9	49.6	12.0	17.9	5.6	19.6
1985	34.6	54.1	14.1	13.8	5.7	14.6
1984	34.9	53.9	15.8	17.7	5.1	11.5
1983	30.4	59.4	13.5	8.3	6.8	13.7
1982	29.5	57.7	10.4	19.5	7.9	10.7
1981	32.7	56.2	10.1	21.9	7.8	8.6
1980	37.2	51.7	6.5	23.7	10.4	14.2
1975	22.3	57.7				
1973	17.2	59.8	10.9	2.3	8.6	5.7
1970	16.0	58.3	12.2	-	7.4	5.0

[1]Source: After Wilen 1993a

funded by the European Community and the Portuguese government should find its way into cork oak farmers' pockets over the next 10 years as incentives to plant more cork oak.

The U.S. market for cork products is primarily one dominated by raw cork and by cork bottle stoppers. Raw cork is a low-value product that is further processed into a variety of value-added cork products, mostly on the east coast. Such products include linoleum products, apparel, and cork and rubber composition products. Cork stoppers are much valued and supply the wine industry on the west coast.

Cork Oak Growth in California

Wilen (1993a) reviewed two major studies completed in the 1940's which assessed potential growth success in California. The available evidence on the success of growing cork oak trees on the Central California Coast is conclusive over a wide range within the region. Murray and Munns (1943) concluded that the Bay Area (100 miles south of San Francisco to about 30 miles north) confined to the rather narrow belt along the coast was among the five best areas in the State. Other areas were in the southwest of the State, the Russian River area, the Sierra Nevada foothills, and northwestern parts of the State. Cork oak does best in deep gravelly or sandy soils that are of granitic origin. The tree also does well in sandy loams or rocky soils with moderate acidity. Ryan (1948) found that most cork oak grew in areas with soils characterized as "brown steppe" soils. These have a zone of accumulated lime or other alkaline substances just below the surface. Ryan's study was comprehensive in bringing together soil, rainfall, and temperature data. Both studies conclude that California has several regions capable of supporting cork oak. These include, but are not limited to, a large part of the Central Coast Region.

Cork Production in California

Professor Wilen's basic strategy was to put together a cost-benefit approach to forecasting the present value of a cork oak forest started from scratch. This meant combining the best information available on tree growth, harvest values, and costs. The problem is complicated because little information is available on very basic parameters such as optimal spacing, optimal timing of harvests, and other plantation information. Mediterranean cork production takes place mostly in natural forests rather than plantations. Harvesting therefore takes place in an irregular manner depending upon the natural distribution of trees. There is little current information about what plantation configuration should be used to maximize profitability. Wilen and his students use the best available data to compute the economic potential of a cork oak plantation in California, using "averages" as best data, rather than best cases, in order to provide a conservative assessment of possibilities. Further study of foreign sources and of raw data reported in existing sources would probably have allowed the determination of more precise estimates.

The primary source of information on cork yield as a function of tree age for California comes from Metcalf (1947) and is derived from his study of about 500 oaks that were stripped in California during the 1940's. The Metcalf estimates of production form the bases for Ryan's quantitative study (1948) of cork potential in the United States which also included estimates of regional cork yield rates in California. The highest cork yield rate is in the northwestern, high-rainfall area around Eureka, with estimated rates between 1.2 and 1.6 percent per year. The lowest projected rates are in the warmer valley areas, the southeastern desert area, and the coastal area south of Monterey to Los Angeles with rates less than 0.8 percent per year. San Francisco Bay area, North Bay, and the Sierra Nevada foothills are projected to have cork yield rates between 0.8 to 1.2 percent.

Wilen reminds us that slow yield rates are not undesirable. Ryan noted in his study that "the finest textured and highest quality cork" comes from Spain and Portugal which have the slowest rates of yield in the Mediterranean region, namely 0.8 and 0.9 percent, respectively. Slow yield results in finer-textured cork with cell structures that are dense and hence suitable for the higher-valued products such as champagne and wine corks.

Densities of around 130 trees per acre are suggested (Natividade 1950) in a forest of trees about 50 years old. A technical planting guide prepared for the Central Coast RC&D Council by Ron Adams (1994) suggests an initial planting of 10 feet by 10 feet (435 trees/acre) with final growing space rogued to no closer than 20 feet by 20 feet between trees (109 trees/acre) when trees are 6 inches or more in diameter.

Yield per acre was computed assuming that density is adjusted in an optimal manner that keeps the canopy maximized. Using Ryan's regional yield rate ranges, Wilen presents yield data which show yield per acre highest where actual cork growth is lowest *(table 2)*. This occurs because the reduction in density needed to compensate for faster tree growth is greater than the corresponding increase in yield per tree. Both cork quality and quantity (pounds per acre) are inversely related to the regional rate of cork yield. Those areas with slowest cork growth, like the coastal areas south of Monterey to Los Angeles, appear to be the best on both accounts.

Table 2—Cork yields per acre for various growth rates.[1]

Stand age	Cork yield rates as a percentage of annual cork yield. 0.8	0.8 -1.2	1.2 -1.5
	lb/yr/acre		
20	83.52	55.34	41.70
30	132.35	87.70	66.09
40	264.10	175.00	131.80
50	324.25	214.85	161.90
60	425.50	281.90	212.40
70	584.70	387.35	292.90
80	831.60	550.90	415.10
90	1,216.00	805.60	607.00
100	1,811.00	1,200.00	904.10

[1]Modified from Wilen 1993a

Natividade (1950) concludes that mature groves (50 to 60 years old) might be able to produce as much as 320 to 366 pounds per year/acre but that only in groves with very old trees could one ever expect production as high as 460 pounds per year/acre. Wilen concludes that production levels of 340 pounds per year/acre are possible in California. This may be optimistic given what we know about data from actual plantations, or it may be pessimistic given that so little information exists about silvicultural practices under plantation conditions.

In a follow-up study, Wilen (1993b) reexamined the Metcalf data in order to assess subsequent uses of it by Ryan and others and in order to re-estimate the potential for cork production in California. The yield estimates computed by Ryan as potential for California are much larger (more than 1000 pounds per year/acre) than any actual experience in any of the major cork-growing areas of the world. Natividade (1950) cites several studies that place estimates of reasonable production from mature forests close to 350 pounds per year/acre.

Metcalf apparently did not do any statistical analysis of the raw data derived from the World War II experimental stripping of trees from various places around California. Wilen extracted raw data on 300 trees from the Metcalf paper. A yield model for the Metcalf data was developed with the aim of examining more precisely what data reveal about real cork growth in California. The estimation Ryan derived based on Metcalf's tentative estimates overpredicts the weight/age relationship. Wilen and his students derive the same relationship on the basis of more careful statistical analysis of the original Metcalf data. The degree of overprediction by Ryan almost doubles those weight/age relationships derived by Wilen. Wilen also notes Metcalf's conclusion that if trees "were stripped every 8 to 10 years beginning at about 20 years, it seems likely that the resultant stimulation may increase the estimated yield" in the data presented "by one and one half to two times." Most studies by cork experts reviewed during Wilen's study now believe that stripping traumatizes cork trees rather than stimulating them.

The issue critical to the feasibility question in California is how much could be produced under optimal conditions of soils, climate, early-period care, and spacing. Wilen concludes it is likely that production potential is higher than his study estimates (340 pounds/year/acre), but it is not clear by how much.

With a planting guide (Adams 1994) having been developed, the Central Coast RC&D Council is now seeking to establish provenance trials on selected sites within the central coast to further examine the social, economic, and environmental compatibility of the place cork oak may have in California.

References

Adams, Ronald S. 1994. **Cork oak provenance trials on the central California coast: a technical guide.** Morro Bay, CA: Central Coast Resource Conservation and Development Council; 56 p.

Bainbridge, David A. 1987. **The use of acorns for food in California: past, present, future.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 453- 458.

Cooke, Giles B. 1961. **Cork and the cork tree.** New York: Pergamon Press.

Metcalf, Woodbridge. 1947. **The cork oak tree in California.** Economic Botany 1(1): 26-46.

Murray, M.A.; Munns, E.N. 1943. **Possibilities of cork oak in the Americas.** Chronica Botanica 7(2).

Natividade, J. Vieira. 1950. **Subericultura**. Lisbon: Ministerio da Economia. (translated into Spanish and published by El Ministerio de Agricultura, Pesca Y Alimentacion, Madrid, 1992).

Ryan, Victor A. 1948. **Some geographic and economic aspects of cork oak.** Baltimore, MD: Crown Cork and Seal Company, Ltd.

Smith, Tony. 1993. **Natural enemies drying up Portugal cork crop.** The Los Angeles Times July 20,1993. Environment.

Wilen, James E. 1993a. **A production, processing, and marketing assessment of domestic cork development on the central California coast.** Davis: University of California; 58 p.

Wilen, James E. 1993b. **An econometric investigation of potential cork yield in California.** Davis: University of California; 20 p.

URBAN FORESTRY INTERFACE ISSUES

VI

California Oaks in the Urbanizing Forest Ecosystem[1]

Rowan A. Rowntree[2]

Among a growing number of planners, managers, and researchers, it is now popular to view individual genera and species in terms of the way they function in changing ecosystems. Of all the tree genera in California, *Quercus* is the one most subjected to ecosystem change due to urbanization. Understanding the consequences for oaks begins with documentation of species composition change with urbanization (McBride and Jacobs 1986). From this description comes an understanding of functional changes such as shifts in water and chemical flux, fire, and disease processes. Our broader understanding of ecosystem change, in return, helps us to know whether, and how, we can sustain certain elements of that ecosystem such as native oaks. Thinking systemically about the future of California oaks at large spatial and temporal scales helps us to see the problem in cumulative terms.

The Landscape Scale: Projecting the Consequences of Future Settlement

The efforts of researchers and planners are helping us to see the changing future geography of oaks in California. The Sierra Nevada Ecosystem Project tells us that the foothill oak woodland is the most endangered forest type in the Sierra Nevada because of projected rapid urbanization in the Central Valley and Sierra Nevada foothills (Sierra Nevada Ecosystem Project 1996). Population in the Sierra Nevada will minimally triple (from approximately 700,000 today) in the next 40 years, and that growth will be focused on oak lands. Many Sierra counties will soon have the ability to produce maps that show where future development will threaten oaks. However, these maps are not a part of the normal county planning process and have been produced for only a few central westside Sierra Nevada counties by independent researchers (Duane 1996, Greenwood and Marose, 1993, Rowntree and others 1993). With the improved use of geographic information systems and better vegetation maps, groups and individuals involved in the planning process at several scales should soon be able to understand, and act upon, the large-scale and long-term projections for oak loss. To sustain an oak canopy within urbanized woodlands, we must protect existing pre-settlement oaks and provide conditions that will encourage new oaks to grow and survive in the evolving urban fabric.

The Community Scale: Preservation and Restoration of Oaks in the Expanding Urban Fabric

Pre-settlement oaks are still found in communities 125-140 years after the onset of urbanization. In Menlo Park, California, McBride and Jacobs (1975) found that, while oak density had dropped during urbanization from 142 to 3 trees/

[1] Presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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acre, oaks continued to reproduce in untended portions of gardens and undeveloped sites within the urban area. Compared with older cities such as Menlo Park, recently developed Sierra Nevada foothill communities tend to have greater densities of surviving pre-settlement oaks (McBride and others 1996). These oaks are a mixture of trees that survived the short-lived urbanization associated with the Gold Rush and second growth trees that date from the 1850's through the early 1900's. If modern techniques of tree protection are followed, many of the second-growth oaks in these communities could potentially live for another 150 years or more. If development occurs in the absence of adequate tree-protection measures, many existing oaks are likely to decline or die within 10 to 50 years (Swiecki 1996).

In Oakland, California, native oaks are the second-most important tree with 13 percent of the basal area (*Eucalyptus globulus* is the most important) (Nowak 1991). These oaks are not just in the relict wildlands lying within the city. Native oaks are the most important tree (as measured by basal area) in the institutional land use category (e.g., parks and educational institutions), and the second-most important tree (as measured by amount of crown cover) in the residential land use category. In Sacramento County, native oaks comprise 27 percent of the total tree basal area, but these trees lie mainly outside the urbanized area (McPherson 1996). In order to keep oaks as a visible component of the urban forest, the city and county of Sacramento passed resolutions a decade ago that require 20 percent of the plantings receiving city or county funds to be native oaks.

Thinking about Oaks in Urban-Influenced Ecosystems

One obvious tenet of ecosystem thinking requires that we expect, and plan for, change. We have learned this from the problems of pre-settlement oaks succumbing in urban irrigated landscapes.

Fire in the interface has raised the question about oaks as fuel and as elements of vegetated firebreaks. We have not yet learned enough about the part oaks played in the 1991 Oakland Hills fire and in the post-fire regeneration and restoration. There is speculation that oaks are less flammable under most fire conditions. Many homeowners now would like to know if a well-maintained mature oak next to their structure can be considered a reasonable landscape element in a fire-prone area.

In the wildland portion of the interface, how may we manage oak woodlands to reduce the possibility that (1) ignitions in the oak zone will not have the chance to develop into serious fires, and (2) active fires moving into an oak zone will diminish in flame length, rate of combustion, and rate of ember production? A useful approach for selecting the correct vegetation structure for both fire control and ecosystem biodiversity is to conduct computer modeling of fire behavior for different vegetation structures (Stephens 1996).

The ecosystem approach does not imply that oaks will be neglected or eliminated for some higher system purpose. The approach will encourage us to understand how the multiple forces that come with urbanization interact to govern both the ecological history and the future of this genus.

Acknowledgments

I am grateful to Ted Swiecki and Joe McBride for conducting this session in my absence and for making improvements in this overview. Maureen Davis was invaluable during the planning and editorial phases of the symposium.

References

Duane, Timothy P. 1996. **Human settlement.** In: Sierra Nevada Ecosystem Project, final report to Congress, vol. II, Assessments and scientific basis of management options. Davis: University of California, Centers for Water and Wildland Resources; 235-360.

Greenwood, G.; Marose, R. 1993. **GIS tools for the assessment of land use impacts on biodiversity.** Sacramento: California Department of Forestry and Fire Protection, Strategic Resources Planning.

McBride, Joe; Jacobs, Diana. 1975. **Urban forest development: a case study, Menlo Park, California.** Urban Ecology 2: 1-14.

McBride, Joe R.; Jacobs, Diana F. 1986. **Presettlement forest structure as a factor in urban forest development.** Urban Ecology 9: 245-266.

McBride, J.R.; Russell,W.; Kloss, S. 1996. **Impact of human settlement of forest composition and structure.** In: Sierra Nevada Ecosystem Project, final report to Congress, vol. II, Assessments and scientific basis of management options. Davis: University of California, Centers for Water and Wildland Resources; 1193-1202.

McPherson, E. Gregory. 1996. **Structure and replacement of the Sacramento urban forest.** Unpublished draft supplied by author.

Nowak, David J. 1991. **Urban forest development and structure: analysis of Oakland, California.** Berkeley: University of California; 232 p. Ph.D. dissertation.

Rowntree, Rowan A.; Greenwood, Gregory; Marose, Robin. 1993. **Land use development and forest ecosystems: linking research and management in the Central Sierra.** In: Ewert, A.W.; Chavez, D.J.; Magill, A.W., eds. Culture, conflict, and communication in the wildland-urban interface. San Francisco: Westview Press; 389-398.

Sierra Nevada Ecosystem Project. 1996. **Sierra Nevada Ecosystem Project, final report to Congress, vol I, Assessment summaries and management strategies.** Davis: University of California, Centers for Water and Wildland Resources; 209 p.

Stephens, Scott L., Research Fire Ecologist, Pacific Southwest Research Station, USDA Forest Service, Albany, CA. [Personal communication with Rowan Rowntree]. 12 June 1996.

Swiecki, Ted, Principal, Phytosphere Research, Vacaville, CA. [Personal communication with Rowan Rowntree]. 13 September 1996.

Using Population Distribution Forecasts and GIS Technology to Assess Potential Hardwood Loss in the Northern Sacramento Valley[1]

Charles W. Nelson[2] Mark Radabaugh[3]

Abstract: *Since its inception, The Northern Sacramento Valley Sustainable Landscapes Project (SLP) has focused on facilitating discussions on long-term management of the extensive oak woodland landscape. The SLP is using geographical information system (GIS) technology to begin a spatial assessment of present and future population patterns. With a GIS, models depicting potential buildout based on current land use and growth projections can be developed. These models can be used as a visual tool to help planners, decision makers, and the interested public to examine potential impacts, initiate discussion, and to formulate workable growth strategies in the oak woodland interface.*

Since early 1994, The Northern Sacramento Valley Sustainable Landscapes Project (SLP) has focused on facilitating informed discussions between public policy makers and resource stakeholders, including the general public, on long-term management of the extensive oak woodland landscape *(fig. 1)*.[4] As part of its goal to develop an acceptable framework for discussing issues related to sustainability, the SLP has chosen to use geographical information system (GIS) technology. By incorporating county and city land-use plans and other relevant information into a GIS, it is possible to begin a spatial assessment of present and future population patterns.

Figure 1—Northern California Sustainable Landscape counties

[1]An abbreviated form of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, California. Base information and data for this paper are the result of research conducted by the junior author and are described in a report by Radabaugh (1995).

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[4]The Northern Sacramento Valley Sustainable Landscape Project includes Butte, Colusa, Glenn, Shasta and Tehama Counties. These five counties contain approximately 7 percent of California's land area. Oak woodlands cover approximately 21 percent of the landscape in the five county region and the region accounts for approximately 14 percent of the state's oak woodland inventory based on Pillsbury (1991).

Like most of California's inland valleys, the population of the northern Sacramento Valley is forecast to more than double by the year 2040 (California Department of Finance 1993). Population growth in the region typically takes the form of low density development (averaging 1 to 3 dwelling units per acre) within the planning areas of incorporated cities. In addition, rural residential lots of 1 to 40 acres per dwelling unit develop around farming communities and in oak woodland and timbered landscapes. Although incorporated cities contain some of the lowest urban densities found in California, this region nonetheless contains extensive acreage of rural residential development.

A doubling of population in the region is expected within the next 20 years. This implies that additional land in the region will be placed under development pressure for urban and rural residential uses. If this pattern of lower-density urban development and extensive rural residential development is projected past the 15- to 20-year time frames of local area plans, it is clear that significant oak woodland acreage will be affected.

Methods

A review of past and present population patterns and growth trends in the five-county SLP region resulted in series of GIS coverages depicting future land use and population density (Radabaugh 1995). Land-use polygons were identified, and population distribution forecasts were made on the basis of key factors, including

- An estimate of existing population based on the 1990 Census, county assessors records, and other data;
- An estimate of population buildout potential described in terms of average density; and
- The estimated average annual population growth rate to be expected within each polygon.

Paper maps of each of the five counties were prepared and digitized using one of five general land-use categories. These categories included

- *Incorporated city spheres of influence* or areas specifically designated for future urban growth and expansion,
- *Unincorporated communities* where water and/or sewer services are provided and residential buildout density is less than one dwelling unit per acre,
- *Rural residential lands* where buildout density is between 1 and 40 acres per dwelling unit and resource production from the parcel is not the primary land use. It is generally located on agricultural, grazing and range, and timber-producing land;
- *Agricultural lands,* which were divided into small-scale agriculture (less than 20 acres per dwelling unit) and large-scale agriculture (greater than 20 acres); and
- *Other resource-producing lands* including lands used for grazing, timber production, mining, wildlife habitat, and open space. Resource lands were divided into foothill rural and timber. Acreages are greater than 40 acres per dwelling unit.

For the purposes of assessing impacts in the oak woodland interface, the first three categories were considered sensitive to population change. As more information like riparian data along the Sacramento River and its tributaries become available, impacts in Valley Oak areas along the river can be added as well.

Information from data collection was digitized using ArcInfo software, a GIS product developed by Environmental Systems Research Institute (ESRI) in

Redlands, California. ESRI desktop GIS software, ArcView, was used for plotting maps and for statistical analysis.

Butte County Demonstration

Butte County is the most populous of the five-county SLP area. It is estimated that 83 percent of its 1995 population resides within one of five city sphere-of- influence planning areas. The Chico sphere accounted for 44 percent of the County's 1995 population, but only slightly greater than half that population lived within the incorporated territory. Population growth in Butte County's urban areas has steadily increased relative to non-urban areas since the mid-1970's.

Although Butte County contains the region's largest urban area population, the population of its unincorporated community centers and towns is the smallest of the five-county area because of limited community water provisions and/or sewers in unincorporated non-urban areas. Nonetheless, Butte County has the second largest inventory of rural residential land and population, following Shasta County.

Butte County was the first area to be digitized and was used as a demonstration area for the purposes of this study. Potential development land-use polygons were digitized into the GIS. Land-use type, average density (in acres per dwelling unit), and annual growth rate (as a percent) were added into the data base for each polygon.

Digital map information developed by Pillsbury (1991) showing California hardwood types was obtained from the California Department of Forestry and Fire Protection (CDF) as a digital file (*fig. 2*).

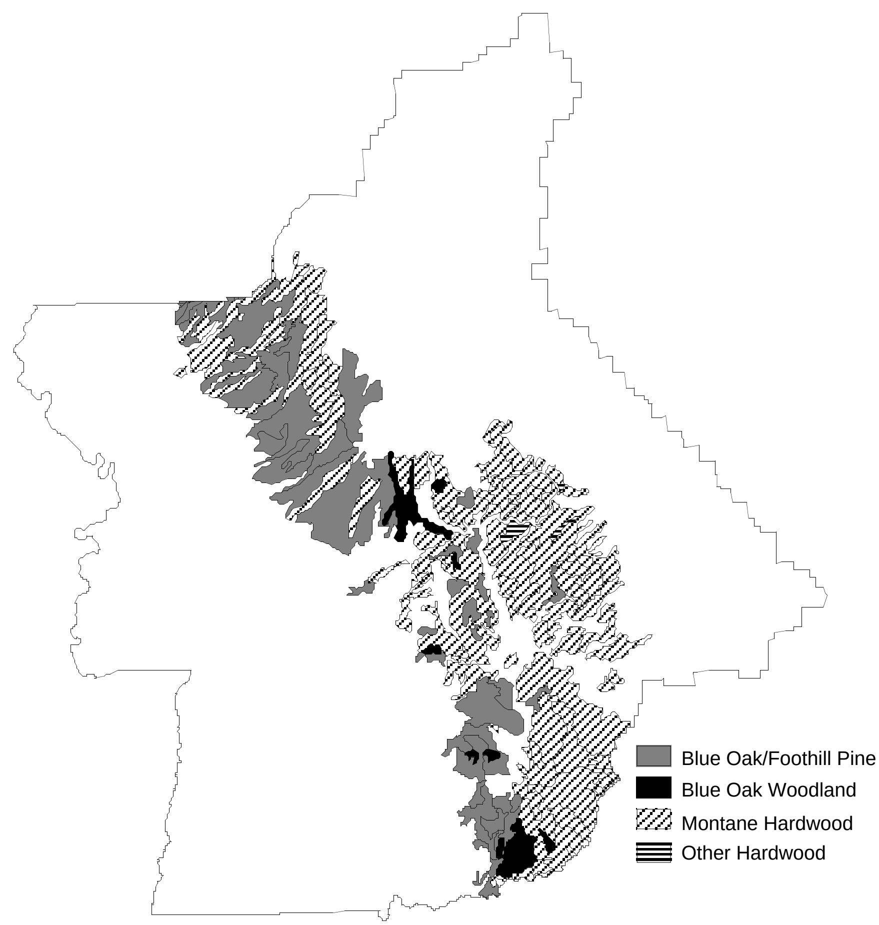

Figure 2—Butte County hardwoods

Using ArcView software, total acreage statistics within each hardwood type were generated.

Hardwood type	*No. of polygons*	*Acres*
Blue oak/foothill pine	49	82,828
Blue oak woodlands	9	10,608
Montane hardwoods	73	148,100
Other hardwoods	3	1,361

Examination of the impact of potential growth on the oak interface requires overlaying the land-use types layer with the hardwood layer. Incorporated city spheres, unincorporated communities, and foothill rural residential were used because they are population sensitive and have the greatest impacts in the oak woodland interface.

Because the purpose of this project is to examine the potential impact of development in the oak woodland interface, those land-use areas which do not lie within the hardwood region were deleted; i.e., the agricultural areas on the valley floor were skipped. In addition, the timber and foothill rural resource areas were deleted as their densities are greater than 40 acres per dwelling unit (*fig. 3*).

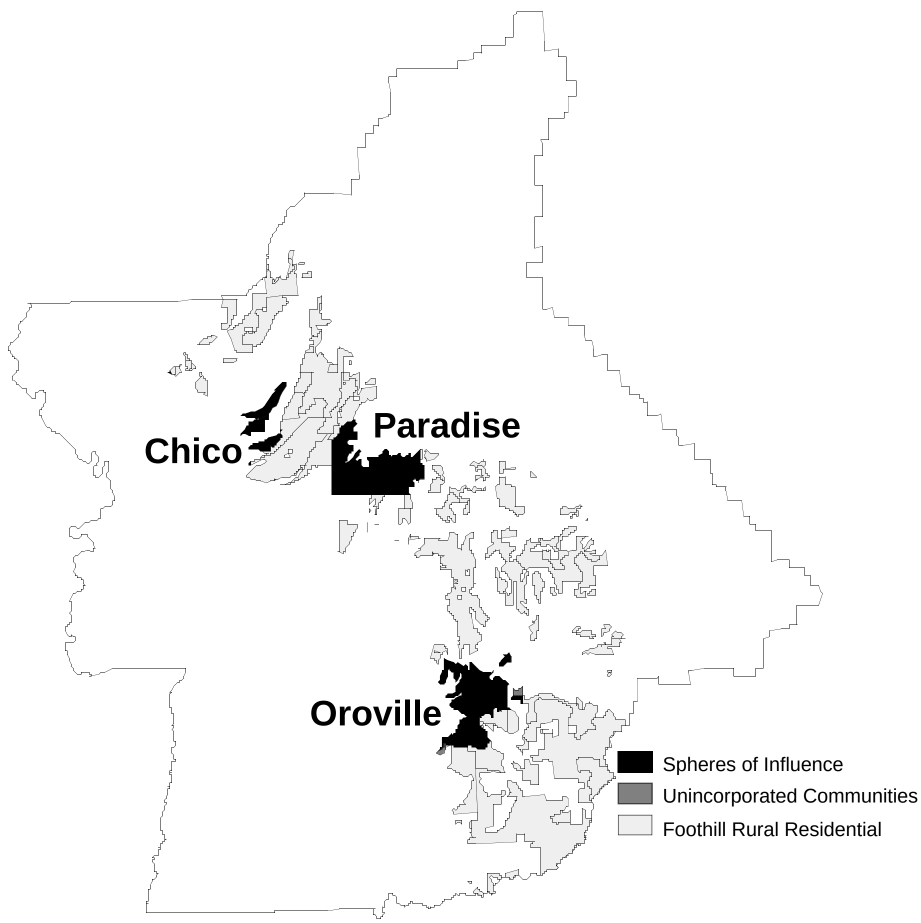

Figure 3—Projected buildout by land use type

When this step is completed and statistics are generated, the impacts of potential buildout within the oak woodland interface become very apparent, and the true extent of the foothill rural residential area becomes defined.

Land use type	*No. of polygons*	*Acres*
Incorporated city spheres	10	25,038
Unincorporated communities	2	330
Foothill rural residential (1-40 ac.)	113	100,484

Since population density statistics were also digitized, it is possible to break down the Foothill Rural Residential type by acres per dwelling unit.

Density	*No. of polygons*	*Acres*
Less than 1 acre per dwelling unit	12	25,358
1 - 2 acres per dwelling unit	2	39
2 - 5 acres per dwelling unit	11	4,405
5 - 10 acres per dwelling unit	15	9,048
11 - 20 acres per dwelling unit	44	24,902
20 - 40 acres per dwelling unit	42	62,091

When the buildout layer was overlaid with the hardwood layer, a third set of data was generated illustrating potential vegetation loss by hardwood type (*fig. 4*).

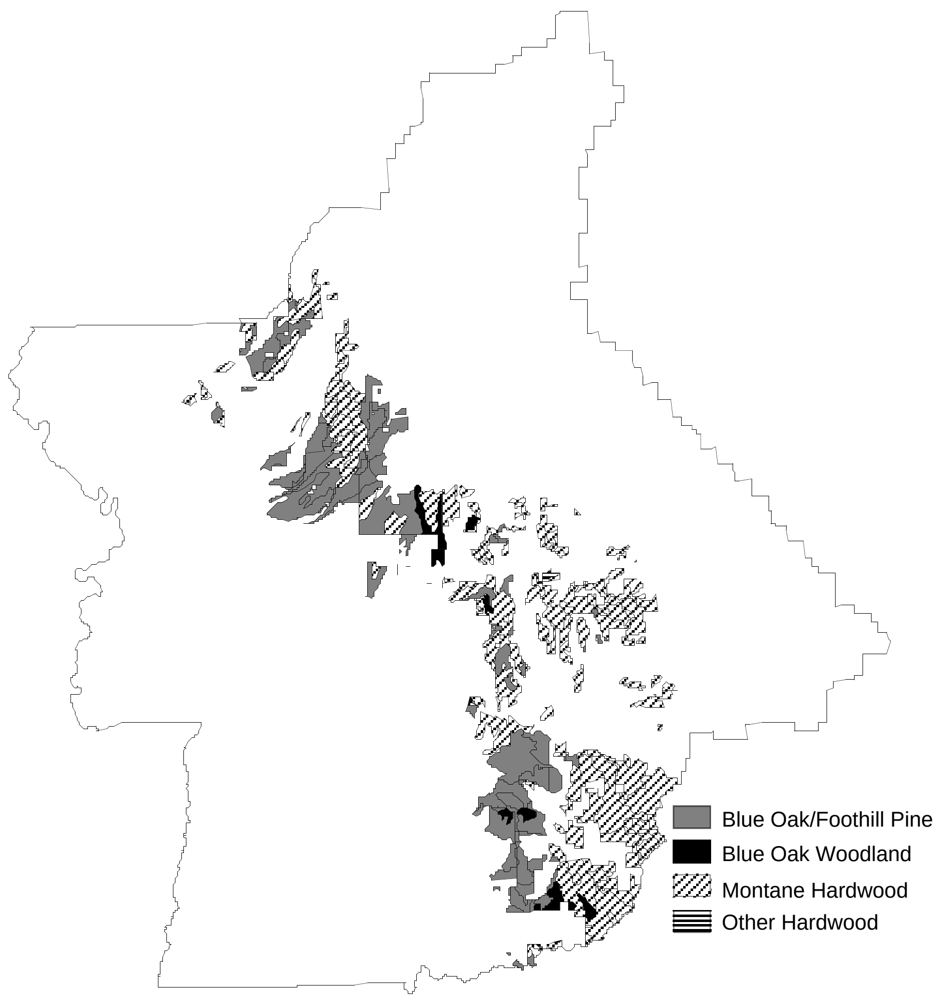

Figure 4—Potential buildout by hardwood types

Loss percentages can be easily calculated and statistical summaries can be generated as needed.

Hardwood type	*No. of polygons*	*Polygon increase*	*Acres*	*Percent of total impacted*
Blue oak/foothill pine	126	77	50,979	62
Blue oak woodlands	19	10	6,302	59
Montane hardwoods	239	166	74,390	50
Other hardwoods	3	0	351	26

Polygon increase shows the fragmentation of remaining hardwood stands if potential development continues with no restrictions. Statistics in Butte show a significant increase in the number of polygons as buildout occurs.

Impact statistics in Butte County, while significant, can be misleading and are open to debate. For instance, the impact of one dwelling unit per 40 acres may be significant or it may have little effect on oak habitat. That is not for me to debate here.

This information should not be used to stop development in Butte County. Rather, it should be used to guide responsible growth. Maps and statistical information merely give planners, decision makers and the interested public the ability to examine potential impacts, initiate discussion, and try to formulate workable growth strategies.

Implications and Conclusions

The ability to graphically illustrate growth projections in a GIS gives the SLP an important planning tool. The potential uses for this type of data are limitless. For instance:

- Incorporation of the SLP maps with other existing digital products like riparian, wetlands, soils, and land ownership data can be easily accomplished by a regional GIS data center like the Geographical Information Center at California State University, Chico (CSU, Chico);
- If a comprehensive GIS data base is developed at the land development and project permit level, it could be tailored to begin providing relatively low-cost natural resource and environmental baseline information to local planning agencies, developers, and interested citizens. A parallel already exists at many California State Universities. For instance, reconnaissance-level archeological information is currently provided at minimal cost to local governments by the Northeastern California Information Center at CSU, Chico;
- The improved ability to assess change in the oak woodland landscape on a comparative basis with other resources can lead to new or expanded ideas regarding oak woodland sustainability;
- Inclusion of a method to spatially assess the impacts of population growth on a variety of other natural resource components will likely lead to more related research in the region;
- A GIS data system is adaptable and can be easily updated to accommodate new spatial information. For instance, a multiagency mapping project is currently under way using Landsat satellite technology to classify California vegetation types. When these digital maps are complete, information can be brought into a GIS and used

to update existing oak woodland statistics; and

- Mapping provides a clear visual format for the area residents to understand relationships between land use and population growth. Low-cost software like ArcView makes desktop GIS and SLP data readily available to local decision makers who will ultimately decide the fate of the oak woodland interface.

References

California Department of Finance. 1993. **Official population projections and average annual growth rate.** Report 93P-1. Sacramento: California Department of Finance.

Pillsbury, N. 1991. **Hardwoods.** Digital map. Sacramento: California Department of Forestry and Fire Protection.

Radabaugh, M. 1995. **Population growth trends and allocation of pattern in the northern Sacramento Valley.** Davis, CA: Common Ground: Center for Cooperative Solutions, University of California Extension.

A Development in Harmony with Nature?[1]

James R. Vilkitis[2]

Abstract: *Buena Vista Country Club (BVCC), Inc. proposes an 18-hole target golf course and support facilities in Santa Cruz County, California. Environmental concerns include federal and state listed endangered plant and animal species, and two habitats of concern to Santa Cruz County including the San Andreas Coastal Live Oak Woodland. An ecosystem management philosophy was developed to design the BVCC in an attempt to maintain the integrity of the site resources. Field research data was put into a geographical information system (GIS) and used to analyze project alternatives and develop a Conservation Plan (Plan). The Plan was developed to protect the endangered species through the implementation of a Habitat Conservation Plan (Salamander Reserve), to maintain the integrity of the biotic communities by establishing an Oak Preserve, and to implement the preferred golf course alternative. It integrates these components into a Plan. The question remains—would it work? The answer lies with the monitoring program and the ability of applied management to respond to the results of monitoring.*

This paper presents an overview of the analysis of the Buena Vista Country Club, Inc. (BVCC) project in Watsonville, California, and the preparation of a Conservation Plan (Plan) that attempts to create a "Development in Harmony With Nature." The Plan consists of three components: (1) a Habitat Conservation Plan, (2) an Oak Preserve, and (3) an 18-hole target golf course.

A Draft Habitat Conservation Plan (DHCP) was developed by the Coastal Resources Institute (CRI) at California Polytechnic State University, San Luis Obispo. The DHCP assessed the action alternatives for the golf course development and country club and identified goals and quantifiable objectives that would enable Alternative 3 to be implemented successfully on the site. The Oak Preserve serves to protect and conserve the remaining natural resources of the site. The goal of the preserve is to maintain the integrity of associated plant communities within the site and serve as the environmental buffer that will sustain the system. The 18-hole target golf course and country club is the project. A target golf course is unique in that it allows the golfer to play over obstacles such as water or vegetation which may allow for more of the natural resources to be preserved. The patchwork of obstacles would serve as the linkage to connect habitats of the Oak Preserve.

In general, the Plan process involved identifying and incorporating the concerns of the stakeholders (public and private) and the developer into two action alternatives that would attempt to avoid, minimize, and prevent significant adverse effects to the natural environment. Environmental monitoring and management elements were incorporated to ensure that the goals and objectives of the Plan were being met.

Major environmental issues included the preservation of the Santa Cruz long-toed salamander (a federal and state listed endangered species) and the California tiger salamander (a federal candidate species and a state Species of Special Concern), four plant species listed by the California Native Plant Society, two habitats that are of special concern to Santa Cruz County (San Andreas Coastal Live Oak Woodland and Maritime Chaparral), wetland sites, and grading.

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[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Implementation Philosophy

The philosophy for developing the Plan was based on preserving and protecting the animal and plant species of concern by maintaining the integrity of the biological and physical attributes of the site upon which they depend while still providing recreational opportunities. An intense environmental audit of the vegetation, soils, drainages, and life histories of the sensitive species was conducted. These data were placed in a geographic information system (GIS) which was used to develop two action alternatives and to assess the effects of each alternative on the plants and animals of the site. Since all issues raised could not be ameliorated, a planning hierarchy for addressing them was developed. The strategy was to first address federal concerns, then those identified by the state and local governments. The issues were assessed using the GIS and interdisciplinary team discussions. Management strategies were developed for components of the Plan to guide project implementation and subsequent monitoring and management activities. The Plan was the result of those efforts.

Site Location and Land Use

The proposed project site encompasses approximately 285 acres in southwestern Santa Cruz County, Calif. It is located 2 miles west of the Watsonville airport and 1.5 miles east of Watsonville. It is bounded on the northeast by State Highway 1, on the south by Fiesta Way and Rancho Road, and on the west by cultivated lands east of Willow Springs Road.

The site encompasses three parcels of privately owned open space with one residential unit occupied by a caretaker who provides security. Most of the property surrounding and adjacent to the proposed golf course is designated either Agriculture or Mountain Residential. These areas are outside the Santa Cruz County Urban Service area; therefore, development is limited at this time.

Environmental Setting

The project location is characterized by warm summers and mild winters with average temperatures from 54 to 58 °F. Precipitation is light, and rainfall averages 20-25 inches per year. Average humidity is fairly high (70-80 percent) during the entire year owing to a strong marine influence. Clouds, fog, or overcast conditions occupy 30-40 percent of the daylight hours throughout the year.

The geology is relatively uniform. It is mapped as Pleistocene, non-marine Quaternary Aromas Formation. The ridgetops and shoulder slopes expose many outcroppings of a weakly cemented sandstone sheet that appears to underlie the entire site. The dune sheet has been eroded into a series of parallel north- to south-tending ridges and valleys. Elevations range from approximately 190 feet at the southern boundary to 470 feet near Highway 1. Four drainages exist on the site (*fig. 1*), two of which have the potential to carry seasonal runoff from Highway 1. The bases of the drainages are influenced by runoff and seasonal seepage from the ground water table. At the present time the surface water table is close to the valley floors and supports seasonal wetlands and intermittent ponds.

Five different soil series were mapped as nine separate soil map units on the basis of slope differences within the series. The site is covered primarily by Baywood loamy sand, 2-60 percent slopes. This soil type is very deep and well drained. Permeability is high, and available water capacity is very low. Surface runoff is rapid and erosion hazard moderate under native vegetation and very high if vegetation is removed and the soil left bare. Other soils present on the site

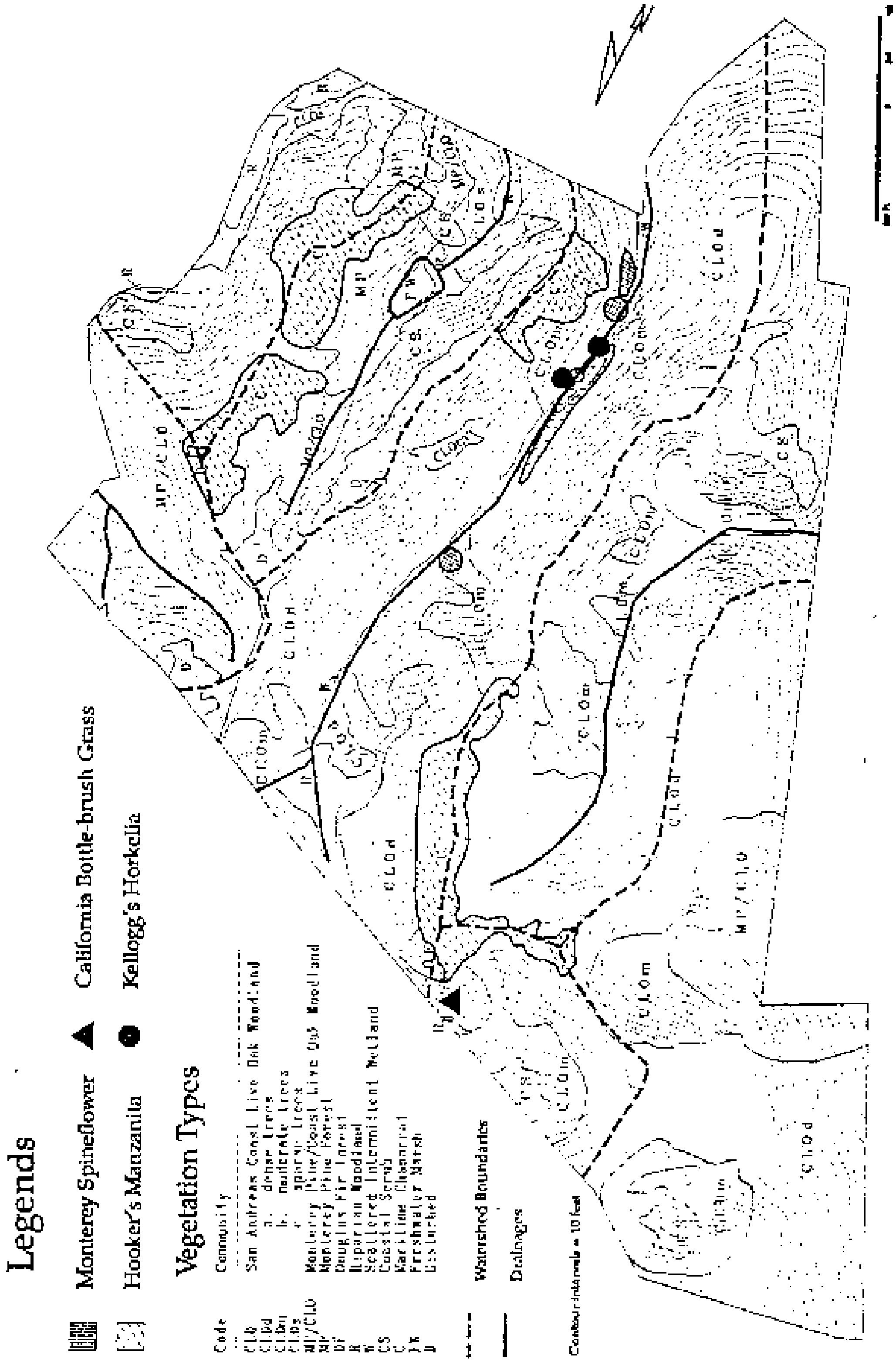


Figure 1—Watershed boundaries, vegetation, and sensitive plant species.

include Seaside sandy loam, 1-15 percent slopes; Yorkville sandy loam, 2-30 percent slopes; Deven variant loam, 5 to 30 percent slopes; and Columbia loamy sand, 1-2 percent slopes. Columbia loamy sand is classified as a hydric soil and was found in the central drainage of the site. Permeability of this soil type is moderately slow, and drainage problems are of primary concern.

The site is covered mostly by woodland or forest type vegetation. The dominant plant cover is San Andreas coastal live oak woodland, hereafter referred to as oak woodland (68 percent). However, Monterey pine/coastal live oak woodland (15 percent), Monterey pine woodland (2 percent), and Douglas-fir woodland (<1 percent) also occur. Combined, these communities cover more than 85 percent of the site (*fig. 1*). San Andreas maritime chaparral covers about 6 percent of the site and northern coastal scrub about 4 percent. Other communities combined cover less than 4 percent of the site (e.g., freshwater marsh, riparian woodland).

The eastern portion of the property, where the residence is located, shows much evidence of human disturbance, including roads, trails, and graded and cleared areas. This region also has the majority of introduced trees and shrubs, including some, such as Monterey pine, which have become naturalized and are actively spreading. On some roads and the areas adjacent to them, the topsoil is gone, and the sandstone parent material is visible. Rancho Reservoir (the freshwater marsh community) was created by a berm that was established across the easternmost drainage. The remainder of the site, approximately two-thirds of the total acreage, shows little sign of human impact except for firebreaks and the trails leading to them, all of which are now overgrown. This region is dominated by the dense phase of the oak woodland. Much of it is inaccessible. In the areas which were sampled, very few non-native plant species were found.

Wildlife species are those that are adapted to oak woodland and chaparral/coastal scrub habitats. They include 5 species of amphibians, 4 reptiles, 29 species of birds, and 12 species of mammals. Characteristic bird species found in the oak woodland and chaparral include the chestnut-backed chickadee, plain titmouse, bushtit, bewick's wren, wrentit, and rufous-sides towhee. The song sparrow can be found in the riparian areas. Species of mammals that are characteristic of the area include the brush rabbit and the black-tailed deer.

Project Descriptions / Components of the Conservation Plan

The 18-hole target golf course and country club were the impetus for the Plan. It will be a members' course open to the public. Membership is expected to reach 500 at full capacity, with an expected daily use of 144 to 240 rounds of golf. The course will include a practice range and 18 holes located along the ridges and valleys of the site. To add to the visual esthetic, wetland values, and habitat diversity, new ponds will be created to supplement Rancho reservoir, which will be enhanced and maintained.

A two-story clubhouse (16,000 square feet), a mid-course facility containing restrooms and a snack bar (180 square feet), a golf cart storage shed, a maintenance building, and a utility washdown shed are the only proposed structures. No homes are planned as part of the project. In full operation, the course will employ 36 persons full-time and 10 to 15 persons part-time. Two parking lots providing a total of 153 parking spaces are planned and will be located north and northwest of the clubhouse. A detention pond will be created for runoff from the highway and the parking area. Auto traffic will be limited to the main road and parking area.

"Target" golf courses, which incorporate more natural vegetation and habitats in their design, require less irrigation than a typical course. It is estimated that approximately 95 acres will be irrigated with reclaimed wastewater from the Watsonville wastewater treatment facility. Turfgrass irrigation requires 1 to 7 inches of water per month, depending on the season—approximately 400,000 gallons per day during July and August, with an annual average of 180,000 gallons.

A Salamander Reserve will be created to protect and preserve the Santa Cruz long-toed Salamander and the California tiger salamander. It will be a natural area dedicated to the salamanders and will exclude any activities that could negatively affect the salamanders. Management will be directed at enhancing the area to stabilize erosion, eliminating exotic plant species, and adding an additional breeding pond and dry-season refuge sites. The establishment of the Salamander Reserve that discontinues landscape abuse, enhances the breeding pond, and provides an additional breeding site should stabilize the population dynamics of the salamanders and increase their chances of survival. The Salamander Reserve under all action alternatives will be larger than the salamanders' minimum known habitat. To ensure that the Salamander Reserve's resources will be maintained primarily for the benefit of the salamanders, monitoring and management plans have been developed and incorporated into the DHCP and Implementation Agreement. Results of monitoring activities will be reviewed annually by the U.S. Fish and Wildlife Service (USFWS) and California Department of Fish and Game (DFG), and management strategies will be adjusted to meet goals and objectives.

An Oak Preserve will be established, as a demonstration forest, to protect and conserve the biological resources of the site, particularly the oak woodland and associated communities. The Oak Preserve will include all areas not considered in the golf course play area and associated structures, including the revegetated areas, wetland areas, freshwater marsh, oak woodland, and maritime chaparral. It will be managed to maintain the mix of plant communities that presently exist on-site and in the area. Exotic plant species and/or non-indigenous plants that are not considered essential to existing communities will be removed.

In an attempt to allow the living landscape to function as naturally as possible, the landscape surrounding the fairways and greens will be designed to prevent overland flow of surface water and ensure that the applied fertilizers and pesticides will not leave the effective root zone of the plants. The golf course will be monitored and managed to maintain the integrity of the natural systems of the site. To assure objectivity, an independent educational institution will coordinate and manage the monitoring programs in cooperation with USFWS and DFG and will provide feedback to the County and regulatory agencies as required.

Major Issues

Issues of concern to federal and state agencies include two species of salamander and four plant taxa listed by the California Native Plant Society (CNPS). Issues of concern to Santa Cruz County, as presented in the General Plan (1980), are the effects of the project on two sensitive plant habitats (communities) as well as the effects that grading will have on indigenous plants and animals.

Animals of Concern

The federal and state listed endangered Santa Cruz long-toed salamander (*Ambystoma macrodactylum croceum*) and the California tiger salamander

(*Ambystoma californiense*), a federal candidate species and a state Species of Special Concern, are the animals of concern. The Santa Cruz long-toed salamander (SCLTS) was listed as endangered in 1966 by the federal government and by the state in 1970. It is classified as a "mole" salamander because it spends most of its life underground, usually in mammal burrows. Five subspecies of the SCLTS are found in the Pacific Northwest. Ten SCLTS breeding populations exist currently in the Monterey Bay region. These populations are found in ponds between Aptos in Santa Cruz County and Castroville in Monterey County, California. The population found on the site, known as the Buena Vista population, is the most newly discovered breeding population.

The California tiger salamander (TS) is a federal Category 1 candidate species and is on the California Natural Diversity Database list of Species of Special Concern. The range of the TS extends from the Sacramento Valley south to Santa Barbara (Stebbins 1985). It is found in the San Joaquin Valley and surrounding foothills of both the Coast Ranges and the Sierra Nevada. This lowland species is restricted to the grasslands and lowest foothill regions of Central and Northern California in which breeding habitat (long-lasting vernal ponds) occurs (Shaffer and Stanley 1992).

The breeding habitat for the SCLTS and TS on site is Rancho Reservoir, a small, manmade, ephemeral pond on the southeastern portion of the site. It is capable of containing up to a half acre of seasonal drainage, but normally the pond area is no more than 20 by 40 feet, and during the summer months it is dry. The slopes surrounding the reservoir appear to have been used extensively for off-road trail vehicles. The natural vegetation has been destroyed in the vehicular pathways. This has accelerated erosion, causing sedimentation of the reservoir area.

Plant Species of Concern

Four plant species found on the site are listed in the California Native Plant Society's (CNPS) Inventory of Rare and Endangered Vascular Plants of California.

Hooker's manzanita (*Arctostaphylos hookeri* ssp. *hookeri*) is currently placed by CNPS on List 1B. It has a R-E-D code of 2-2-3. It is not presently listed by the state or federal government as endangered or threatened, but it has been placed on the California Department of Fish and Game's Natural Diversity Data Base list of Special Plants (1996). Hooker's manzanita is found on sandy soils, sandy shales, and sandstone outcrops from the Santa Cruz Mountains south to the Carmel area. The species has a very limited distribution over two U.S. Geological Survey quadrangles and is limited to small, localized populations in these areas (LSA Associates, Inc. 1993). On the site, Hooker's manzanita is found as a dominant or co-dominant species throughout the maritime chaparral (*fig. 1*). It is also found in regions where chaparral is grading into such communities as oak woodland, Monterey pine woodland, and Douglas-fir woodland.

Monterey spineflower (*Chorizanthe pungens* var. *pungens*) has been placed on List 1B by the CNPS and has a R-E-D code of 2-2-3. It is not listed by the State of California, but was determined by the federal government to have threatened status as of February 1994 (United States Department of the Interior, Fish and Wildlife Service 1994a). Monterey spineflower is found in coastal dune, coastal scrub, grassland, maritime chaparral, and oak woodland communities adjacent to the coast of southern Santa Cruz and northern Monterey counties and inland to the coastal plain of Salinas Valley (United States Department of the Interior, Fish and Wildlife Service 1994b). The vegetation survey conducted by CRI identified this species in the central canyon bottom, roughly 700 to 1,000 feet from the southern boundary of the property. Further field studies revealed approximately 300 plants in several open sandy areas of the same canyon (*fig. 1*).

This species has potential to occur in the oak woodland, coastal scrub, and maritime chaparral communities, but was not observed in these areas during field surveys.

California bottlebrush grass (*Elymus californicus*) is a CNPS List 4 species and has a R-E-D Code of 1-1-3. It is not presently listed by the State of California as endangered or threatened, but has been placed on the California Department of Fish and Game's Natural Diversity Database list of Special Plants (1996). The U.S. Fish and Wildlife Service has placed California bottlebrush grass in Category 3c (C3c), which identifies the species as being too widespread or not threatened at this time. In the vicinity of the project site, California bottlebrush grass has been reported growing in association with closed-cone pine and mixed evergreen (Douglas-fir) forests. LSA Associates, Inc. (1993) reports it growing within about 1 mile northwest of the site in five localized areas. The vegetation survey conducted by CRI identified this species on the northern portion of the site in the dense phase of the oak woodland (*fig. 1*).

Kellogg's horkelia (*Horkelia cuneata* ssp. *sericea*) has been placed on List 1B by the CNPS and has a R-E-D code of 3-3-3. It is not listed by the State of California, but is listed as C2 by the federal government. Kellogg's horkelia occurs in coastal sandy sites and in coastal dune scrub. It was found during the environmental audit at one location in the central canyon, roughly 700 to 1000 feet from the southern boundary of the property. Further field studies found plants at this and one additional location in the central drainage (*fig. 1*).

Sensitive Communities

The site contains several plant_communities that are considered sensitive: San Andreas coastal live oak woodland, San Andreas maritime chaparral, and wetland sites (which include riparian woodland, freshwater marsh, and scattered/seasonal wetlands). The first two communities have been identified by Santa Cruz County as "habitats" of special local concern. We will use the term "community" to identify them.

San Andreas coastal live oak woodland, hereafter referred to as oak woodland, is considered a locally rare community in the Biotic Resources Section of the Santa Cruz County Growth Management Plan (Santa Cruz County 1977) and as a sensitive community type in the Santa Cruz County Local Coastal Program Land Use Plan (1982). It is often composed of almost pure stands of coast live oak (*Quercus agrifolia*) and is restricted to the sandy, infertile soils on hillsides and canyons north of Watsonville.

The oak woodland is the dominant vegetation type (68 percent) on the site and occupies the mesic slopes and canyon areas (*fig. 1*). Community structure varies over the site according to moisture and aspect. In many places the oak trees are large, sprawling, multiple-trunked trees that dominate the area. In a few areas that have been influenced by humans in the past, the oaks form a more open woodland with grassland and scattered shrubs as understory. Of the 193.4 acres on site, approximately 152 acres have been classified as "dense," 35 acres as "moderately dense," and 6 acres as "sparse." The dense phase is considered to be the climax community for the site. On the eastern portion of the site, the oak woodland has been degraded by disturbance and escaped ornamental exotic species such as Monterey pine (*Pinus radiata*). These areas no longer retain their original community complexity and structure.

San Andreas maritime chaparral, hereafter referred to as maritime chaparral, occurs along the windswept coastal hillsides and sand dunes of central and northern California from Santa Barbara to Santa Cruz County. It often forms a mosaic with oak woodlands and is a successional stage of that community. The maritime chaparral on site is considered a distinctive type of chaparral referred to by Santa Cruz County as "San Andreas maritime chaparral." It is dominated by two species of manzanita: Hooker's manzanita (a CNPS listed plant) and Woolly manzanita (*Arctostaphylos tomentosa*). This community has a highly restricted distribution of approximately 209 acres (LSA Associates, Inc. 1993). Because of its unique species composition (i.e., Hooker's manzanita) and limited distribution, it is considered a sensitive habitat by Santa Cruz County. It represents 18 acres on the site (*fig. 1*) which is 8.6 percent of the total cover of this community type in Santa Cruz County.

Sensitive wetland sites consist of riparian woodlands, a freshwater marsh, and scattered intermittent wetlands. A total of 6.6 acres occur on the site. Section 5.2 of Santa Cruz County's General Plan seeks to protect, preserve, and restore riparian and wetland areas. Wetland areas are defined as transitional areas between terrestrial and aquatic systems where the water table is usually at or near the surface, or the land is covered by shallow water. Under a "unified" methodology now being employed by all federal agencies, wetlands are defined as those areas meeting certain criteria for hydrology, vegetation, and soils. Development in riparian and wetland areas is prohibited unless an exception is granted. Development is defined as any type of activity, including grading.

Riparian woodlands occur along the creeks that border the eastern portion of the site, around the manmade Rancho Reservoir and the drainage south of it, and along the canyon bottoms near the center of the site (*fig. 1*). Areas of riparian woodland large enough to be mapped occur on 5.12 acres of the site. Of this area, 0.56 acres are associated with Rancho Reservoir. Where pools of water occur along the site's drainages, small patches of freshwater marsh-type vegetation (0.5 acres) have become established and form a mosaic within the oak woodland and riparian woodland communities (*fig. 1*). The largest area of freshwater marsh covers is a result of the development of Rancho Reservoir. Several small areas of intermittent wetlands (2.1 acres) along some of the canyon bottoms and in other drainages are too small to be mapped individually. The area they occupy, however, is identified as a narrow corridor along the bottom of the central drainage (*fig. 1*). These areas receive surface flow only during the rainy season and are dry most of the year. As with the freshwater marsh, parts of the scattered intermittent wetlands may be an artifact of past disturbance.

Grading

Grading is an important issue because of the site's varying topography, with several ridges and valleys traversing the site (*fig. 1*). The action alternatives would move between 450,000 to 950,000 cubic yards of earth. The magnitude and location of this activity can disturb drainage and the soil and vegetation that provide habitat for various species of plants and animals.

Alternatives

Five alternatives have been identified and assessed to provide a better understanding of the project's effects on the environment and to aid in developing the Conservation Plan. The alternatives are: No Project, three action alternatives (Alternatives 1, 2, and 3 [*fig. 2*]), and Alternative Sites. The goals, objectives, and philosophy for developing the site are consistent for all the action alternatives. The primary difference is in the golf course layout and its effect on the physical and biological resources of the site. Under all action alternatives, the Salamander Reserve would be monitored and managed as identified in the DHCP and specified in the Implementation Agreement.

The grading plan for the action alternatives identifies the maximum potential area that could be disturbed if implemented. Because it is not known what linkages (natural areas) within the grading footprint can be avoided, it is assumed

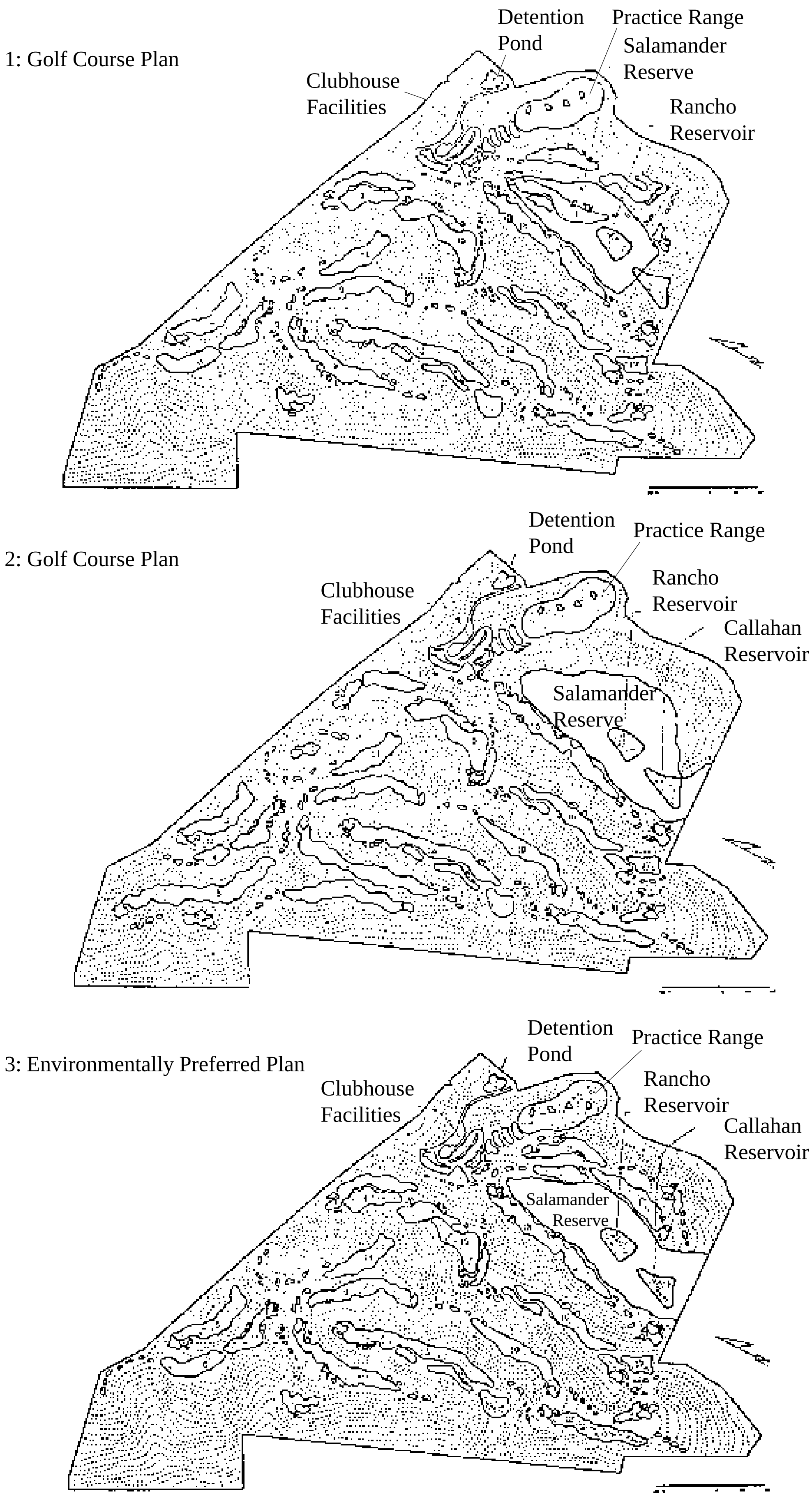


Figure 2—Alternative golf course plans.

Table 1—Comparative effects matrix

	No Project Alternative	Alternative 1	Alternative 2	Alternative 3
Santa Cruz long-toed salamander	–[1]	+[2]/–	+	+
Tiger salamander	–	+/–	+	+
Salamander Reserve				
Acres	0[3]	13.6	22.9	19.6
Percent		4.8	8.1	6.9
Monterey spineflower	– eliminated naturally	– eliminated induced	–/+	–/0
Kellogg's horkelia	– eliminated naturally	– eliminated induced	–/0	–/0
Hooker's manzanita	–	–	–/0	–/0
California bottlbrush grass	0	0	0	0
San Andreas Coastal Live Oak Woodland	0/–	–	–/+	–
Acres		83.3	109.6	82.3
Percent		43.0	56.6	42.6
San Andreas Maritime Chaparral	0/–	–	–/+	–
Acres		11.3	8.5	12.9
Percent		62.3	47.0	71.9
Wetland sites	0/–	–	–/+	–/+
Oak Preserve				
Acres	0	171.7	–/+	–/+
Percent		60.0	53.4	60.0
Grading				
Cubic yards	0	450,000	950,000	550,000
Acres	0	123.7	141.1	122
Percent		43.5	49.6	43.2
Golf course				
Acres	0	99.2	109.7	94.2
Percent		34.9	38.6	33.1

[1]Negatively impacted
[2]Benefically impacted
[3]No impact

that the entire area will be disturbed. The following narrative presents the effects of the action alternatives, and *table 1* summarizes these effects for all the action alternatives.

The No Project Alternative provides baseline information for the comparative analysis among action alternatives. For this alternative, a projection of the natural successional processes as interpreted from the analysis of the physical and biological resources of the site is assumed. Development pressure in the area and region is forecasted. This alternative would leave the site as privately owned open space with one residential unit. Land would not be dedicated to and managed for the SCLTS, TS, and other resources of the site, or be protected from local uses and potential urban expansion.

Alternative 1, the original layout, was designed before CRI involvement and was considered environmentally sensitive to the land form and oak woodland community (*fig. 2*). Other aspects of the biological and physical landscape were not considered because a complete on-site resource environmental audit had not been completed. The SCLTS was known to exist on the property, and a habitat (13.6 acres) identified as necessary for its protection would be established as the Salamander Reserve. Some of the reserve would be lost to a fairway and associated tees. No active resource management of the various plant communities outside of the Salamander Reserve is proposed. Under this alternative, 123.7 acres (450,000 cubic yards) would be graded to create a 99-acre golf course, and a Conservation Plan would not exist.

Alternative 2 reflects a design that responds to the environmental audit and concerns identified by the various regulatory agencies (*fig. 2*). Under this alternative, the natural resources (biological and physical) of the site are an integral part of the golf course design; however, they are not integrated into a comprehensive plan. Primary consideration has been given to avoiding or minimizing negative effects to the salamanders of concern. A buffer strip on the outer perimeter of the Salamander Reserve would be constructed to discourage egress. The Salamander Reserve area could be enhanced by stabilizing erosion, removing exotic plants, and adding 9.4 acres to the minimum habitat identified as necessary to protect the salamanders. The addition would serve as potential breeding and dry-season refuge sites. An Oak Preserve would be established to protect and conserve the natural biological resources of the site that were not part of the Salamander Reserve or golf course. Under this alternative, 141.1 acres (950,000 cubic yards) would be graded to create a 109.8-acre golf course.

Alternative 3 is similar to Alternative 2, but emphasizes the interdependence of the Salamander Reserve, Oak Preserve, and the golf course as a sustainable unit (*fig. 2*). The natural resources of the site become a functioning part of the golf course design and are preserved and managed in perpetuity through enactment of the Conservation Plan. Primary consideration has been given to avoiding or minimizing negative effects to the animals, plants, and habitats of concern. As in Alternative 2, no human activities that would negatively affect the salamanders would be allowed, erosion would be stabilized, exotic plant species eliminated, and area (6.0 acres) would be added to the Salamander Reserve as potential breeding and dry-season refuge sites. Under this alternative, 122.9 acres (550,000 cubic yards) would be graded to create a 94.2-acre golf course.

Four alternative sites were assessed before selecting the present site for development. The criteria employed in assessing the suitability of each site for golf course development included location within the County, distance from urban development, adequacy of acreage for an 18-hole course, land costs, development constraints, access, topography, and view.

Alternative Effects

The following describes the effects of the alternatives on the site as interpreted by the interdisciplinary research team (*table 1*). The Alternative Sites analysis was excluded.

For the No Project Alternative, residential development, based on existing conditions, could be limited to as few as five single family units. This number of housing units would not significantly affect the natural resources of the site. Erosion, in the Rancho Reservoir area, if gone unchecked, could cause the extinction of the SCLTS and TS within 20 years. Monterey spineflower and Kellogg's horkelia are early successional species and would be replaced by encroachment of adjacent plant communities. Hooker's manzanita, a main component of the maritime chaparral, is dependent on periodic fire and open exposure for survival. California bottlebrush grass is likely to remain on the site as long as the oak woodland community is present. The sensitive plant communities would continue their natural successional process, harmed mostly by competition with exotic species, erosion, and fire suppression. The property is dominated by dense oak woodland which is considered the climax community on the site. If undisturbed, it would remain dominant over time because individual coastal live oak trees can easily live hundreds of years and community change is gradual. Maritime chaparral is in an early successional stage to the oak woodland and is likely to be replaced by it. Both the oak woodland and the maritime chaparral communities on the eastern third of the site would be harmed by competition and shading from planted invasive species (Monterey pine, acacia, eucalyptus, and pampas grass). Invasive plant species are also present adjacent to Rancho Reservoir (pampas grass, French and Spanish broom) and in some of the riparian woodlands (German ivy). If not controlled, these species could continue to spread at the expense of indigenous vegetation. The freshwater marsh in Rancho Reservoir and the scattered seasonal wetlands in the central drainage would turn into upland communities at the present rate of erosion. The riparian woodlands, however, appear to be stable.

The three action alternatives differ primarily in juxtaposition and size of the golf course, the Salamander Reserve and Oak Preserve, and in the management strategies associated with each. The following narrative distinguished the more substantive issues associated with each of the major issues.

The Salamander Reserve is affected for all action alternatives. For Alternative 1, approximately 5.3 acres of critical dry-season refuge sites within and not including the Salamander Reserve (13.6) would be lost to a fairway and associated tees. A 20-foot buffer strip internal to the Salamander Reserve would be planted with native shrubs and annuals to prevent erosion from overland flow and discourage human encroachment. This activity would disrupt dry-season refuge sites. Rancho Reservoir would be enhanced to retain water throughout the year which would allow greater reproductive success during low rainfall years but could attract aquatic salamander predators. Alternative 2 is similar but is directed at maximizing benefits for the salamanders. The Salamander Reserve would be increased to 23.0 acres; no acreage would be lost to the golf course design; a 20-foot external buffer would be established; the reservoir would retain water only during the breeding and juvenile season and would be allowed to remain dry during the remainder of the year, and a secondary breeding pond would be constructed to encourage population expansion. Areas disturbed through the creation of a new pond would be revegetated to enhance the availability of dry-season refuge sites. Alternative 3 is similar to Alternative 2 with the following changes: the Salamander Reserve would be 19.6 acres; the golf course area juxtaposed to the Salamander Reserve would be landscaped to prevent erosion from overland flow; no external buffer strip (signs would be erected to explain the reserve and its functions); water levels in new breeding reservoir would be adjusted by mechanical means to correspond to those in Rancho Reservoir (water would come from groundwater wells); and revegetation of any disturbed areas would be with species that are found in the Salamander Reserve. Field research identified 2.85 acres as the minimum known habitat for the adult SCLTS on site, and 12.5 acres as potential habitat. It was estimated that, by increasing the size of the reserve to 19.6 acres, the adult salamander population would not be significantly affected. However, the perimeter of the juvenile movement was not determined, because almost 70 percent were found in the outer ring of the pit-fall traps. This suggests that the juveniles may move beyond the established reserve border.

The four plant species of concern would be affected to one degree or another by each of the alternatives. The Monterey spineflower and Kellogg's horkelia present in the central drainage would be eliminated by fairway construction or through plant succession. Hooker's manzanita could potentially be eliminated in all areas of maritime chaparral or moderately dense oak woodland that come under the grading plan acreage, or replaced through plant succession to the oak woodland climax. For Alternative 3, a management plan has been developed that includes periodic prescribed burning which will benefit the Oak Preserve. The transect location where California bottlebrush grass was found is located within the grading plan. This area would be flagged and construction would be prohibited. This species is likely to remain on the site as long as oak woodland habitat is preserved.

The effect of the golf course on the plant communities is a function of grading. The impact on the oak woodland and maritime chaparral are adequately presented in *table 1*. The wetland areas, because of their location and small size, present a different situation. For Alternative 1, all of the intermittent wetlands (approximately 2 acres) and 2.5 acres (48.8 percent) of the riparian woodlands are within the grading plan and would be lost. One acre of the scattered intermittent wetland area would be restored. The freshwater marsh would be altered through enhancement of Rancho Reservoir in the Salamander Reserve. Although this alternative identifies 8.9 acres of ponds for the visual esthetics of the site, these would not be managed as wetland habitat under this alternative. Alternative 2 would disrupt 3.4 acres of the wetland areas, and remove approximately 99.0 percent of the scattered intermittent wetlands. The latter habitat would be replaced with open intermittent wetlands and more permanent riparian habitat during construction. All riparian woodland would be preserved or enhanced. The freshwater marsh would experience no disturbance. Restoring and revegetating 4.7 acres to open freshwater marsh and wetland types would result in a net gain of 1.3 acres (16.5 percent). Alternative 3 has potential to benefit all wetland sites. Areas of riparian woodland would be preserved or enhanced. The woodland site below Rancho Reservoir would become part of the Salamander Reserve and be developed into a riparian woodland for salamander breeding. The freshwater marsh on the site would experience no disturbance. It would be enhanced for salamander reproduction through the restructuring of the subsurface to prevent rapid percolation of rainwater. The pond would be augmented if necessary during the breeding season and allowed to dry out thereafter.

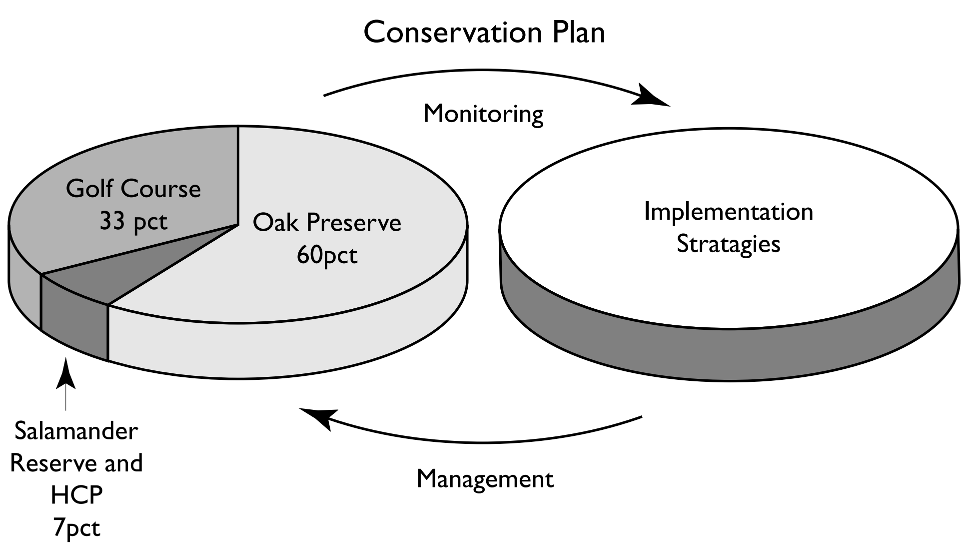
The Site Conservation Plan

The Conservation Plan (Plan) is an approach to managing the living landscapes of the BVCC site by addressing the needs of different species and communities that are common to the site's biological system through time. The goal of the Plan is to maintain the integrity of the oak woodland and associated plant communities and the Salamander Reserve while operating an 18-hole target golf course. Management of the broader landscape, as opposed to the affected area, in a manner compatible with the needs of the listed species and communities, will more likely add to the survival of the biological system than species-specific management. The Plan attempts to use the fairways, greens, and target areas as open space and linkage among the golf course, Oak Preserve, and Salamander Reserve. The recreational area serves as the linkage to undisturbed natural habitat and may provide an acceptable approach to the dilemma of managing endangered species and sensitive habitat at the site. Management that can annually adapt its implementation strategies to the site on the basis of updated scientific information obtained from monitoring the major components is key to the successful execution of the Plan.

An interdisciplinary team of scientists, resource managers, and analysts from CRI conducted a natural resources inventory of the site. The inventory, topographic information, and the original golf course design served as the data base for the assessment. GIS was used to evaluate the effects associated with various alternative 18-hole golf course scenarios. From this analysis it became apparent that a holistic integrated approach to planning and management would be necessary if the development was to exist in harmony with nature. The interdisciplinary team identified two action alternatives that met the developers' objectives and would least affect the site resources. These action alternatives attempted to integrate the issues and concerns identified by the regulatory agencies, the physical constraints of the landscape, the biological requirements of the organisms of concern, and the goal of developing an 18-hole target golf course into one site plan. Alternative 3 appeared to be the only alternative that lent itself to an integrated Plan. The major components of the Plan include the Salamander Reserve (DHCP and Implementation Plan), the golf course, an Oak Preserve, monitoring program, implementation strategy, and adaptive management for the entire site. Implementation strategies would develop annually as a result of analyzing the interactions of the major components (*fig. 3*). To ensure that the components are consistent with the goal, the Plan would call for overseeing the implementation of the golf course design, creation of the Salamander Preserve and Oak Reserve, and the perpetual management of the three components as one site through time.

Alternative 1 did not accomplish the requirements of the Plan. Although it has a Salamander Reserve and golf course plan, these were developed as independent non-integrated components. Management of the oak woodlands would be a function of the site manager with no formal policy directives in place. Each component would be managed independent of the others. Alternative 2 is a major redesign of the golf course in an attempt to maximize the size of the Salamander Reserve and minimize losses to the San Andreas Maritime Chaparral (Hooker's manzanita). It identifies specific management strategies for each of the three components which includes a fire management program to prevent the extirpation of the maritime chaparral by fire suppression. The draw-back to this strategy is that 49.6 percent of the site would be graded with the movement of 950,000 cubic yards of earth. With this amount of site alteration it was assumed

Figure 3—Conservation Plan diagram.



that the integrity of the system would be lost. Alternative 3 was developed to meet the intent of the Conservation Plan. This alternative seemed to provide all the positive attributes of Alternative 2 without the massive detrimental effects of grading and site alteration. It was believed that by reducing the grading and compromising on the Salamander Reserve and maritime chaparral that the integrity of the biological systems could be maintained. In particular, the greatest threat to the salamanders would be the loss of the breeding reservoir and the destruction or disturbance of the contiguous dry-season habitat. The greatest threat to the San Andreas maritime chaparral would be the loss of fire for regeneration while the Oak Preserve would mostly be threatened by the loss of spatial continuity or linkage. The Plan addresses these issues.

The Conservation Plan identifies elements of the three components that would require annual monitoring to maintain the integrity of the system. Success criteria for meeting site objectives and means of revising the implementation strategies to ensure that the success criteria are met would be developed in cooperation with the various regulatory agencies before construction or upon approval of the project. *Figure 3* illustrates the conceptual design of the Plan. It is apparent that 67 percent of the site would not be disturbed. That monitoring of the major components would lead to refinement of the implementation strategies by increasing the understanding of the biological process on site and the consequences of applied management. The strategies would be improved annually on the basis of new information. However, the application of resources management theory beyond the species and community level is still evolving. Thus the Plan should be viewed as a hypothetical means to achieve a "development in harmony with nature." It is prudent to ask, "Will it work?" The answer will come with analysis of monitoring data and evaluation of the applied management program for the Plan, if it is allowed to proceed.

References

California Department of Fish and Game. January, 1996. **Natural diversity data base**. Special plant list. Quarterly publication; Sacramento: California Department of Fish and Game; 74 p.

LSA Associates, Inc. 1993. **Biological resources Buena Vista Property, Santa Cruz County, California**. Santa Cruz, CA: LSA Associates.

Santa Cruz County, Community Resources Agency, Office of Resources Planning, 1977. **Technical Section**; Biotic Resources Section of the Santa Cruz County Growth Management Plan. Prepared by S.E. Singer, Watershed Analyst, Community Resources Agency, Santa Cruz County, California. 51 p. and appendix.

Santa Cruz County, Planning Department, 1980. **County of Santa Cruz General Plan**.

Santa Cruz County, Planning Department, 1982. **Santa Cruz County Local Coastal Program Land Use Plan (Final)**. 222 p. and amendments.

Shaffer, H.B.; Stanley, S. 1992. **Final report to California Department of Fish and Game; California tiger salamander surveys, 1991—contract (FG 9422)**. Rancho Cordova, CA: California Department of Fish and Game, Inland Fisheries Division.

Stebbins, R.C. 1985. **A field guide to western reptiles and amphibians**. 2d ed., revised. Boston: Houghton Mifflin Book Co.; 336 p.

United States Department of the Interior, Fish and Wildlife Service. February 4, 1994a. **Rules and regulations**. Federal Register 59(24) 5499-5510.

United States Department of the Interior, Fish and Wildlife Service. March 7, 1994b. **Endangered and threatened wildlife and plants; endangered status for three plants and threatened status for one plant from sandy and sedimentary soils of central coastal California**. 50 CFR Part 17.

Monitoring Survival and Vigor of Specimen Valley Oaks Influenced by Urban Development Sites[1]

Douglas V. Nickles[2]

Abstract: *In July 1985, a study was conducted of more than 400 valley oaks (*Quercus lobata*, Née) in the Conejo Valley area in Ventura County, California. The intent was to document the survival and vigor of trees in representative growing conditions that were in or adjacent to urban development sites. Each tree was visually evaluated for vigor; selected tree sites were documented through photography. During the summer and fall of 1995, the selected tree sites were revisited to extend the study on a 10-year interval basis. The sites were evaluated using the same process, with any changes noted in the condition of either the trees or the sites.*

The southern limit of the valley oak habitat extends to southeastern Ventura County and southwestern Los Angeles County. The valley habitat favored by the tree is a preferred type of development site. Development now threatens the future existence of the valley oak in this region. Much of the development in this region that has impacted the valley oak occurred in the 1960's and 1970's, before enactment of oak protection ordinances. Development continues today in urban-wildland interface areas.

The residents of the Conejo Valley have enjoyed a long-standing love affair with the valley oak. Stories of stagecoach stops identified by an oak tree, 100 cattle resting under a single tree, and landmark trees for property boundaries abound in the written and oral history of the region. Historic photographs document the savannah vegetation type covering the valley, including large valley oaks, just before the major housing and community developments of the 1960's. The local residents even selected the name of "Thousand Oaks" for the newly formed city in 1963, reflecting their admiration for the dominant valley oak. An ordinance to protect the oaks in the city (one of the first to protect native trees in the state of California) was enacted in 1972 after a development project removed many large valley oaks (Elmendorf 1991).

While oaks have been provided with special protective measures during the development process for the past two decades, the effectiveness of these measures has been questioned. Despite all the efforts including careful urban planning, mitigating oak-tree impacts, strict environmental protection, and preservation of thousands of acres of open space, the future presence of the valley oak in the region is threatened. This appears to be due to three factors: urban sprawl, natural mortality, and negligible propagation. Urban sprawl contributes by removing trees, changing land use patterns which reduces the land base for natural regeneration, and introducing negative environmental impacts harmful to residual trees. The natural mortality of the valley oak as documented by Brown and Davis (1991) in the nearby Santa Ynez Valley is about one tree annually per 220 trees for valley-floor habitat type. For unknown reasons, natural regeneration of the valley oak is in decline. The valley oak is now restricted to only a few remaining viable sites in the Conejo Valley.

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Methods

Initial Study—1985

In July 1985, a one-time study was conducted on the valley oaks in the Conejo Valley area of Ventura County (Nickles 1985). The intent was to document the survival and vigor of trees in representative growing conditions that were in or adjacent to urban development sites. In addition, several of the tree sites were photographed as examples of the risk categories used to evaluate vigor and the different site categories.

In order to document the survival and vigor of specimen valley oaks in the Conejo Valley and to provide a baseline from which to determine what factors may contribute to their health and mortality, tree sites were selected for analysis within the urbanized area of the valley floor. Criteria for selection were convenience, accessibility, quantity of trees in each location, and availability of historical records such as those provided by Conejo School (1940). Five risk levels were defined to classify the condition of the trees as a measure of vigor:

	Risk level	*Description*
Low Risk	Vigorous	Excellent shape and form; crown full with no evidence of dieback; good color; new growth visible throughout crown.
	Healthy	Good shape and form; missing foliage in less than 25 percent of crown; color good to fair; minimal evidence of dieback; some new growth visible.
	Maintaining	Adequate form; missing foliage in 25 percent to 50 percent of crown; color fair; obvious evidence of dieback; minimal to no new growth.
	Declining	Poor form; missing foliage in more than 50 percent of crown; poor color; major evidence of dieback; no new growth; reduction of crown size apparent from previous year.
High Risk	Dead	No evidence of green foliage; bark sloughing from many branches.

Two general categories for distinguishing tree population were used for comparison purposes: Disturbed (developed or landscaped) and Greenbelt (natural or open space).

More than 400 valley oaks were included as part of the initial study; each tree evaluated was mature, established, and among some of the larger specimens in the Conejo Valley (average diameter at breast height estimated at 24 inches). A tally sheet was prepared (*table 1*) with additional data regarding site condition. This included information such as landscaping material and location in parking lots and vacant lots. Representative trees at 19 different sites were selected at random to be photographed as examples of the different risk levels and site categories (*table 2*).

Current Study—1995

In early 1995 it was determined that an abbreviated version of the initial study could be performed and continued on a 10-year interval basis to track the survival and vigor of the sampled tree sites. Each of the 19 sites was observed during the late summer of 1995. During the field visit, the tree sites were evaluated for their risk level and site category and conditions using the same criteria as in 1985 (*table 2*). Photographs were also taken with an attempt to replicate the original photograph.

Table 1—Data for 1985 initial study

Risk Level	Vigorous	Healthy	Maintaining	Declining	Dead	**Total**
Disturbed						
Park/recreation	1	4	2	3	0	10
Building	3	29	21	11	2	66
Parking lot	0	6	7	4	0	17
Road	3	13	9	14	1	40
Landscaping	15	41	37	20	5	118
Animal/pasture	0	1	1	1	1	4
Vacant lot	8	5	1	2	0	16
Subtotal	30	99	78	55	9	271
Greenbelt						
Flat	16	24	25	42	12	119
North exposure	2	2	4	4	5	17
South exposure	0	0	0	0	0	0
East exposure	1	1	4	3	0	9
West exposure	2	0	1	1	0	4
Subtotal	21	27	34	50	17	149
Total	51	126	112	105	26	420

Table 2—Data for selected trees in 1985 and 1995

No.	Address	Site category		Risk level		Condition		**Comments**	
		1985	1995	1985	1995	1985	1995	**1985**	**1995**
1	1595 La Granada	Disturbed	Disturbed	Declining	Declining	Vacant lot	Vacant lot		No change
2	1516 La Granada	Disturbed	Disturbed	Vigorous	Vigorous	Landscaped/dirt	Landscaped/dirt		No change
3	1574 El Cerito	Disturbed	Disturbed	Maintaining	Maintaining	Landscaped/lawn	Landscaped/lawn		No change
4	1590 El Cerito	Disturbed	Disturbed	Healthy	Maintaining	Landscaped/plants	Landscaped/plants		
5	1356 La Jolla Dr.	Disturbed	Disturbed	Healthy	Maintaining	Landscaped/lawn	Landscaped/lawn		
6	750 Erbes Rd.	Disturbed	Disturbed	Vigorous	Healthy	Vacant area of lot	Vacant area of lot		
7	600 Blk. Erbes Rd.	Greenbelt	Greenbelt	Dead	Not visible	Open space/creek	Open space/creek		Likely decayed
[1]8	400 Blk. Rancho Rd.	Disturbed	Disturbed	Vigorous	Vigorous	Landscaped/dirt	Landscaped/dirt		Pruned branches
9	Old Meadows Park	Greenbelt	Greenbelt	Dead	Fallen	Open space/creek	Open space/creek	Regeneration	Shrub encroachment
10	2522 Pleasant Way	Disturbed	Disturbed	Maintaining	Missing	Landscaped/dirt	New park site	Tallest	Possibly removed
11	2522 Pleasant Way	Disturbed	Disturbed	Healthy	Healthy	Landscaped/dirt	New park Site	Widest	
12	Prudential/GTE Place	Disturbed	Disturbed	Vigorous	Healthy	Parking lot	Parking lot		
13	100 S. Lkvw Cyn Rd.[2]	Greenbelt	Disturbed	Various	Uncertain	Undeveloped land	Developed lot	Multiple trees	Status uncertain
14	4400 E. T.O. Blvd.[2]	Greenbelt	Disturbed	Various	Uncertain	Undeveloped land	Parking lot	Multiple trees	Status uncertain
15	4300 E. T.O. Blvd.[2]	Greenbelt	Disturbed	Various	Uncertain	Undeveloped land	Parking lot	Multiple trees	Status uncertain
16	100 Via Merida[2]	Greenbelt	Disturbed	Dec./Maint.	Uncertain	Undeveloped land	Developed lot	Multiple trees	Status uncertain
17	30856 Agoura Rd.	Disturbed	Disturbed	Shock	Maintaining	Grading in process	Landscaped/plants		Retaining wall
18	29851 Agoura Rd.	Disturbed	Disturbed	Declining	Missing	Parking lot	Parking lot		Died & replaced
19	29851 Agoura Rd.	Disturbed	Disturbed	Vigorous	Vigorous	Parking lot	Parking lot	Best specimen	No change

[1]*Quercus agrifolia*
[2]Tree sites - several trees evaluated

Results

In comparing the data from 1985 and 1995 for the sampled tree sites, noticeable changes occurred in both the risk levels and site categories (*table 2*). Of the 13 trees originally in the Disturbed category, six (46 percent) had an increase in risk level from 1985 to 1995, representing a reduction in vigor (Nos. 4, 5, 6, 10, 12, 18). As there was no obvious change in the conditions surrounding the trees, the reason for the reduced vigor is uncertain. It is possible the trees are gradually succumbing to development impacts suffered earlier. Two trees (13 percent) died in the intervening period; one is believed to have been removed as part of a development project (No. 10), and one (No. 18) declined to the point of collapsing from rot (personal observation). [The three trees noted as dead in 1985 have since fallen or are no longer visible.]

In evaluating the trees by site category, four 1985 Greenbelt sites (No. 13 through 16) have been developed and are now in the Disturbed category. As a result, it was difficult to locate the trees for lack of a common fixed reference point. Sites 13 and 16 were not located with certainty because of the changes in the terrain from the surrounding development. Sites 14 and 15 appear to be preserved in the landscaped portion of a parking lot, but identification of the exact trees was difficult because of the landscaping. However, they appear to have maintained their vigor, possibly because of the design and recent nature of the development.

Discussion

Initial Study—1985

An unsuccessful attempt was made to analyze the 1985 data statistically by assigning number values to the risk levels. The statistical test was presented as part of the initial study results, but a simple review of the raw data was determined to be more informative. Overall, the Disturbed sites had most of the trees in the Healthy category, while the Greenbelt population sites had most of the trees in the Declining category (*table 1*). The study concluded the following: (1) trees in disturbed (developed) sites receive more care and attention, resulting in improved health; (2) trees of poor quality (higher risk) are more likely to be removed in the development process; (3) dead and dying trees are left to decay as part of the life cycle in a natural setting (and conversely, quickly removed in a developed setting); and (4) the impacts from relatively recent development (20 to 35 years) are not yet fully known (Nickles 1985).

While the initial study was not adequately designed for scientific analysis, it provided a simple evaluation technique to document the effects of urban development on valley oaks. The review of the data and accompanying photographic documentation led to the repeat study of the Conejo Valley oaks in 1995. It appears that a more effective method for analyzing the impact of urban development on oaks may be to continue risk-level evaluation by site, while documenting the condition of a selected sample of trees with photography over time. Hence, the 1995 study continued the risk assessment, site assessment, and photographic record approach.

Current Study—1995

A number of issues arose in 1995 that made it difficult to assess several of the trees from the initial study. Tree number 10 could not be located, and tree number 11 was located with some question as to its being the same tree. (Both of these trees were in the vicinity of a new park, which was built as part of a redevelopment project.) Tree number 12 was also located with some question as to its being the same tree, even though the parking lot surrounding it had not changed. Tree number 17, which was in shock because of extensive grading in 1985, has recovered and is now at the Maintaining risk level. Tree number 18, which was rapidly declining in 1985, eventually died and has been replaced with three saplings.

If the conversion rate from Greenbelt to Disturbed site category was extended and used to forecast future impacts to valley oaks, all oaks in the Conejo Valley (growing on an undisturbed site that is developable [any slope less than 25 percent by local standards]) are subject to development impacts. The photographs developed from the study are intended to provide ongoing documentation of the ultimate result of those impacts, particularly in those instances where it is not immediately detected. For example, an individual tree's incremental increase in risk level from Maintaining to Declining may not be readily discernible by visual observation from one year to the next, but comparison of two photographs over time would provide the basis necessary to document the decline.

The implications from this study are noteworthy considering the small size of the sample, but not surprising as the sampled sites that were converted to the Disturbed category were on land zoned for development. However, it is clear that increased development in the Conejo Valley will cause more impacts to the valley oaks. Whether or not these impacts are detrimental (either short term or long term) is unknown at this time.

In order to ensure that future monitoring is representative of the valley oak population as a whole, a larger sample population must be identified that includes trees in other communities as well. Other factors must also be part of the evaluation such as rainfall (the late 1980's were drought years), tree age (all were established trees in this study), total population size, age class distribution, land-use patterns, and protection measures and maintenance of oaks in disturbed settings.

Summary

The use and continuation of this study should be most helpful to those involved in the preservation of established valley oak trees in developing communities. The design of the study was not intended for research purposes, but rather as a simple approach to tree evaluation for oak tree preservation practitioners. Those active in urban planning, oak tree preservation, and urban-wildland interface management must be provided with information on how urban development affects oak trees on a long-term basis. Altered construction design, landscape constraints, and other mitigation measures currently in use may not necessarily be providing the effectiveness desired for the overall protection of the valley oak habitat.

References

Brown, Rodney W.; Davis, Frank W. 1991. **Historical mortality of valley oak (*Quercus lobata*, Née) in the Santa Ynez Valley, Santa Barbara County, 1938-1989**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 202-207.

Conejo School. 1940. **Oak census.** Unpublished draft supplied by author.

Elmendorf, William F. 1991. **Oak tree preservation in Thousand Oaks, California**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31-November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 262-265.

Nickles, Douglas V. 1985. **Statistical analysis of the Conejo valley oaks.** Unpublished draft supplied by author.

Managing Development in California's Oak Woodlands [1]

Bruce W. Hagen[2]

Abstract: *Much of California's oak woodland habitat is at risk from urban expansion. Growth continues with little regard for wildlife habit, open space preservation, soil erosion, and risk of wildfire. Local planners must develop an effective natural resource management strategy, based on a careful assessment of the local oak/hardwood resources. In this manner, they can identify critical areas, e.g., wetlands, riparian corridors, steep slopes, unstable soils, wildfire prone vegetation and terrain, and lowlands subject to flooding. Thus, specific areas can be targeted for growth, preservation, or other compatible uses. Planners will be more successful by working closely with landowners, the public, other governmental agencies, and environmental groups to promote education, land stewardship, local assistance programs, and by offering incentives. In addition, more effective tree preservation ordinances must be developed to minimize tree losses during development. Successful tree retention programs begin at project conception, and continue through planning, design, construction, post-construction, and landscaping.*

Urban expansion into the surrounding wildlands has destroyed or degraded much of California's oak woodlands and created a serious wildfire hazard. Furthermore, concerns about fire hazard, flood potential, soil stability, and open space preservation have not been adequately addressed. Since the mid-1940's, more than 1.2 million acres of oak woodland habitat have been converted to urban and agricultural uses, and another 0.25 million acres are at risk. An estimated 14,000 acres are lost each year primarily to residential development. Wood cutting accounts for a similar amount, although the effects are reversible. Oak woodlands are a significant natural resource providing soil stabilization, ground water recharge, air and water quality, wildlife habitat, nutrient cycling, recreational opportunities, wood production, livestock grazing, and esthetic qualities. Urban development, undeniably, has had a major impact on these values. Current building policies seldom require careful site assessment of oak woodlands before development, to minimize tree removal and/or protect high-value trees, stands, or critical habitat areas. In addition, the cumulative environmental effects of unrestricted development are rarely considered. It is still permissible, in some counties, to clear and mass-grade wooded land to facilitate development. Moreover, many cities and counties lack effective tree preservation ordinances or staffing for enforcement. Thus, more trees are removed than necessary, and those designated for retention are often inadvertently killed or damaged. Attempts to preserve important stands or groups of oaks and individual trees during development are often unsuccessful because of poor planning, lack of coordination, and inadequate tree protection measures.

Habitat Fragmentation

Remaining oak woodlands are becoming increasingly fragmented as large blocks are progressively subdivided. The end result is reduced wildlife habitat.

[1]An abbreviated form of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Fragmentation isolates plant and animal populations by restricting their movement/dispersal. Many animals must move daily in search for food, water, and shelter. Their survival is dependent on access to favorable habitat. Wildlife abundance and diversity depend on large-scale, interconnected open space. Roads, fences, structures, and other barriers which limit movement to suitable habitat affect dispersal and/or migration. Isolated populations face greater competition for limited resources and are unable to interbreed with other populations. Consequently species' health may suffer. In addition, many native plants depend on wildlife to disperse their seed to maintain or increase distribution. When roads and homes are built in the wildlands, vegetation is removed, streams are often diverted or channelized, drainage patterns are altered, wildfire is suppressed, and exotic plants and animals are introduced. Species adapted to the native habitat and to the natural ecological processes may not survive.

Planning and Resource Management

Many municipalities under pressure for residential development have expanded rapidly into their surrounding oak woodlands with little regard for natural resource management and open space planning. Local, county, and regional planners and political leaders thus play key roles in managing the remaining oak woodlands and their associated values. Planning must address the impacts of development on a large scale (landscape, county, or regional basis), rather than on an individual tree or stand basis. Instead of passing ordinances that prevent the removal of trees during development or on private property, it is more important to plan for the long-term maintenance of large blocks of interconnected open space. Planners must balance the need to preserve valuable oak resources with the need for some economic development and urbanization.

Elements of Successful Planning and Resource Management

- Recognize the inherent community and ecological value of oak woodlands.
- Survey and assess the local oak/hardwood habitats and associated plant and animal populations.
- Obtain technical input from staff specialists or private consultants.
- Identify species most sensitive to development.
- Identify habitat with highest wildlife values, e.g., riparian areas.
- Understand local ecological processes, e.g., fire, flooding, water flow, etc.
- Identify areas of high fire hazard and determine whether and how development in such areas should take place, e.g., fuel modification requirements, building material standards, structure siting, and landscaping restrictions, etc.
- Define local development goals and policies regarding public and private land use, and provide for adequate open space preservation and resource management in the general plan.
- Set urban growth boundaries and future development zones.
- Develop a natural resources management strategy.
- Target specific habitats for preservation and other compatible uses.
- Regulate land use by zoning (mapping based on habitat/species survey).

- Specify management practices for targeted habitat areas.
- Shift development away from high-quality habitat or protect it while allowing some economic use, e.g., cluster housing to retain larger open space and reduce fragmentation and other environmental impacts.
- Maintain corridors between targeted habitat areas.
- Plan for public access and trails.
- Seek permanent protection of targeted habitat through legislation and acquisition.
- Encourage local conservation districts to develop oak woodland management guidelines for landowners.
- Encourage landowners to develop forestry/resource management plans for their holdings.
- Encourage education and land stewardship by distributing information on tree and land management, and State and Federal incentive programs.
- Offer landowner incentives to encourage cooperation, e.g., sale or transfer of development rights, sale of conservation easments, tax reduction, etc.
- Regulate tree removal during development through a tree preservation ordinance.
- Require the posting of substantial performance bonds.
- Outline tree removal procedures, replacement standards, and required construction/excavation practices for developing around trees.
- Require mapping of oak trees and habitat on proposed subdivision maps.
- Inspect site for mapping accuracy.
- Analyze proposed subdivision plan, and suggest or require changes to minimize tree removals and impacts to existing trees/habitat.
- Inspect site during and after construction to check for compliance.
- Review proposed landscaping plan and require modification as necessary for approval.
- Require planting to mitigate for the removal of mature oaks.
- Where appropriate, regulate tree removal following development through an ordinance permitting process. Effective ordinances allow for a case-by-case review, considering the owner's needs, fire hazard or safety concerns, community benefit, and habitat degradation.
- Monitor and evaluate effectiveness of proposed habitat management measures.

Development and Oak Tree Preservation

A successful tree retention program begins with project conception and continues through the planning, design, construction, and maintenance phases. When retention efforts are delayed or ignored, tree health and survival are compromised.

Elements of a Successful Tree Retention Program

Site Evaluation (conceptual phase): A resource specialist may be required to

- Accurately map location of tree stands, groups of trees, and significant individual trees;

- Map water courses, wetlands, flood plains, unstable areas, rock outcroppings, meadows, scenic views, etc. ;
- Identify important wildlife habitat and migration corridors;
- Characterize soil conditions and drainage patterns;
- Prepare preliminary site map (building envelope, roads, parking, utility routing, etc.).

Arborist Report/Tree inventory (based on a preliminary plan):

- Accurately map all trees to be impacted by construction activities, indicating their respective root protection zones (RPZ).
- Determine which RPZ you will use:
  Dripline (industry standard).
  Dripline plus ten feet (better).
  Dripline plus 0.5 radius (best).
  40 percent tree height (conifers and fastigiate hardwoods).
  One foot of clearance for each inch of diameter at breast height (wide- spreading crowns and young trees).
- Number and describe all trees in list form, e.g., species, height, diameter class, condition, health, defects, etc.
- Indicate all trees to be removed and evaluate border-line trees for removal or retention.
- Estimate percent root loss.
- Consider cumulative impacts based on local species profile.
- Recommend changes and alternatives to minimize tree loss or construction impacts.
- Base priority for tree retention on health, stability, esthetics, expected longevity, and probability of surviving construction impacts.
- Designate hazardous trees for removal.
- Recommend arboricultural care: pruning, root pruning, irrigation, hazard abatement, removals, tree wells, aeration systems, retaining walls, foundation construction (pier and beam), and other protection measures, etc.
- Provide education and facilitate cooperation.

Tree conservation plan:

- Use a team approach: include developer, owner(s), contractors, construction superintendent, architect(s), engineer(s), landscape architect(s), and arborist.
- Develop preliminary grading plan, establish building site, delineate parking, location of roads, and routing of utilities, etc., emphasizing the least impact on existing trees.
- Designate trees to remove/retain on the map and clearly mark in the field.
- Accurately map all trees that will be impacted by construction activities on the plat map.
- Delineate RPZ on the plat map.
- Indicate trees to be removed or retained on the map, and clearly mark them in the
- Prescribe arboricultural work, e.g., clearance pruning, hazard abatement, irrigation, root pruning, aeration systems, chip mulch installation to reduce soil compaction, etc.
- Stipulate all concerns to architect for final layout, e.g., utility routing, grade change, retaining walls, foundations, pavement, changes in drainage, etc.

- Recommend alternatives to minimize tree removal while retraining the most valuable trees.
- Outline **all** tree protection requirements/restrictions, and include in all construction plans and documents:
  - Designated area(s) for soil and building materials storage.
  - Method of trenching within dripline (hand dig or auger) and/or minimum distance to trunk , e.g., one foot per inch or trunk diameter.
  - Machinery access routes.
  - Location and specifications for wood chip mulch installation.
  - Designated employee parking area.
  - Designated site to clean equipment or dump toxic building materials.
  - Construction specifications for aeration systems, tree wells, and retaining walls.
  - Drainage structures and placement.
  - Method of marking trees for removal/retention.
  - Location of fencing, type of material and installation procedure, and define encroachment procedures.
- Discuss tree preservation concerns with foremen, subcontractors, equipment operators, and utility representatives.
- Require performance bonds to assure compliance and set penalties for infractions.

Plan review: (arborist reviews preliminary excavation/construction/landscaping plan:

- Look for discrepancies.
- Ensure that adequate root protection measures will be taken.
- Provide guidance, list alternatives and negotiate with engineer to modify plan.
- Plan to minimize impacts where possible.

Pre-construction:

- Mark and fence RPZ's, and clearly mark trees for removal retention.
- Post signs to warn equipment operators and contractors.
- Clear brush, prune trees, remove hazard and marked tree, do root pruning, Irrigation, install chip mulch, etc.
- Stake or mark utility routing, roads, foundations, and retaining walls.

Construction:

- Provide for periodic arborist supervision, especially during critical phases, e.g., grade change, road construction, aeration and drainage system installation, trenching for footings, foundations and utilities near trees.
- Report infractions to construction supervisor and assess fines for tree damage or death. Use the International Society of Arboriculture tree valuation method to determine value.
- Provide education and facilitate cooperation.

Post construction:

- Pruning of damaged limbs.
- Irrigation, fertilization, mulching, etc.
- Soil aeration
- Monitoring, pest management.
- Education of new owner about landscape maintenance.
- Review landscaping plan and make appropriate recommendations.

Managing California's remaining native oak resources is largely dependent on a combination of strategies, e.g., General Plan development, resource conservation planning, development standards, ordinances, education, and incentive programs.

Available Resources

Technical Advice: Integrated Hardwood and Range Management Program (University of California at Berkeley); Natural Diversity Data Base (California Department of Fish and Game, Sacramento).

Resource mapping: Oak Woodland Mapping (California Department of Forestry and Fire Protection, Strategic Planning Program, Geological Information Survey, Sacramento; California Wildlife Habitat Relationships (WHR Data Base) (California Department of Fish and Game, Sacramento).

Improved Methods to Evaluate the Impact of Subdivisions on Wildlife in Oak-Dominated Woodlands in California[1]

Dale Sanders[2] **Michael Baefsky**[3]

Abstract: *This study includes a review of scientific and planning literature, interviews with practicing wildlife biologists, and an analysis of case studies (development projects) located in Northern California and concentrated in oak woodlands at the urban/wildland interface. The goal was to discover and test improved methods for the assessment of wildlife populations and biological diversity where subdivisions have been built.*

Our analysis indicates that a major problem is a lack of communication between professionals in the disciplines of planning and wildlife biology leading to poor understanding of ecological concepts in the preparation of reports and planning documents.

We found that there are few, if any, standardized methods or consistent qualifications for those engaged in the preparation and interpretation of biological surveys and environmental documents. The information presented in environmental assessment documents often lies somewhere between guesswork and science, generally, within the realm of anecdote. Oftentimes, what passes as evidence of absence is, in reality, absence of evidence.

Promising methods and techniques which could improve the wildlife analysis and the decision-making process are: standardized survey methods, improved documentation, use of the compact camcorder, analysis based upon the principles of landscape ecology (ecosystem ecology), the use of adaptive management strategies, and development of community-based coordinated resource management and planning processes (CRMPs).

There are significant impacts on wildlife (defined by the U.S. Fish and Wildlife Service as all living things) because of the land-use policies and regulations governing subdivisions in California. To understand these complex interactions, one must delve into the local, state, and federal statutes, programs, and administrative activities. There are some fundamental and significant uncertainties regarding the impacts development in urbanizing areas of California, particularly in the oak woodland/urban interface.

Over the past two decades, subdivision development and ranching in and adjacent to oak woodlands in California have caused significant losses of oak woodlands (Barbour and others 1993, Pavlik and others 1991). The loss of oak woodland habitats and the decline of wildlife species associated with those habitats appear to be interrelated. However, quantifying this apparent relationship has only recently come under scientific investigation (Block and Morrison 1990 and Block and others 1990). The conversion of forest, farm, and grassland into urban/suburban subdivisions is contributing to the decline of certain habitats and wildlife and may be leading to the ascension of others (Jensen and others 1993). Buildings, concrete, blacktop, and manicured landscapes support populations of exotic wildlife such as starlings, house mice, and argentine ants which may compete with or disrupt native species (Jahn 1991). Subdivisions may also create isolated islands or fragmented remnant habitats (Morrison and others 1992, Soulé 1991).

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, California

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Literature Review

Our survey of the scientific literature included peer-reviewed articles, refereed journals, and proceedings and transactions from technical conferences of professional organizations.

Describing the type of oak woodland or other habitat type is part of analyzing a subdivision's impact on wildlife (Allen 1987). The use of mathematical models for predicting occurrences of wildlife within given habitats shows some promise with bird species (James and Shugart 1970, Morrison and others 1987, Raphael and others 1988).

Studies to detect presence and numbers of animals are many and include studies on birds (Morrison and Meslow 1983, Soulé 1991, Verner 1987), mammals (Barrett 1987, Hayne 1978) and herpetofauna (Grant and others 1992, Welsh 1987).

There has been a significant increase in what might be called anecdotal literature, focusing on the human and biological consequences of activities in the urban/wildland interface. There is a growing recognition that there is a lack of quantifiable data demonstrating the effects of the human desire to convert natural landscapes to "higher and better uses" at the potential expense of natural resources (Beatley 1994, Giusti 1993, Keeley 1993, Platt and others 1994). Some planning agencies are developing strategies which directly apply to regulation and management of the environment. For example, the County of Tuolumne developed a Wildlife Project which included mapping and inventory work, specific mitigation measures, a process for evaluating wildlife impacts, and, most importantly, specifications for a monitoring program (Grandholm 1987). The process is still functioning and is being updated and expanded (Augustine 1996). Santa Barbara County has a mitigation and critical habitat program through the use of a Master Environmental Assessment, which focuses on developable areas in specific plans (Santa Barbara County Department of Resource Management, 1992).

The University of California Integrated Hardwood Range Management Program (IHRMP) has published the *Planners Guide for Oak Woodlands* (Giusti and Timmins 1993), *Quercus*, *Wildlife Among the Oaks: A Management Guide for Landowners* (Johnson 1994) and *Landscape Conservation Planning: Preserving Ecosystems in Open Space Networks* (Peck 1993).

There are aids to help planners and biologists communicate. The *Wildland Planning Glossary* is a classic, but it is out-of-date (Schwartz and others 1976). Perhaps the single most important recent publication to address California's natural resources is *Life on the Edge: A Guide to California's Endangered Natural Resources, Wildlife* (Thelander and Crabtree 1994). This thorough reference is insightful and honest about the future of the state's landscape. It should be a text for anyone interested in the diversity and complexity of California.

There has been an increased interest in joint ventures aimed at expanding general awareness and education regarding wildlife. The Wild Earth Project is in its third year and is a combination of efforts by environmental/conservation groups and well-known conservation biologists such as Reed Noss and Michael Soulé under the auspices of the Cenozoic Society. Their publication *Wild Earth* is very informative, is written in an understandable manner, without jargon and gets to the heart of the difficulties of addressing and affecting significant changes in how we humans act as stewards of the natural landscape (Wild Earth 1995/96).

Supplemental Interviews with Practicing Professional Wildlife Biologists

Five wildlife biologists were interviewed for the purpose of surveying the apparent gap between scientific and other published literature and the actual practice of applied wildlife biology. All of the professionals interviewed are involved in the planning process and its relationship to wildlife and habitat evaluation. The purpose of the interviews was *not* to provide statistical values—only to shed light on a complicated issue.

These professional wildlife biologists differed on some details but were mostly concerned with the amount of time spent in the field, adequacy of training and uniformity and consistency of observations and reporting. They expressed a lack of confidence in mitigation measures but were highly supportive of good mapping and documentation of resources.

Case Study Analysis[4]

For inclusion in this study, projects had to meet certain criteria: (1) location in oak-dominated woodlands of unspecified species composition, (2) sites located in the urban/wildland interface, (3) some record of wildlife investigation and analysis, (4) project approved and at least partially built, and (5) accessible for field investigation.

Selection began with queries to the California State Clearinghouse database, various counties, and cities and regional governments. Five central and northern California counties were contacted. Ten environmental impact reports (EIRs) were reviewed, and eventually four projects were selected, two in Solano and two in Contra Costa Counties.

A critique of information provided and existing methods used for evaluating wildlife populations in proximity to subdivisions in EIRs was carried out in this portion of the study. We identified and evaluated existing procedures and potential techniques which may be useful to planners and field biologists involved in the process of recommending and making decisions about wildlife and subdivisions. Project EIRs were reviewed and analyzed; the treatment of wildlife impacts, discussion of habitats, and mitigation measures were reviewed.

The goal of conducting field surveys for each potential case study was to become familiar with the general urban and wildland context of subdivisions in oak woodlands, to assess the usefulness and accuracy of the planning and environmental literature for the specific case study as well as the applicability of available scientific information.

The goals for the field surveys for each project were: (1) to become familiar with the general context of each subdivision, (2) to determine the level of development completion, (3) to compare the extent and quality of information presented in the environmental documents, and, (4) to develop parameters and conduct field testing of new methodologies.

[4]Detailed analysis of the professional interviews and case studies are available in the complete report under separate cover from the IHRMP office at 160 Mulford Hall, University of California, Berkeley, CA 94720 and at the Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture, P.O. Box 245, Berkeley, CA 94701-0245

Discussion and Conclusions

Some difficult questions must be addressed if significant progress is to be made in the arena of resource protection and prevention of wildlife losses in oak woodlands and other habitats. Clearly the majority of land-use and resource management decisions operate between guesswork and science along the lines of informed anecdote.

We have identified several problems with the current methods used to evaluate potential impacts on wildlife in oak woodlands. These include regulatory and California Environmental Quality Act (CEQA) issues, adequacy of studies and surveys conducted for CEQA documents, professional communication and training, and the lack of bioregional land-use planning.

Regulatory and California Environmental Quality Act Issues

There is an expectation that the resource protection agencies are looking out for the public's interest in public resources. With the exception of water rights and the Endangered Species Act, there is little legal protection for wildlife on private land. Clearly, private property rights prevail over the responsibility of public agencies to enter lands for the purpose of protecting organisms and/or habitat. Given today's deregulation environment at the state and federal levels, it is unlikely that the public interest in these issues could be elevated to "protection at any cost" (i.e., regardless of private property rights).

In the process of developing land, regulatory forces can influence habitat and wildlife populations. California oak woodland habitat is affected by regulatory actions initiated at city and county levels (Barbour and others 1993, Whittington and Tietje 1992). The discretionary decisions by local governments in approving development projects are primarily nested in general plan and zoning statutes, the Subdivision Map Act, CEQA (1986, California Code of Regulations, CCR Section 15000 *et seq.*) and its Guidelines (Public Resources Code Section 21000 *et seq.*, PRC), and the local implementation through county and city ordinances. And even though California has some of the most detailed and restrictive land-use and planning controls in the nation, there is a "lack of effective wildland land-use planning" (Irwin 1987, 1995).

Replicated experiments and statistical analyses are not required for the preparation of planning documents. CEQA (1986) states, in Section 15147, that an EIR in its analysis "need not be exhaustive.... does not need to be perfection.... good faith effort at full disclosure" 1986). All but a few studies conducted for CEQA documents are "descriptive" studies. They provide estimates and descriptions of the status of a habitat and its inhabitants and do not normally involve "treatments," "test plots," "randomization," or "replication," which are expected in experimental studies. It is apparent that field studies for environmental and planning documents seldom ask the ecological questions, let alone predict outcomes with any testable certainty (Schamberger and O'Neil 1986).

Application and practice of planning and environmental laws and other regulations are often irregular and vary at the local level because of policy, tradition, personal attitudes of decision-makers, and interests of professionals staffing the land-use agencies. The end result is that CEQA is the primary vehicle for citizens and agencies to have input into the planning process. Despite this public process, significant and unmitigated impacts on wildlife may remain. The lead agency decision-makers still have the discretion to approve a project with a "statement of overriding consideration of public good and benefit," (CEQA Section 15093(b)). Too often, disagreements end up in court, resolved to the letter of the law, rather than the legislative intent or spirit (i.e., to improve California's environment).

Adequacy of Studies and Surveys

The basic problem with CEQA is that it does not differentiate between data and analysis prepared by a first-year graduating biology student and a published researcher who may be the leader in her/his field.

Our examination of the EIRs for our case studies pointed out many potential problems. The EIRs and maps are often incomplete or inaccurate: surveys did not encompass the entire project site, no season or time of day was indicated for some surveys, important habitats and conditions were not reported or analyzed, the project description and maps used in the EIRs did not necessarily correlate with the as-built project, and some mitigation measures were completed while others were not incorporated into the conditions of approval or final improvement plans for the project.

In one case, the EIR for Baywood indicated that riparian and wetland values were sacrificed to accommodate utilities, roads, yards, and homes, while the apparent benefits of preserving large areas of grassland and oak woodland by providing common open space may be outweighed by fragmentation and destruction of other habitats not preserved as open space. Was it worth the loss? A herpetologist might give you a different opinion than an oak woodland specialist. The comparison between the subdivisions providing common open space with smaller concentrated housing lots and the large lot subdivisions with no tracts of common oak woodland and grassland is commonly understood to reduce fragmentation and provide corridors in the former and not the latter. But, scientific criteria have seldom been applied to analysis of these situations to bring any facts to bear on decisions to approve or deny subdivisions.

Few documents we reviewed discussed important ecological concepts such as ecotones, edge effects, niches, or recognized that what you may record about a subject could change significantly minutes or hours later. While numerous techniques for monitoring populations of wildlife are suggested in the scientific literature, few are used by biologists involved in the preparation of relevant sections of EIRs or other environmental documents used in the land use decision-making process (Hayne 1978, Morrison and others 1992, Raphael and others 1988).

According to recent testimony to Congress regarding the requirements and regulations within the Endangered Species Act (ESA) and the National Biological Survey (NBS), landowners and developers are fighting data collection. They fear that new information (e.g., a new location for a listed endangered species) will have a negative impact on their actions or plans (Lewis 1995). Some of the NBS scientists have said, "somewhere along the line, some people figured out that information, true information, is not their friend," and "good science does not always mean good business, at least in the short term."

Professional Communication and Training

The need for better communication is apparent from several recent articles drawing attention to a gap in information and understanding (Giusti 1993, Grumbine 1994, Soulé 1991, Turner and Gardner 1990). We need to speak a common language if we are to fill these gaps with better data, objective documentation, ecological understanding, and, hopefully, sustainable management action.

Professional biologists, as well as non-scientists with experience in various disciplines, are employed to prepare sections of planning documents related to habitat and wildlife; few reports have glossaries or definitions of terms and concepts. These professionals use a variety of standards, languages, and methodologies to assess the environment. The existing gap between traditional scientific methodologies for assessing habitat and wildlife and the practices currently used in the planning process should be closed (Leopold 1992). The information in documents comes from a variety of methodologies which are then used by planning officials, and elected decision-makers make decisions about subdivisions (Johnston and Madison 1991).

A significant concern raised by our study is the qualifications of persons conducting survey work. This is an issue which should be of concern to everyone (Leopold 1992). The wildlife biologists we interviewed consistently identified this as a concern to them.

The question of who is qualified to conduct site investigations, prepare reports, evaluate results and draw conclusions is a difficult one. Criticizing old

EIRs while interpreting existing conditions makes one aware of the biases and prejudices we all bring to projects. We reviewed several certification and licensing programs to detect requirements for level of education, training, and experience. Because there is a lack of legal requirements for "a minimum level of knowledge in biology, environmental laws, or government processes, for biologists who develop or review environmental documentation," legislation for licensing of natural resource biologists has been proposed (Steele 1991). The California Board of Forestry (1991) has a licensing program under Public Resources Code (PRC), Section 750 *et seq.,* titled *Wildland Biologist*, which has limited application to planning and general environmental documents. Voluntary certification programs have been developed by several professional organizations such as the Ecological Society of America, the Association of Environmental Professionals, and the Society for Restoration Ecology. These programs rely on relatively strong ethics statements and experience parameters; the effectiveness of these programs is questionable because they are largely self-policed, voluntary, and often without peer review.

Bioregional Planning and Landscape Ecology

Our study supports others in recognizing the need for a bioregional land-use planning and landscape ecology approach to addressing social and biological issues (Giusti 1993, Naveh and Lieberman 1994). Increased fragmentation of habitat and disruption of wildlife corridors continue to be a result of the disjointed and piecemeal local land-use planning process. This can be expected to continue without a broad commitment to look at land use changes ecologically across jurisdictional boundaries. Local land-use decision-makers seldom work together on these issues. The problem is exacerbated because professional planners and field biologists do not communicate on an ongoing basis. It seems that such approaches are possible at the bioregional level where enough land could be available to meet the many goals of various landowners and resource interests.

Recommendations

These recommendations are intended to stimulate discussion over a wide range of issues and subjects; basically we want to suggest how to reduce the risk to wildlife and habitats and prevent further losses of biodiversity. Our suggestions include regulatory and administrative changes to codes and procedures, public and professional education for improving knowledge of wildlife and the use of standardized field survey methods and techniques for facilitating community involvement.

Regulatory and CEQA Actions

The Resources Agency and the Governor's Office of Planning and Research could conduct a fact-finding session or public hearing on the potential for implementing and codifying methods to improve the sustainability of wildlife and biodiversity. For example:

(1) Development and fostering of legislation to require "no net loss" of species, significant habitat, and biological diversity;

(2) Require performance standards for inclusion in Land Use and Open Space/Conservation Elements of General Plans that would influence zoning regulations and incentives and rewards for jurisdictions which use the standards;

(3) Bolster and fine-tune the California planning and environmental laws (e.g., General Plan, Subdivision Map Act, zoning statutes,

CEQA), and their uniform interpretation and application by professional planners, agencies, and decision-makers;

(4) CEQA statute and guidelines could be amended to require minimum standards for those conducting environmental assessments, how the assessment should be conducted and documented, and methods of analysis and the level of confidence associated with proposed mitigation recommendations. The biological sections of CEQA documents prepared by lead agencies should be standardized and the guidelines revised to include identification of the surveyor, a statement of field conditions and limitations for surveys (e.g., date, time, frequency of sampling, routes, a qualitative assessment of biological diversity). Furthermore, the level of confidence expressed in the analysis and conclusions of CEQA documents should have no less than 80 percent probability of accuracy. We must move towards a more scientific basis for confidence in land-use decisions;

(5) A sample section demonstrating what adequate coverage looks like should be added to the CEQA Guidelines Appendix (e.g., similar to archaeology and energy);

(6) Lead agency decision-makers could be required to make specific findings on impacts to wildlife in any "statement of overriding considerations" they may adopt. Some of these issues have recently been addressed in depth by Landis and others (1995) in their landmark study "Fixing CEQA."

Improving Adequacy of Studies and Surveys

The use of field survey techniques for assessing populations of vertebrates developed by the Museum of Vertebrate Zoology (MVZ) at the University of California at Berkeley is being tested for its applicability to assess the impacts of subdivisions on wildlife (Stebbins and others 1996a). These methods involve intensive mapping and note-taking. The use of field survey techniques in the preparation of EIRs was evaluated in our study, and this method should be considered as a minimum standard for CEQA field surveys by the State Resources Agency and the Governor's Office of Planning and Research. In addition, the California Native Plant Society (CNPS) has published guidelines for assessing effects of proposed development on rare plants and plant communities (Skinner and Pavlik 1994).

We suggest that the data collection process for environmental and planning documents can be significantly improved if resource analyses were standardized through the use of documentable techniques, be they MVZ, CNPS, or other methods.

Wildlife Habitat Relationships (WHR) program is a database that identifies habitat types and the general distribution of amphibians, reptiles, birds, and mammals within California habitats. Shortcomings of the WHR model include the lack of specific soil investigations, the use of broad descriptive units, and the omission of invertebrates. Because it is commonly used in EIRs, an analysis of the four case study sites was performed with the WHR and California endangered species listings in the and California Natural Diversity Data Base (CNDDB) program, *Rarefind*. No recorded locations for rare, endangered or threatened species or critical habitat were identified for any of the case study sites.

These general resource databases such as *Rarefind* and *WHR* are available through the California Department of Fish and Game, Natural Heritage Division. These are useful tools but they are not substitutes for carefully documented field investigation and analysis, and we recommend that they be used in conjunction with the MVZ Survey Methods, particularly if there is an opportunity to target or search for specific indicator organisms (Stebbins and others 1996b).

Video recording with the relatively inexpensive and readily available compact video recorder is an obvious candidate for increasing the quantity and quality of data gathered and retained during field surveys. The most recent version of the MVZ methods outlines how the medium can be of use in that regard. We have prepared a demonstration video on how the camcorder can be used for field surveys which is available through the IHRMP office at 160 Mulford Hall, University of California, Berkeley, CA 94720.

Professional Communication and Training

There is a need for clear working definitions of *wildlife* and *biodiversity* The terms "wildlife" and "biodiversity" have no commonly agreed upon definition, by scientists or the public. We recommend that the State of California formally adopt the U.S. Fish and Wildlife Service definition of wildlife as "all living things" and that Edward O. Wilson's (1992) definition of biodiversity be adopted: "The variety of organisms considered at all levels, from genetic varieties belonging to the same species to arrays of species, to arrays of genera, families and still higher taxonomic levels; includes the variety of ecosystems which comprise both the communities of organisms and the particular habitat and physical conditions under which they live" This definition implies that biodiversity is not just an extensive list of organisms, but also includes the systems and functions it takes to maintain and sustain the organisms.

Please see recommendations above on training and outreach under ***Regulatory and CEQA Actions***.

Bioregional and Landscape Planning

Landscape ecology is a unifying concept that ensures that all factors are considered. Its principles and practice allow us to deal with issues from the perspective of property owners who are more likely to become involved if it is understood that they and their concerns are accommodated from the beginning while still addressing the need for objective scientific criteria. So, landscape ecology provides a mechanism to converse and understand the forces at work at the urban/wildland interface. The concepts of ecology and economics can be dealt with simultaneously and from a regional perspective.

The State Resources Agency and the Governor's Office of Planning and Research should develop a policy for implementing a statewide program to establish landscape ecology as the guiding philosophy for environmental considerations in California (Naveh and Lieberman 1994).

An adjunct to landscape ecology is adaptive management which is an emerging approach to quantification of management decisions and testing success of actions. The principles and practices of adaptive management have direct application to natural or renewable resources. One of the most important features is the requirement that management actions *must* have a monitoring or feedback element to determine whether the actions were successful. The principles have been applied to USDA Forest Service programs (e.g., Sequoia National Forest) and some Canadian fisheries programs. Adaptive management would be an appropriate approach to improve the level of confidence in approved mitigation measures. A confidence level of 80 percent has been proposed for use in the planning process (Sanders and Baefsky 1994), in contrast to 95 to 99 percent levels commonly used in science-based experimental research; this seems more realistic and defensible with the reliance on a scientific monitoring program that strives for higher confidence levels through a feedback and review process.

Coordinated resource management and planning (CRMP) a current method for developing bioregional biodiversity planning by federal, state, and local agencies in conjunction with non-governmental organizations and individuals, through a memorandum of understanding, appears to be working in California (Hoshofsky 1992). Perhaps this process provides the greatest opportunity to address the major problems of habitat fragmentation and destruction of physical corridors through bioregional planning by increasing opportunities for serious discussions about the importance of resource issues in California (CRMP 1993, Giusti 1993, Tietje and Berlund 1995). The beauty of the CRMP process is that *all* stakeholders have a place at the negotiating table and when the process is completed, they will all leave with the feeling that they were heard and made written commitments to each other. No one will get all they want, but history has shown that this process often leaves permanent bonds between people and places and the work will be accomplished in the field where it matters and not at the podium where rhetoric rules over reason.

This report is presented against the backdrop of two considerations which run through our analysis and understanding of the problems presented. First, there seems to be an unwritten assumption on the part of the general public—a belief, rather—that our public wildlife resources are being looked after and protected by someone, and second, there seems to also be a notion that absence of evidence is synonymous with evidence of absence. Neither of these assumptions is borne out by our study. There needs to be a public trust doctrine with regard to wildlife protection and a greater demand for scientific proof that there will be no net loss of wildlife values resulting from the development process. Our finding is that these two issues must become important in the minds of the public and elected officials if significant progress is to be made in lowering risk to wildlife and prevention of loss of biodiversity and extinctions in oak woodlands and other habitats in the urban/wildland interface in California.

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References

Allen, Barbara 1987. **Ecological type classification for California: The Forest Service approach**. Gen. Tech. Rep. PSW-98. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 8 p.

Augustine, Amy, Principal, Augustine Consulting, Sonora, CA. [Telephone interview with Dale Sanders.] 5 January 1996.

Barbour, Michael; Pavlik, Bruce; Drysdale, Frank; Lindstrom, Susan. 1993. **California's changing landscape: diversity and conservation of California vegetation**. Sacramento: 246 p.

Barrett, Reginald H. 1987. **Monitoring small mammal populations in oak woodlands.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 223-226.

Beatley, Timothy. 1994. **Habitat conservation planning.** Austin: University of Texas; 234 p.

Block, William; Morrison, Michael L. 1990. **Wildlife diversity of the central Sierra foothills.** California Agriculture 44(2): 19-22 .

Block, William H.; Morrison, Michael L.; Verner, Jared. 1990. **Wildlife and oak woodland interdependency.** Fremontia 18(3): 72-76.

California Board of Forestry. 1991. **Public Resources Code, Section 750, *et seq.***

California Environmental Quality Act, 1986. **California Code of Regulations, Section 15000 *et seq.***

California Environmental Quality Act, *Guidelines*, 1986. **Public Resources Code, Section 21000 *et seq.***

Coordinated Resource Management and Planning. 1993. **CRMP Handbook.** Sacramento: Natural Resource Conservation Service, U.S. Department of Agriculture; 23 p.

Giusti, A. Gregory. 1993. **Managing the human element in bio-regional and bio-diversity planning: an extension approach.** Proceedings Annual Conference, Western Section, The Wildlife Society, Monterey, California: 1-9.

Giusti, Gregory A.; Timmins, Paula J., eds. 1993. **A planner's guide for oak woodlands**. Berkeley: University of California, Integrated Hardwood Range Program and Sacramento: California Department of Forestry and Fire Protection; 94 p.

Granholm, Stephen L. 1987. **Wildlife Project Handbook, Tuolumne County Wildlife Inventory and Evaluation Project.** Sonora, CA: Tuolumne County Planning Department.

Grant, Bruce W.; Tucker, Anton D.; Lovich, Jeffrey E.; Mills, Anthony M.; Dixon, Philip M.; Gibbons, J. Whitfied. 1992. **The use of cover boards in estimating patterns of reptile and amphibian biodiversity.** In: McCollough, Dale R.; Barrett, Reginald, eds. Wildlife 2001: populations. London and New York: Elsevier Applied Science; 379-403.

Grumbine, R. Edward, ed. 1994. **Environmental policy and biodiversity.** Washington, DC: Island Press; 415 p.

Hayne, D.W. 1978. **Experimental designs and statistical analyses in small mammal populations studies.** In: Snyder, Dana P., ed. Populations of small mammals under natural conditions. Proceedings of the Pymatuning Symposium on Geology. Pittsburgh, PA: University of Pittsburgh Special Publication Series S:3-13.

Hoshofsky, Mark. 1992. **Developing partnerships in conserving California's biological diversity.** Fremontia 20(1): 19-23.

Irwin, Robert L. 1987. **Local planning considerations for the wildland-structural intermix in the year 2000**. Gen. Tech. Rep. PSW-101. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 38-46.

Irwin, Robert L. 1995. **"What do we do now, Ollie?"** In: Weise, David R.; Martin, Robert E., technical coordinators. The Biswell symposium: fire issues and solutions in urban interface and wildland ecosystems; 15-17 February 1994; Walnut Creek, CA. Gen. Tech. Rep. PSW-GTR-158. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 17-21.

Jahn, Laurence R. 1991. **Foreword.** In: Rodiek, J.E.; Bolen, E.G., eds. Wildlife and habitats in managed landscapes. Washington, DC: Island Press; xvii.

James, Frances C.; Shugart, Herman H., Jr., 1970. **A quantitative method of habitat description.** Audubon Field Notes 24: 727-736.

Jensen, Deborah; Torn, Margaret S.; Harte, John. 1993. **In your own hands: a strategy for conserving California's biological diversity.** Berkeley: University of California Press; 302 p.

Johnson, Sharon C. 1994. **Wildlife among the oaks: a management guide for landowners**. Berkeley: Integrated Hardwood Range Management Program, University of California; 8 p.

Johnston, Robert A.; Madison, Mary E. 1991. **Planning for habitat protection in California: state policies and county actions to implement CEQA through improved general plans**. Sacramento: California Department of Forestry and Fire Protection, Forest and Rangelands Resources Assessment Program; 1-12.

Keeley, J.E., ed. 1993. **Proceedings of the symposium: interface between ecology and land development in California**. Los Angeles: Southern California Academy of Sciences; 297 p.

Landis, John D.; Pendall, Rolf; Olshansky, Robert; Huang, William. 1995. **Fixing CEQA: options and opportunities for reforming the California Environmental Quality Act.** Volume 1. Berkeley: California Policy Seminar, University of California; 202 p.

Leopold, Luna. 1992. **Symposium proceedings. Panel discussion and comments. Science, biodiversity, and the public trust doctrine;** 7 May 1992; Sacramento, CA: State Lands Commission; 3p.

Lewis, Michael; Doyle, Michael. Contra Costa Times, August 28, 1995, page 14A.

Morrison, M.L.; Meslow, E. Charles. 1983. **Bird community structure and early growth clearcuts in western Oregon.** American Midland Naturalist 111(1): 129-137.

Morrison, M.L.; Timossi, I.C.; With, K.A. 1987. **Development and testing of linear regression models predicting bird-habitat relationships**. Journal of Wildlife Management 511(1): 247-253.

Morrison, Michael L.; Marcot, Bruce G.; Mannan, William R. 1992. **Wildlife habitat relationships: concepts and applications.** Madison: University of Wisconsin Press; 343 p.

Naveh, Zev; Lieberman, Arthur S. 1994. **Landscape ecology: theory and practice.** 2d ed. New York and Berlin: Springer-Verlag; 360 p.

Pavlik, Bruce M.; Muick, Pamela C.; Johnson, Sharon; Popper, Marjorie. 1991. **Oaks of California.** Los Olivos, CA: Cachuma Press, Inc. and The California Oak Foundation; 185 p.

Peck, Sheila 1993. **Landscape conservation planning: preserving ecosystems in open space networks.** Berkeley: Integrated Hardwood Range Management Program, University of California; 72 p.

Platt, Rutherford H.; Rowntree, Rowan; Muick, Pamela C., eds. 1994. **The ecological city: preserving and restoring urban biodiversity.** Amherst: University of Massachusetts Press; 291 p.

Raphael, M.G.; Rosenberg, K.V.; Marcot, B.G. 1988. **Large-scale changes in bird populations of Douglas-fir forests, Northwestern California.** Bird Conservation 3: 63-83.

Sanders, Dale; Baefsky, Michael. **Perspectives.** In: *Quercus* March, 1994. Published by the Integrated Hardwood Range Management Program, 160 Mulford Hall, University of California, Berkeley, CA 94720; 3-4.

Santa Barbara County Department of Resource Management. 1990. **Environmental threshholds and guidelines manual.** Santa Barbara, CA: Santa Barbara County Department of Resource Management; 59 p.

Santa Barbara County Department of Resource Management. 1992. **Standard conditions of approval and standard mitigation measures**. Santa Barbara, CA: Santa Barbara County Department of Resource Management; 39 p.

Schamberger, Melvin L.; O'Neil, Jean L. 1986. **Concepts and constraints of habitat-model testing.** In: Verner, Jared and others, eds. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. Madison: University of Wisconsin Press; 8-10.

Schwartz, Charles F.; Thor, Edward M.; Elsner, Gary H. 1976. **Wildland planning glossary.** Gen. Tech. Rep. PSW-13. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 252 p.

Skinner, Mark W.; Pavlik, Bruce M. 1994. **Inventory of rare and endangered vascular plants of California.** Sacramento, CA.: California Native Plant Society; 388 p.

Soulé, Michael E. 1991. **Land use planning and wildlife maintenance: guidelines for conserving wildlife in an urban landscape**. Journal of the American Planning Association 57(3): 313-323.

Stebbins, Robert C.; Staff of East Bay Municipal Utility District. 1996a. **Biological survey studies. Guidelines 1. Gathering and recording wildlife information.** Oakland, CA: East Bay Municipal Utility District; 37 p.

Stebbins, Robert C.; Staff of East Bay Municipal Utility District. 1996b. **Guidelines 2. Inventory of plants and animals on watershed lands of the East Bay Municipal Utility District.** Oakland, CA: East Bay Municipal Utility District; 40 p.

Steele, James. 1991. **Proposal for the natural resource biologists law, Department of Fish and Game**, State of California, Department of Fish and Game, Environmental Services Branch, November 4, 1991; 9 p.

Thelander, Carl; Crabtree, Margo. 1994. **Life on the edge: a guide to California's endangered natural resources. Wildlife.** Santa Cruz, CA: Biosystems Books; 550 p.

Tietje, William; Berlund, Tristan. 1995. **Land-use planning in oak woodland: applying the concepts of landscape ecology using GIS technology and the CDF oak woodland maps.** In: *Quercus*, Fall 1995. Berkeley, CA: Integrated Hardwood Range Management Program, University of California, 160 Mulford Hall, Berkeley, CA 94720; 1-8.

Turner, Monica G.; Gardner, Robert H., eds. 1990. **Quantitative methods in landscape ecology.** Ecological Study Series Vol. 82. New York and Berlin: Springer-Verlag; 536 p.

Verner, Jared. 1987. **Birds of California oak habitats: management implications.** In: Plumb, Timothy, R., technical coordinator. Proceedings of the symposium on ecology, management and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 246-264.

Welsh, Hartwell H. Jr., 1987. **Monitoring herpetofauna in woodland habitats of northwestern California and southwestern Oregon: a comprehensive strategy** In: Plumb, Timothy R., Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 203-213.

Whittington, Jan M.; Tietje, William D. 1992. **Saving native oaks calls for planning**. California Agriculture 46(2): 20-23.

Wild Earth. Winter 1995/96 Vol. 5 (#4). Published by the Cenozoic Society, Richmond, Vermont; 97 p.

Wilson, Edward O. 1992. **The diversity of life.** New York: W.W. Norton & Co.; 424 p.

DAMAGING AGENTS AND PROTECTION

VII

Section Overview

Damaging Agents and Oak Ecology: Management Implications[1]

Tedmund J. Swiecki[2]

Oaks, like most trees, have indeterminate life spans. Damaging agents kill oaks in all age classes and thereby limit the longevity of individual oaks. People who manage oak trees or woodlands are concerned with the health and survival of oaks and must therefore deal with the effects of various damaging agents. Before considering any action to reduce or mitigate damage, an oak manager needs to identify the causal agents and factors and must assess their individual and cumulative impacts. This process requires an understanding of the ecological relationships between oaks and damaging agents.

Oaks evolved under the challenge of various abiotic factors. Some of these factors, such as soil moisture and temperature, are not intrinsically harmful but can become damaging when they reach levels beyond an oak's range of tolerance. Not all oak life stages tolerate the same range of environmental conditions: mature oaks may withstand temperature and moisture extremes that would kill seedlings of the same species. Environmental factors that become critically damaging to one or more oak life stages limit the geographic distribution of the species and may also limit each species to certain kinds of sites within its range. When oaks are growing in favorable sites within their native range, natural abiotic factors usually cause little damage except under atypical conditions, such as extended droughts, high winds, or floods.

Oaks have also evolved under the relentless attack of many different biotic agents. Over time, natural selection tends to weed out the most susceptible host genotypes, so an oak population typically exhibits a moderate level of resistance or tolerance to native pests and pathogens. Nonetheless, oaks may be seriously damaged or killed by some native biotic agents. Under natural conditions, insects and vertebrates that consume acorns can adversely affect oak reproduction. Native pathogenic wood-decay fungi are responsible for most natural mortality of mature oaks. Indeed, in combination with environmental factors, damaging biotic agents may act to limit the native ranges of oak species.

In 1769, or about one to two oak generations ago, the first Spanish settlement was established in California. Since that time, California oaks have been subjected to various new damaging agents which were introduced by settlers. Livestock directly damage and kill young oaks by browsing and trampling and cause further indirect damage by compacting soil and removing organic matter from the soil surface. Livestock grazing has also contributed to the replacement of native understory grasses and forbs with competitive, non-native grasses and weedy broadleaf species. These herbaceous species can rapidly deplete soil moisture, increasing water stress in oak seedlings. Grazing-related changes in the herbaceous layer and the elimination of vertebrate predators have influenced rodent populations and may have increased the amount of damage caused by these native agents.

[1]Presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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Humans have also unwittingly introduced into California various insects and pathogens that damage oaks. Non-native pests and pathogens have the potential to cause greater damage to oaks than native pests because there has been no opportunity for adaptive selection to occur. Fortunately, non-native pests and diseases do not appear to have greatly affected California's oak resource to date. State quarantine and inspection programs have prevented the introduction and establishment of especially serious exotic agents such as gypsy moth and oak wilt, at least so far.

In the past 150 years, humans themselves have become the most significant of all the agents that damage oaks in California. Californians have cut countless oaks to obtain wood products and have cleared vast areas of oak woodland for agriculture and urban uses. Human activities also result in much unintentional oak damage and destruction, especially at the urban-woodland interface. Activities related to development and construction can greatly alter the environmental conditions under which oaks have been growing. Many of these activities, such as grading, trenching, paving, and compacting the soil, can damage oak roots directly. These and other activities (e.g., groundwater pumping, diverting watercourses, irrigating) can also change site microclimate and alter soil moisture and aeration levels to the point that oaks become more susceptible to other damaging agents.

Throughout California's oak woodlands, but especially at the urban-woodland interface, humans have drastically altered the ecosystem in which our native oaks have evolved. Native oak species must now resist the combined action of many different natural and human-related damaging agents acting simultaneously or in sequence. Together, these agents can debilitate or kill oaks that might otherwise tolerate natural agents acting alone. As a result, some oaks may no longer be able to survive and reproduce within portions of their historic range.

Oaks cannot evolve fast enough to adapt to the radical ecosystem changes brought about by California's nonindigenous human population. It is up to us to change our activities and management practices in ways that will allow California's oaks and oak woodlands to persist and flourish. We can follow practices that reduce or eliminate impacts related to human activities, but this alone will not make up for elevated levels of stress and damage associated with altered ecosystems. To ensure the long-term sustainability of oak woodlands, it may be necessary to focus on restoring major parts of the ecosystems in which California's oaks evolved. Although resource managers and policy makers often focus on immediate threats to oaks and oak woodlands, such as clearing for urban development, they must also realize that sparing a tree or woodland from immediate destruction will not guarantee its future survival.

The California Oak Disease and Arthropod (CODA) Database[1]

Tedmund J. Swiecki[2] Elizabeth A. Bernhardt[2] Richard A. Arnold[3]

Abstract: *The California Oak Disease and Arthropod (CODA) host index database is a compilation of information on agents that colonize or feed on oaks in California. Agents in the database include plant-feeding insects and mites, nematodes, microorganisms, viruses, and abiotic disease agents. CODA contains summarized information on hosts, agents, information sources, and the details of the host-agent interaction. Most of the 853 insect species in CODA are in the orders* Lepidoptera, Coleoptera, Hymenoptera, *and* Homoptera. *About 40 percent of the 378 species of fungi in CODA are pathogens. Of these, basidiomycete wood decay fungi have the most significant ecological impact.*

Landowners and resource managers need to consider the effects of diseases and arthropod pests on oaks when formulating management plans for oak woodlands or individual oaks. Over the past century, many different researchers have described a wide array of diseases and arthropods that affect oaks in California. However, the reports are found in numerous sources, many of which are not readily available to professionals involved with oak management in California.

As part of a project to study the impacts of diseases and arthropods on California rangeland oaks (Swiecki and others 1990, 1991a, 1991b), we set out to compile the existing information on agents affecting oaks in California. Our goal was to organize this information in a format that was readily accessible and easy to update. We developed a computerized database, the California Oak Disease and Arthropod (CODA) Host Index (Swiecki and others 1996), to store and organize preexisting and new information on arthropods, microorganisms, and abiotic factors that affect oak health in California.

Methods

Review of Literature and Unpublished Data

We obtained records for CODA from both published and unpublished sources. We reviewed numerous synoptic references and review articles and searched several computerized bibliographic databases, including AGRICOLA, BIOSIS, Entomological Abstracts, and CAB Abstracts, to obtain occurrence records. We subsequently checked most records against the original articles to verify each report and obtain additional information on the host-agent interaction.

Although we consulted nearly 2,000 publications during the literature review, our review of the literature was not necessarily complete for all groups of agents, particularly the insects. Because of time and budget constraints, we focused our initial efforts on groups of agents that were likely to cause noticeable damage to oaks. We restricted our initial search for arthropod records to phytophagous insects and mites, concentrating on taxa that are known pests of oaks or other deciduous trees in California and elsewhere. In searching for records on microbial agents, we concentrated our efforts on known or likely pathogens.

We also obtained unpublished records in the form of database files and card files from various sources, including the California Department of Food and Agriculture (CDFA); USDA Forest Service's Pacific Southwest Forest and Range Experiment Station [now Pacific Southwest Research Station]; Jerry Powell,

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Department of Entomology, University of California at Berkeley; and Isabelle Tavares, University Herbarium, University of California at Berkeley. We have also added records based on our own and others' collections and identifications. To date, we have contacted more than 125 entomologists, acarologists, plant pathologists, mycologists, and other specialists in taxonomy, forestry, and landscape pests, to supplement or confirm information obtained from the literature or other sources.

Database Design

The information in CODA is stored in a relational database composed of multiple DBase III-compatible files. The individual files store information on the host species, agents, specifics of the host-agent interaction, and the references that pertain to each combination. We developed a stand-alone software application for IBM-compatible personal computers that allows users to access the data in the CODA database (Swiecki and others 1990, 1996).

Much of the information in CODA is specific to each reported host-agent interaction, including the fields that describe the following: reported distribution of the host-agent interaction; types of growing situations (e.g., range, urban landscape) under which the interaction has been observed; host life stages attacked; host symptoms and agent signs, including the location and maturity of affected plant parts; whether the agent attacks healthy or compromised tissue; whether symptoms listed are a direct or indirect result of attack; and other notes about the interaction (*fig. 1*). Because of the limitations of available data, many records in CODA do not contain complete information in all of these fields.

CODA also contains information specific to each disease agent, host, and reference. Disease agents and arthropods are identified with hierarchical taxonomic and non-taxonomic codes. True taxonomic synonyms as well as other scientific names that have been encountered in the literature are listed in a synonym field for each agent. CODA also contains descriptions of the included oak host species, and full literature citations and descriptive notes for references (*fig. 1*).

Because of software limitations at the time that the program was developed, much of the host-agent interaction data is abbreviated or coded. All codes are described in the software documentation, and functions in the access program allow the user to translate all displayed codes on screen and in printed reports (*fig. 1*). These codes can be used in various combinations to filter records from the database.

We used Paradox® 5.0 for Windows database software (Borland International, Inc., Scotts Valley, Calif.) to tabulate statistics on the CODA database contents. Statistics are based on queries of the January 1996 version of the CODA database files.

Results and Discussion

The CODA Software

We released and distributed the first version of the CODA software in 1990. Since that time, we have edited and updated the information extensively and have released several different versions of the data and access program. As of February 1996, we had distributed more than 150 copies of the software.

The categories and format of the information stored in the CODA databases are shown in a sample report for one occurrence record (*fig. 1*). The information for a given record can be displayed on screen, sent to a printer, or saved to a text file.

Figure 1—Full-length report for the record of *Inonotus andersonii* on *Q. douglasii* printed from the CODA software.

```
Quercus douglasii                        Agent:  B P F BAS POL
Common: Blue oak                         Genus:  Inonotus
                                       Species:  andersonii
Distribution: BA,NV,CI,SV,CC             Subsp:
  Situation:  RL                        Common:  Canker-rot
     Stages:  3D                       Synonym:  Chromosporium pactolinum

                 Maturity   Site   Symptoms/Sign                            Status
----------------------------------------------------------------------------------
    Flowers:
     Acorns:
     Leaves:
   Branches:        M        HW    WROT,PCANK,FAIL,TCANK,BRES                 1d
      Trunk:        M        HW    WROT,PCANK,FAIL,TCANK,BRES                 1d
      Roots:
----------------------------------------------------------------------------------
  CODE DESCRIPTIONS:

Agent Codes:
  B      Biotic (Organisms, viruses, and genetic factors)
  P      Pathogens (disease-causing agents)
  F      Fungi
  BAS    Basidiomycetes
  POL    Polyporales (Polypores)

Distribution codes:
  BA     Bay area:  Alam,CCosta,Marin,Napa,SMateo,SFran,SClara,Solano,Sonoma
  NV     North Valley:  Butte,Colusa,Glenn,Lake,Sacto,Sutter,Tehama,Yolo,Yuba
  CI     Central Interior:  Alpne,Amadr,Calavrs,EDorad,Marip,Nev,Placer,Tuolum
  SV     South Valley:  Fresno,Kern,Kings,Madera,Merced,SJoaquin,Stanisls,Tulare
  CC     Central Coast:  Monterey,SBenito,SLuisObispo,SBarbara,SCruz,Ventura

Situation code:
  R      Range
  L      Landscape

Stage codes:
  3      Mature
  D      Dead

Maturity Codes:
  M      Mature tissues

Site Codes:
  H      Heartwood (older wood near center of stem)
  W      Wounds, includes fire scars, branch stubs, leaf scars, pruning wounds

Symptoms/Sign Codes:
  WROT   White rot (light-colored decay; spongy, stringy, crumbly, or brittle)
  PCANK  Perennial canker (discrete lesion that persists 2 or more years)
  FAIL   Failure (breakage or collapse of limbs, trunk or roots)
  TCANK  Target canker (regular, concentrically zonate perennial canker)
  BRES   Basidiocarp-resupinate (a sheet-like fruiting body)

Status Codes:
  1      Primary - agent attacks healthy tissue
  D      Direct symptom
----------------------------------------------------------------------------------
  GENERAL NOTES:

-Observations suggest that various types of target cankers, especially those
associated with old branch stubs, may be caused by the interaction between
this fungus and certain trees.
-Probably one of the most significant causes of decay and mortality in blue
oak over much of its range. In the field, distribution of affected trees is
variable, and “hot spots” or disease foci may occur.
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continued

Figure 1 continued

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REFERENCES:

 AUTHOR:   Swiecki, T. J.; Bernhardt, E. A.
  TITLE:   Field notes, observations, and collections
           1988-1992
 SOURCE:
   DATE:   1988-92
NOTES:
These records are based on field observations and material collected from
various oak hosts by T. J. Swiecki and E. A. Bernhardt. Records of these
observations are on file at Phytosphere Research, 1027 Davis Street,
Vacaville, CA 95687-5495. Phone 707-452-8735. Some of the collected materials
were deposited at the UC Berkeley Herbarium.

 AUTHOR:   Gilbertson, R. L.; Ryvarden, L.
  TITLE:   North American Polypores
 SOURCE:   Fungiflora A/S, Oslo, Norway
   DATE:   1986
NOTES:
A two-volume monograph on the fungi in the Polyporales that occur in North
America. Contains keys to species, descriptions, notes on distribution,
cultural characteristics, type of rot caused, hosts, and other data.

 AUTHOR:   Sinclair, W.A.; Lyon, H.H.; Johnson, W.T.
  TITLE:   Diseases of trees and shrubs.
 SOURCE:   Cornell University Press, Ithaca, NY
   DATE:   1987
NOTES:
A general reference to diseases of trees and woody shrubs. Includes color
photographs of symptoms, descriptions of causal agents, disease cycles,
distribution, host range, and other information.
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 AGENT NOTES:

-Widely distributed in U.S., to PA, WI, TX, AZ, CA and OR on Quercus,
Populus, Salix, and Carya.
-Causes a white rot of the heartwood of living oaks. Bark cankers are formed
where the fungus invades and kills the sapwood and cambium. Cankers are a
common site of branch or trunk failure. Infection typically occurs at wounds,
especially branch stubs.
-Basidiocarps are annual, sheetlike, often large (to over 50 cm long), and
develop under outer layers of sapwood or bark. The bark and/or sapwood is
ruptured by the basidiocarp as it matures. Spore deposits are bright golden
yellow.
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 HOST NOTES:

-Subgenus Quercus (Lepidobalanus): White oaks
-Also called mountain white oak, iron oak, post oak
-Deciduous tree with rounded crown, 6-20 m high.
-Endemic to California, blue oak grows on dry rocky slopes of foothills of
Sierra Nevada and Coast Ranges from Shasta Co to Los Angeles Co. Also extends
well out onto valley floors in areas, such as near Burch Creek and the
Sacramento River (Tehama Co) and near Thornton (San Joaquin Co).
-Bark checked, light gray to almost white.
-Leaves 3-6(-8) cm long with petiole 3-9 mm, shallowly and irregularly lobed
or entire, minutely pubescent, dull bluish green above, paler below.
-Acorns maturing the first year, variable in shape, commonly ovoid, nut 2-3
cm long, cap 12-20 mm wide, 6-10 mm deep cup to bowl shaped, scales slightly
tubercled.
-Hybridizes with Q. garryana, Q. john-tuckeri, Q. lobata.
```

Organizing the information found in CODA as a computer database application provides several advantages over presenting the same information in the form of a publication. Many of the records in CODA describe one-to-many relationships, such as an agent which occurs on many oak species. These relationships are easily organized and displayed with relational database software, but are difficult to present as printed material. By using functions built into the CODA software, the CODA databases can be filtered or queried easily to produce subsets of data. This allows the database to be used as a simple expert system for diagnosing pest and disease problems. To remain current, the information in CODA needs to be updated periodically to account for taxonomic changes and add new records and additional details. Compared with a lengthy publication, a database can be updated and distributed to users more quickly, easily, and at a lower cost.

We designed the database to easily handle simple changes in agent names. However, more complex changes, such as those that involve the lumping or splitting of taxa, require careful examination of existing records to avoid introducing inaccuracies into the database. For example, agents originally described as occurring on *Q. dumosa* Nutt. needed to be reassigned to either *Q. dumosa* (strict sense) or *Q. berberidifolia* Liebm. after the taxonomic status of this species was revised (Hickman 1993). Some records contained enough detail to be reassigned definitively, but many records could not be reassigned and have been retained provisionally under a separate host entry for the wide sense of *Q. dumosa*.

In addition to updating the data in CODA, it will also be necessary to periodically revise the user interface. The current interface software runs readily on most platforms that can run DOS applications, and 87 percent of the respondents to our 1993 user survey (Swiecki 1993) rated the program as easy or very easy to use.

CODA Host Index Statistics

The databases that comprise CODA contain information on 45 native and cultivated oak species in California, 1,259 agents that affect these oaks, and 320 references that describe these interactions. CODA contains information on 2,619 individual interactions between oaks and biotic or abiotic agents.

Native Host Oak Species

Of the oaks listed in CODA, 20 species, along with eight varieties and hybrids, are native to California. The oak species with the greatest numbers of associated agent records are listed in *table 1*. The number of agents listed for each oak species in CODA is a function of the total amount of arthropod and microbial biodiversity associated with each host species and the degree to which each host has been studied by researchers. For example, many of the arthropod records reported for *Q. agrifolia* are lepidoptera that have been collected or reared from this oak by Jerry Powell and his students over a 30-year period. If complete surveys of each oak species were conducted, it is likely that the number of agents associated with most of the native oak species would increase substantially.

Table 1—Counts of agents associated with the certain California tree oak species listed in the CODA database as of January 1996

Oak species	Arthropod species and subspecies	Diseases and microbial agents	Total number of agents
Q. agrifolia	299	148	447
Q. chrysolepis	111	58	169
Q. douglasii	141	50	191
Q. garryana	94	14	108
Q. kelloggii	150	85	235
Q. lobata	155	54	209
Q. wislizenii	132	33	165
Not specified	357	208	565

Arthropods

CODA currently contains records for 1,788 insect-oak interactions and an additional 52 interactions between plant-feeding mites and oaks. These interactions involve 853 species of insects and mites, representing 14 orders and more than 120 families (*table 2*). Although most of the conspicuous oak-feeding arthropods are included in CODA, further searching of host records for certain insect taxa would probably yield some additional records. However, some likely occurrences have not been added to CODA because the reports do not specifically indicate that the interaction has been observed in California. Many reports in the entomological literature provide only general locality information, such as western United States or Pacific Coast, and general host information, such as *Quercus* sp., and we have not included these general listings in CODA. Therefore, the total number of arthropod species that feed on oaks in California is probably much higher than the current total contained in CODA.

Table 2—Counts of families, genera, and species of mites and insects known to feed on **Quercus** *in California, listed in the CODA database as of January 1996*[1]

Order	Common name	Families	Genera	Species
Acarina	Mites	4	18	32
Microcoryphia	Bristletails	1	1	1
Embioptera	Webspinners	1	1	1
Phasmatodea	Walkingsticks	1	1	1
Orthoptera	Grasshoppers, crickets, katydids	1	3	3
Isoptera	Termites	2	3	3
Psocoptera	Booklice, barklice	6	8	8
Hemiptera	True bugs	6	9	12
Homoptera	Cicadas, leafhoppers, aphids, scales	16	69	137
Thysanoptera	Thrips	3	20	21
Coleoptera	Beetles	24	105	194
Hymenoptera	Bees, ants, wasps	13	52	172
Lepidoptera	Butterflies, moths	36	122	290
Diptera	Flies	7	11	11
Totals		121	423	853

[1]Ordinal arrangement follows Arnett 1985.

Within the CODA database, the orders Hymenoptera, Lepidoptera, Coleoptera, and Homoptera are represented by the greatest number of species. The most taxonomically diverse collection of oak-feeders is found within the Lepidoptera, which has representatives from 36 families. Most of these are leaf-mining and external foliar-feeding moths. The arthropod family represented by the greatest number of species (126) is the Cynipidae. These are highly specialized gall-forming wasps.

Few non-phytophagous arthropods are currently represented in CODA. However, only a portion of the arthropods that are associated with oaks would be classified as oak feeders. Many insects are predaceous or parasitic on oak-feeding insects and therefore indirectly depend on oaks for their existence. Also, numerous arthropods that do not feed directly on oaks live in tunnels or galls produced by oak-feeding insects. Additional insects are associated with the fungi that colonize living or dead oaks. Still other insects are detritus feeders that opportunistically feed on decaying wood, but are not necessarily limited to oaks. If these additional species are considered, there may be between 4,000 and 5,000 arthropod species associated with California oaks. This total is more than 10 times the number of terrestrial vertebrates found in oak-dominated hardwood rangeland in California (Guisti and others 1996).

Diseases and Microbial Interactions

CODA contains records of 766 interactions between *Quercus* species and abiotic diseases, and saprophytic, pathogenic, or beneficial microorganisms. Although representatives from almost all of the major groups of plant pathogens are represented in CODA, 97 percent of the microorganisms listed in CODA are fungi. Counts of non-fungal disease agents in the CODA database that are reported to affect California oaks are listed below:

Agent	*Count*
Bacteria	1
Viruses	2
Vascular plants	5
Nematodes	13
Genetic diseases	1
Abiotic agents	6
Total	28

No oak diseases caused by phytoplasmas (plant-infecting spiroplasmas and mycoplasma-like organisms) are currently included in CODA, although such agents have been found in many woody species, including oaks in the eastern United States (Sinclair and others 1994). Undoubtedly, more nonfungal microbial agents are associated with oaks in California than are currently reported. However, detecting and identifying many of these agents, including bacteria, viruses, and phytoplasmas, are difficult and require specialized techniques. Additional diseases involving nonfungal agents are unlikely to be reported in the absence of targeted research in this area.

The fungi are the best characterized group of microoganisms associated with oaks in California, largely because many fungal fruiting bodies are easy to observe and collect. Many of the associations between oaks and fungi included in CODA have not been published and are known only through herbarium records. Primary pathogens, secondary or opportunistic pathogens, saprophytes, and mycorrhizal species are all represented among the fungi in CODA *(table 3)*. Although a few individual oak diseases have been studied in some detail, most interactions between California oaks and fungi remain unexplored, and the oak-associated mycoflora probably includes many more species than are currently reported.

Table 3—Counts of fungal species associated with* Quercus *in California, subtotaled by taxonomic group*[1] *and ecological niche, listed in the CODA database as of January 1996

Taxonomic group	Pathogenic species	Saprophytic species	Mycorrhizal species	Not specified	Totals
Myxomycota					
Myxomycetes	0	11	0	0	11
Eumycota					
Mastigomycotina					
Oomycetes	6	0	0	0	6
Ascomycotina	52	67	0	1	120
Basidiomycotina	33	102	10	2	147
Deuteromycotina	65	25	1	3	94
Totals	156	205	11	6	378

[1]Taxonomic arrangement follows Farr and others (1989).

Damage to Oaks Caused by Arthropods and Diseases

Arthropods

Insects and mites feed on every part of oak trees and attack all life stages of oaks in California, but arthropod damage records for mature oaks far outnumber those for seedlings and saplings. Part of this difference is almost certainly due to the fact that mature trees have been studied in greater detail. In addition, mature trees provide a greater quantity and wider variety of arthropod feeding sites than do seedlings or saplings. For blue oak (*Q. douglasii* Hook. & Arn.), Swiecki and others (1990) observed fewer insect taxa feeding on small seedlings than on adjacent overstory trees over several seasons.

Most of the arthropods that attack oaks are native species that appear to be in ecological equilibrium with their hosts. Their aggregate impact on oak health and survival appears to be low when trees are growing under favorable conditions. However, the impact of insect and mite damage may be much more significant when oaks are stressed, wounded, or otherwise disturbed. This is especially true for insects such as bark beetles (*Scolytidae*) and wood borers. Furthermore, although much of the damage caused by insects does not significantly affect oak survival, the damage, insects, and/or their by-products (honeydew, fecal pellets, etc.) may not be tolerated in urban situations.

Insects that damage acorns can have a significant impact on this vulnerable oak life stage. CODA includes 14 insect species in seven genera which feed on or form galls in or on acorns. Of these, the filbertworm (*Cydia latiferreana* [Walshingham]) and three species of filbert weevils (*Curculio* spp.) are most destructive and may destroy a large percentage of the mast crop within a location in a given year (Keen 1958; Swiecki and others 1990, 1991a). Thus, even though relatively few species of insects damage acorns, their impact on oak reproduction can be substantial.

In contrast, at least 350 insect species feed on or produce galls on oak leaves, but the aggregate impact of these insects on the long-term health of mature oaks is generally considered to be minor. Only a few species, such as the California oak moth (*Phryganidia californica* Packard) and the fruit tree leaf roller (*Archips argyrospilus* [Wlk.]), are capable of defoliating entire trees or stands of trees. However, these and other moth larvae typically do not cause severe defoliation in successive years, and outbreaks are usually of short duration, so long-term damage to oaks is generally minimal if trees are not also stressed by other agents or factors.

Diseases

The diseases that have the greatest potential to affect the reproduction and survival of California oaks are those caused by acorn pathogens and wood-decay fungi. Both fungi (Swiecki and others 1990, 1991a) and bacteria (Hildebrand and Schroth 1967) cause decay of acorns. These pathogens most frequently gain entry through wounds caused by insects, but acorns are often severely decayed even when insect damage is slight (Swiecki and others 1990, 1991a). As a result of this synergism between microorganisms and insects, damage to the acorn crop may be elevated beyond levels that would exist if these agents acted independently. Acorn-decaying pathogens are one of several groups of acorn-destroying agents that collectively reduce the reproductive potential of California oaks.

Various species of wood-decay fungi, primarily in the Polyporales, constitute the most significant oak pathogens in California. CODA includes more than 40 species of fungi that cause branch or trunk cankers or decay the trunk, root crown, or roots of oaks growing under natural conditions. Canker rot fungi, including several species of *Inonotus*, are important pathogens of blue oak and other oaks in both rangeland (Swiecki and others 1990, 1991b) and urban settings. Canker rot fungi are wood decay fungi that attack living trees and also kill phloem and vascular cambium, giving rise to perennial cankers (Sinclair and others 1987). Trees colonized by canker rot fungi usually decline slowly and literally fall apart as large branches, and eventually the trunk, fail.

Mature oaks are also killed by root-rotting fungi. Certain fungi, such as *Armillaria mellea* and *Phytophthora* spp., are significant pathogens of urban oaks that are subjected to summer irrigation and stressed by other rootzone disturbances. Other fungi, including species of *Ganoderma* and several other fungi in the Basidiomycotina, kill mature oaks in undisturbed stands as well as those which become incorporated into urban landscapes.

In addition to causing tree mortality, wood-decay fungi also reduce the quantity and quality of wood products that may be harvested from a stand. On the other hand, these fungi play a direct role in improving wildlife habitat value. Decay caused by these fungi aids in the development of cavities in trees, which are utilized by a number of different vertebrate species. Wood-decay fungi affect the amount of dead and downed wood and standing snags in an oak woodland, which in turn contribute to wildlife habitat value (Tietje and others, these proceedings).

At least 40 species of fungi attack the leaves and/or twigs of living oaks in California. The most common and conspicuous of these are the powdery mildews (*Erysiphales*) and the anthracnose fungi. Symptoms caused by these fungi are sometimes severe enough in urban oaks to prompt concern, but these fungi normally have little impact on long-term health or survival of oaks in either urban or rangeland conditions.

Conclusions

Our knowledge and understanding of the interactions between oaks and their associated arthropods and microorganisms will continue to expand only if researchers, resource managers, consultants, and landowners recognize and exchange information on these interactions. CODA provides a means for collecting, organizing, and distributing information on these interactions. However, the CODA software must be distributed, supported, and maintained if it is to remain a useful resource.

Acknowledgments

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References

Arnett, R.H., Jr. 1985. **American insects; a handbook of the insects of America north of Mexico**. New York: Van Nostrand Reinhold Co.; 850 p.

Farr, D.F.; Bills, G.F.; Chamuris, G.P.; Rossman, A.Y. 1989. **Fungi on plants and plant products in the United States**. St. Paul, MN: The American Phytopathological Society; 1252 p.

Guisti, Gregory A.; Scott, Thomas A.; Garrison, Barrett A. 1996. **Oak woodland wildlife ecology and habitat relationships**. In: Standiford, R.B.; Tinnin, P., tech. coord. Guidelines for managing California's hardwood rangelands. Publication 3368. Berkeley, CA: University of California Division of Agriculture and Natural Resources.

Hickman, James C., ed. 1993. **The Jepson manual: higher plants of California**. Berkeley: University of California Press; 1,400 p.

Hildebrand, D.C.; Schroth, M.N. 1967. **A new species of *Erwinia* causing drippy nut of live oaks**. Phytopathology 57: 250-253.

Keen, F.P. 1958. **Cone and seed insects of western forest trees**. Tech. Bull. 1169. Washington, DC: U.S. Department of Agriculture.

Sinclair, Wayne A.; Lyon, Howard H.; Johnson, Warren T. 1987. **Diseases of trees and shrubs**. Ithaca, NY: Cornell University Press; 574 p.

Sinclair, Wayne A.; Griffith, Helen M.; Lee, Ing-Ming. 1994. **Mycoplasma-like organisms as causes of slow growth and decline of trees and shrubs**. Journal of Arboriculture 20(3): 176-189.

Swiecki, Tedmund J. 1993. **Support services to manage distribution of the California Oak Disease and Arthropod (CODA) Host Index Database**. Final Report. Prepared for: California Department of Forestry and Fire Protection, Strategic Planning Program, Sacramento, CA. 6 p.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1990. **Impacts of diseases and arthropods on California's rangeland oaks**. Prepared for: California Department of Forestry and Fire Protection, Forest and Rangeland Resources Assessment Program, Sacramento, CA. 94 p. plus appendix.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1991a. **Insect and disease impacts on blue oak seedlings and acorns**. In: Standiford, Richard B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 149-155.

Swiecki, Tedmund J.; Bernhardt, Elizabeth A.; Arnold, Richard A. 1991b. **Monitoring insect and disease impacts on rangeland oaks in California**. In: Standiford, Richard B., tech. coord. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 208-213.

Swiecki, T.J.; Bernhardt, E.A.; Arnold, R.A.; Kellogg, J. **CODA - California Oak Disease and Arthropod Host Index Database, Version 3.3, Release 1/96** [Computer program]. 1996. Vacaville, CA: Phytosphere Research. DBase III database files and compiled access program, for IBM-compatible personal computers. Available from: Phytosphere Research, 1027 Davis Street, Vacaville, CA 95687.

Tietje, William; Berlund, Tristan; Garcia, Sergio; Halpin, Chris; Jensen, Wayne. 1997. **Contribution of downed woody material by blue, valley, and coast live oaks in coastal California**. [These proceedings].

The Effect of Low Oxygen Stress on *Phytophthora cinnamomi* Infection and Disease of Cork Oak Roots[1]

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Abstract: *The incidence and severity of* Phytophthora cinnamomi *Rands root disease was quantified in cork oak (*Quercus suber *L.) roots subjected to low oxygen (hypoxia) stress. Seedling root tips were inoculated with mycelial plugs of the fungus and incubated in ≤1, 3-4, or 21 percent oxygen for 5 days. Ninety-four percent of roots became necrotic in the ≤1 percent oxygen treatment, compared to 60 and 46 percent in the 3-4 and 21 percent oxygen treatments, respectively. Root colonization and necrosis did not differ significantly between treatments. Fifty percent of inoculated roots remained asymptomatic in the atmospheric oxygen treatment, compared to 6 percent of roots in the near anoxic treatment. The asymptomatic roots were characterized by continued tip extension growth and lateral root formation above the inoculation point. Hypoxia increased the likelihood that roots became diseased, but not the severity of symptoms.*

Root and crown rots caused by *Phytophthora* spp. are especially problematic in wet soils in which oxygen availability to roots may be restricted. Low oxygen (hypoxia) may directly injure roots by impairing root function (Drew and Lynch 1980, Levitt 1980), and may enhance disease by predisposing plants to infection by fungal pathogens (Shoenoweiss 1986, Stolzy and Fluhler 1984). A number of plant species including avocado (*Persea americana* Mill.), cherry (*Prunus serotina* Ehrh.), citrus (*Citrus sinensis* L.), eucalyptus (*Eucalyptus* sp.), rhododendron (*Rhododendron* sp.), and safflower (*Carthamus tinctorius* L.) exhibit increased susceptibility to *Phytophthora* sp. when their roots suffer from hypoxia directly, or indirectly as a result of flooding (Blaker and MacDonald 1981; Davison and Tay 1987; Heritage and Duniway 1985; Stolzy and others 1965, 1967; Wilcox and Mircetich 1985).

Several oak species, including cork oak (*Q. suber* L.), are susceptible to Phytophthora root and crown rot in California. Although more than one *Phytophthora* species is involved, *P. cinnamomi* Rands is the principal causal agent on cork oak (Mircetich and others 1977). The disease occurs where trees are grown in irrigated turf grass and compacted soils, and the symptoms include a blackened, sometimes "bleeding" inner periderm and cambium of the trunk, root necrosis, foliar chlorosis, and drying.

Costello and others (1991) reported that urban soils in which cork and coast live oak (*Q. agrifolia* Née) were declining had oxygen diffusion rates (ODR) below 0.3 $\mu g \cdot cm^{-2} \cdot min^{-1}$ in the upper soil profile. An ODR below 0.2 corresponds to very low soil oxygen concentrations in clayey soils, i.e. 0-2 percent (Letey and Stolzy 1967, Valoras and others 1964). Root growth in cork oak seedlings is reduced significantly at an oxygen level of 4 percent or less (Jacobs and others, these proceedings). In that study, 3-4 percent oxygen corresponded to an ODR of 0.3.

The purpose of this study was to determine whether hypoxia increases the susceptibility of cork oak roots to *P. cinnamomi* root rot.

[1] An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Materials and Methods

Experimental Procedures

We collected acorns for 3 years from several cork oaks on the campus of the University of California at Davis in October and November of 1987-1990. Seeds were soaked overnight, air-dried, and stored at 4-6 °C for at least 3 months. To initiate germination, batches of seeds were removed from cold storage and placed in trays containing vermiculite in the greenhouse. Acorns were dipped 4-5 minutes in a dilute solution of the broad-spectrum fungicide Imazalil (Jannsen Inc., Belgium) before germination, to suppress the growth of saprophytic fungi that might have contaminated seed coats.

A strain of *P. cinnamomi* that had been recovered from a diseased cork oak on the campus of the University of California at Davis was used as the source of inoculum for the study. We re-isolated the strain from diseased seedlings after each trial to sustain its virulence throughout the study. Stock cultures of the fungus were maintained on corn meal agar (Difco, Detroit, Mich.) at 6 °C, and in sterile water containing autoclaved hemp seeds at 25 °C.

Germinated acorns were transferred to mini-rhizotrons when radicles were approximately 50 mm long. The mini-rhizotrons were constructed from 24- by 32- by 2- cm plastic lids and had a removable surface to permit root viewing and inoculation. The mini-rhizotrons were kept at a 45° angle to encourage root growth along the removable surface. Before treatment, we placed the mini-rhizotrons containing seedlings in a growth chamber at 25 °C for 1 week to allow the seedlings to acclimate. At the end of 1 week the mini-rhizotrons were opened, and we selected unbranched, 1- to 2-mm diameter roots for inoculation. Inoculation was done by inserting each root tip into a 10 mm × 5 mm diameter glass tube containing an agar plug of *P. cinnamomi*. Tips of control roots were inserted into water agar plugs. We then placed the mini-rhizotrons into airtight chambers that were vented continuously with a gas mixture of known oxygen concentration between 0 and 21 percent, as described in Jacobs and others (these proceedings).

Seedlings were exposed to the oxygen treatments for 5 days after which time we opened the mini-rhizotrons and evaluated roots. Approximately 80 roots were inoculated for each of three oxygen treatments: ≤1, 3-4, and 21 percent oxygen. The oxygen treatments were repeated 14-18 times, and for statistical analyses each repetition was considered a replicate composed of several observations (inoculated roots). We assessed the variation between replications by determining soil moisture contents via water release curves, and continuously monitored soil oxygen levels inside the mini-rhizotrons.

Disease Assessment

Disease incidence was calculated as the percent of inoculated roots that exhibited necrosis originating from the point of inoculation, and from which the pathogen was successfully recovered onto the semi-selective medium PARP (Kannwisher and Mitchell 1978). Disease severity was assessed by measuring the length of root necrosis originating from the point of inoculation and the length of root tissue from which *P. cinnamomi* was re-isolated. We obtained the latter measurement by plating consecutive, 10-mm segments of each root onto PARP medium (*fig. 1*).

If inoculated roots continued growing through the inoculum plug but did not become necrotic, we confirmed the viability of the fungus by plating the inoculum plug onto PARP medium. If the inoculum was viable, roots were considered to have "escaped" disease. Inoculum viability was verified in asymptomatic roots from the 21 and ≤1 percent oxygen treatments only.

Figure 1—Evaluation of root colonization by *P. cinnamomi*. One-cm segments of an inoculated root were plated sequentially onto the semi-selective medium, PARP, beginning with the root tip (arrowhead). Photo shows a root colonized 60 mm.

Data Analysis

Disease incidence and severity were evaluated by analysis of variance and Tukey-Kramer and Duncan tests for means separation. Oxygen level was considered a fixed effect, and infection frequency, length of colonization, and necrosis were analyzed as continuous variables. We also summarized the disease incidence data as frequency counts and analyzed them using chi-square tests (SAS Institute 1991).

Results

Ninety-four percent of inoculated roots that were incubated at ≤1 percent oxygen became diseased, as evidenced by necrosis originating from the point of inoculation and successful pathogen recovery from root tissue. By contrast, only 60 and 46 percent of roots incubated at 3-4 percent and 21 percent oxygen, respectively, became diseased (*fig. 2*). A significantly higher (P = 0.05) mean frequency of disease occurred in the ≤1 percent oxygen treatment compared to the 3-4 and 21 percent treatments. The chi-square tests also indicated that disease frequency varied significantly (P = 0.01) between oxygen treatments.

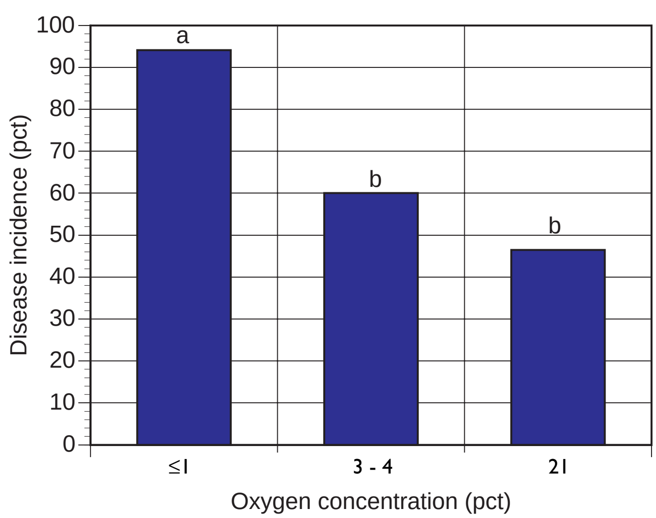

Figure 2—Disease incidence measured as the percent of inoculated roots that became diseased during a 5-day incubation at different oxygen concentrations. Lowercase letters above bars indicate significant differences between treatments at the P = 0.01 level. Approximately 80 inoculated roots (230 total) were used for each oxygen concentration.

Disease severity (i.e., the length of root colonized by *P. cinnamomi*) ranged from 30 to 60 mm and did not differ significantly (P = 0.05) between oxygen treatments (*fig. 3*). Root necrosis ranged from 15 to 45 mm from the point of inoculation. Colonization exceeded visible root necrosis by about 15 mm in all oxygen treatments, based upon recovery of the fungus from root sections.

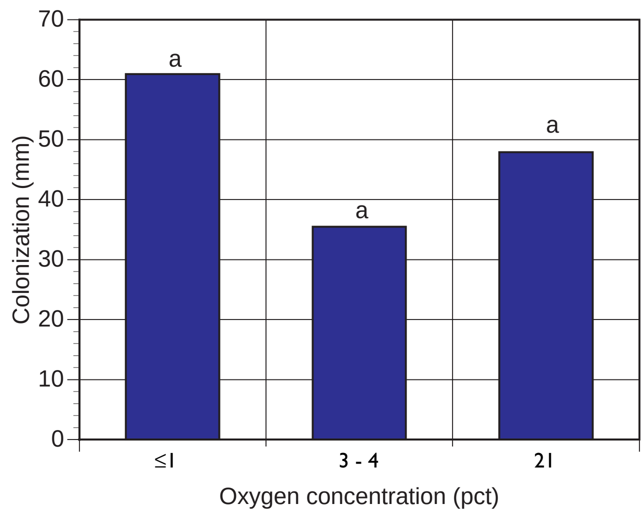

Figure 3—Average length of root from which *P. cinnamomi* was re-isolated. Lowercase letters above bars indicate no significant differences (P = 0.01) between oxygen treatments.

We refer to necrotic roots as "diseased" rather than "infected" because some asymptomatic roots were superficially colonized by the fungus (Jacobs 1991). These asymptomatic or "escape" roots differed from diseased roots in other ways: the root tip continued growing through the inoculum plug, and lateral roots were produced above the inoculation point in escape roots (*fig. 4*). Forty-six percent of inoculated roots from the 21 percent oxygen treatment escaped disease compared to only 2 percent of roots from the ≤1 percent oxygen treatment. In 4 percent of inoculated but asymptomatic roots, *P. cinnamomi* was not recovered from the inoculum plug; consequently, the roots were not considered to be escapes.

Figure 4—Morphology of inoculated seedlings that became diseased (right) and remained asymptomatic (left) during incubation at 21 percent oxygen. Note root tip growth through inoculum plug, and development of lateral roots above the inoculation point on left seedling. Seedling on right shows typical disease response in which root tip ceased growing and no laterals were formed.

Discussion

Disease incidence (percent of inoculations that resulted in symptomatic roots) was greater in the hypoxic treatments than the atmospheric oxygen treatment, but a significant increase in disease occurred only in the ≤1 percent oxygen treatment. Total root growth of cork oak seedlings began declining at 6 percent oxygen, and a 50 percent reduction in root length occurred when oxygen levels fell below 3-4 percent (Jacobs and others, these proceedings). Thus, roots became more susceptible to *P. cinnamomi* only at oxygen levels below that which retards root growth.

The cause(s) of increased susceptibility of plants to Phytophthora root rot in hypoxic conditions is not well understood. Inhibited root growth and regeneration and the resulting lack of compensatory roots are thought to be primary reasons for increased susceptibility (Duniway 1983). Our results further indicate that in addition to poor root regeneration, hypoxia renders already inoculated roots more susceptible to disease than if the roots were in well-aerated conditions.

Disease severity (i.e., root colonization by *P. cinnamomi*) did not differ between treatments despite the increase in disease incidence in the hypoxic treatments. Also, when *P. cinnamomi* was grown in pure culture, colony diameters were equal after 5 days in ≤1, 3-4 or 21 percent oxygen (Jacobs, unpublished[6]). Several *Phytophthora* spp. grow well at low oxygen tensions (Mitchell and Zentmyer 1971). The fact that growth of *P. cinnamomi* was apparently unaffected by hypoxia suggests that host factors were responsible for the greater susceptibility of hypoxic roots to disease. Low oxygen impairs root function, including the formation of physical barriers to pathogen ingress, i.e., suberin and lignin (Drew and Lynch 1980). Levels of barrier compounds (e.g. polymerized phenolics) differed between cork oak roots incubated at near-anoxic oxygen and atmospheric oxygen (Jacobs 1991).

[6]Unpublished data, K.A. Jacobs.

It may be possible to limit *Phytophthora* root rot of cork oak in the field by maintaining soil conditions that support adequate root growth. Under our study conditions, soil oxygen levels above 3-4 percent permitted adequate root growth. However, oxygen diffusion in the mini-rhizotrons was not impeded because of the uniform texture and good drainage of the soil medium. Under field conditions, aerated shoots may help to oxygenate the rhizosphere and allow plants to tolerate root hypoxia longer (Crawford 1982), so lower oxygen levels may suffice. Alternatively, if soils are poorly drained, compacted, or otherwise present impediments to oxygen diffusion, 3-4 percent oxygen may not be adequate to support root growth and prevent predisposition to *P. cinnamomi*. MacDonald and others (1993) note that in soils where oxygen diffusion is limited, the ODR is a better indicator of soil aeration than oxygen concentration. An ODR of 0.3 and higher corresponded to 3-4 percent oxygen in the mini-rhizotrons, and this could be considered the threshold diffusion rate needed to minimize root rot.

Acknowledgments

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References

Blaker, N.S.; MacDonald, J.D. 1981. **Predisposing effects of soil moisture extremes on the susceptibility of Rhododendron to Phytophthora root and crown rot.** Phytopathology 71: 831-834.

Costello, L.R.; MacDonald, J.D.; Jacobs, K.A. 1991. **Soil aeration and tree health: correlating soil oxygen measurement with the decline of established oaks.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990. Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 295-299.

Crawford, R.M.M. 1982. **Physiological responses to flooding**. In: Lange, O.L.; Nobel, P.S.; Osmond, C.B.; Zeigler, H., eds. Physiological plant ecology II: water relations and carbon assimilation. (Encyclopedia of plant physiology Vol. 12B). Berlin: Springer-Verlag; 453-477.

Davison, E.M.; Tay, F.C. 1987. **The effect of waterlogging on infection of *Eucalyptus marginata* seedlings by *Phytophthora cinnamomi*.** New Phytologist 105: 585-594.

Drew, M.C.; Lynch, J.M. 1980. **Soil anaerobiosis, microorganisms, and root function.** Annual Review Phytopathology 18: 37-66.

Duniway, J.M. 1983. **Role of physical factors in the development of *Phytophthora* diseases.** In: Irwin, D.C.; Bartnicki-Garcia, S.; Tsao, P.H., eds. *Phytophthora*: its biology, taxonomy, ecology and pathology. St. Paul, MN: APS Press; 175-187.

Heritage, A.D.; Duniway, J.M. 1985. **Influence of depleted oxygen supply on Phytophthora root rot of safflower in nutrient solution.** In: Parker, C.A.; Rovira, A.D.; Moore, K.J.; Wong, P.T.W., eds. Ecology and management of soilborne plant pathogens. St. Paul, MN: American Phytopathological Society; 199-202.

Jacobs, K.A. 1991. **Oak root pathology: effects of oxygen stress on root growth and infection by *Phytophthora cinnamomi* and identification of *Armillaria* spp. in California**. Davis: University of California; 90 p. Ph.D. dissertation.

Jacobs, K.A.; MacDonald, J.D.; Berry, A.M.; Costello, L.R. 1996. **Rooting responses of three oak species to low oxygen stress.** [These Proceedings].

Kannwisher, M.l.; Mitchell, D.J. 1978. **The influence of a fungicide on the epidemiology of black shank of tobacco.** Phytopathology 68: 1760-1765.

Letey, J.; Stolzy, J.H. 1967. **Limiting distances between root and gas phase for adequate oxygen supply.** Soil Science 103: 404-409.

Levitt, J. 1980. **Responses of plants to environmental stresses**. In: Kozlowski, T.T., ed. Physiological Ecology. New York: Academic Press; 213-228.

MacDonald, J.D.; Costello, L.R.; Berger,T. 1993. **An evaluation of soil aeration status around healthy and declining oaks in an urban environment in California.** Journal of Arboriculture 19: 209-219.

Mircetich, S.M.; Campbell, R.N.; Matheron, M.E. 1977. **Phytophthora (*P. citricola*, *P. cactorum*) trunk canker of coast live oak and cork oak (*Quercus agrifolia*, *Q. suber*) trees in California.** Plant Disease Reporter 61: 66-70.

Mitchell, D.J.; Zentmyer, G.A. 1971. **Effects of oxygen and carbon dioxide tensions on growth of several species of *Phytophthora*.** Phytopathology 61: 787-791.

SAS Institute. 1991. **JMP and SAS basics**. Cary, NC: SAS Institute, Inc.

Shoenoweiss, D.F. 1986. **Water stress predisposition to disease: an overview**. In: Ayres, P.G.; Boddy, L., eds. Water, fungi and plants. Cambridge, England: Cambridge University Press; 157-174.

Stolzy, L.H.; Fluhler, H. 1984. **Measurement and prediction of anaerobiosis in soils.** In: Kozlowski, T.T., ed. Flooding and plant growth. Orlando, FL: Academic Press; 363-426.

Stolzy, L.H.; Letey, J.; Klotz, L.J.; Labanauskas, C.K. 1965. **Water and aeration as factors in root decay of *Citrus sinsensis*.** Phytopathology 55: 270-275.

Stolzy, L.H.; Zentmyer, G.A.; Klotz, L.J.; Labanauskas, C.K. 1967. **Oxygen diffusion, water and *Phytophthora cinnamomi* in root decay and nutrition of avocados.** Proceedings of the American Society of Horticultural Science 90: 67-76.

Valoras, N.; Letey, J.; Stolzy, L.H.; Frolich, E.F. 1964. **The oxygen requirement for root growth of three avocado varieties.** Proceedings of the American Society of Horticultural Science 85: 172-178.

Wilcox, W.F.; Mircetich, S.M. 1985. **Effects of flooding duration on the development of Phytophthora root and crown rots of cherry.** Phytopathology 75: 1451-1455.

Wildfire and Oak Regeneration at the Urban Fringe[1]

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Abstract: *In July 1992, wildfire burned 500 acres of rural lands owned by Stanford University. Within the fire zone are five plots, ranging in size from 0.1 acre to more than 1 acre, on which nearly 600 naturally established juvenile California oaks (*Q. agrifolia, Q. douglasii, *and* Q. lobata*) have been monitored since 1990. Surveys following the fire revealed that although 32 percent of the oaks up to 10 inches tall died, only 9 percent of the oaks taller than 10 inches died. Twenty-two percent of all juvenile oaks were topkilled, but 22 percent of those resprouted in years following the fire.*

Both naturally occurring and human-induced fires have been important elements of California native oak ecology. In recent decades, people have prevented or rapidly suppressed many fires in oak habitat. As humans have built and paved in and near oak habitat, we have extended the urban-open space interface, and fire management has become an increasing concern. Land managers and restoration ecologists are accordingly interested in the effects of fire and its suppression on native oak populations.

However, only a few studies have explored how fires—whether uncontrolled or managed—affect California oaks (Allen-Diaz and Bartolome 1992, Haggerty 1991). This paper describes the effects of a 1992 wildfire on young, naturally occurring oaks located within a 500-acre oak woodland at the urban interface.

Site Description and Methods

Stanford University lands include approximately 1,600 acres adjacent to the central campus that remain rural in character. This property, denoted "Academic Reserve," is currently used for recreation, livestock grazing, and a handful of academic programs, and is adjoined by housing developments. Located at 38° north latitude, 20 miles inland from the Pacific Ocean and 3 miles from the San Francisco Bay, Stanford enjoys a Mediterranean climate, with mild winters and warm, dry summers. Average annual rainfall is 14.8 inches, almost all of which falls between October and May. The Reserve is divided by a prominent, flat-topped southeast-northwest ridge with relatively steep (sometimes >30°) slopes. Soils vary and may be loosely classified as loams, clays, and stony clays with zones of admixture.

Oak woodlands cover many northern exposures on the ridge; grassland and oak savanna dominate southern slopes. A few areas of chaparral persist, and native woody plants like toyon (*Heteromeles arbutifolia* [Lindley] Roemer), coyote brush (*Baccharis pilularis* DC.), chamise (*Adenostoma fasciculatum* Hook. & Arn.), and poison oak (*Toxicodendron diversiloba* [Torrey & A. Gray] E. Greene) occur widely. Native grasses and forbs have been largely supplanted by exotic annuals like wild oat (*Avena fatua* L.), rye grass (*Lolium multiflorum* Lam.), nonnative mustard (*Brassica* spp.), and milk thistle (*Carduus nutans* L.). The oak population consists of coast live (*Quercus agrifolia* Née), blue (*Q. douglasii* Hook. & Arn.), and valley (*Q. lobata* Née) oaks.

In the early 1980's, University land managers became concerned that too few seedlings were surviving to maintain stable oak populations. Severely skewed age

[1]An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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distribution of oaks on the Reserve indicated that for several decades, relatively few seedlings had been surviving beyond their 10th year (Zebroski and McBride 1983). For more than 50 years, a lessee had grazed cattle on the Reserve from December through May. In 1984, University planners closed part of the Reserve to grazing. In 1989, they expanded the area of cattle exclusion (*fig. 1*).

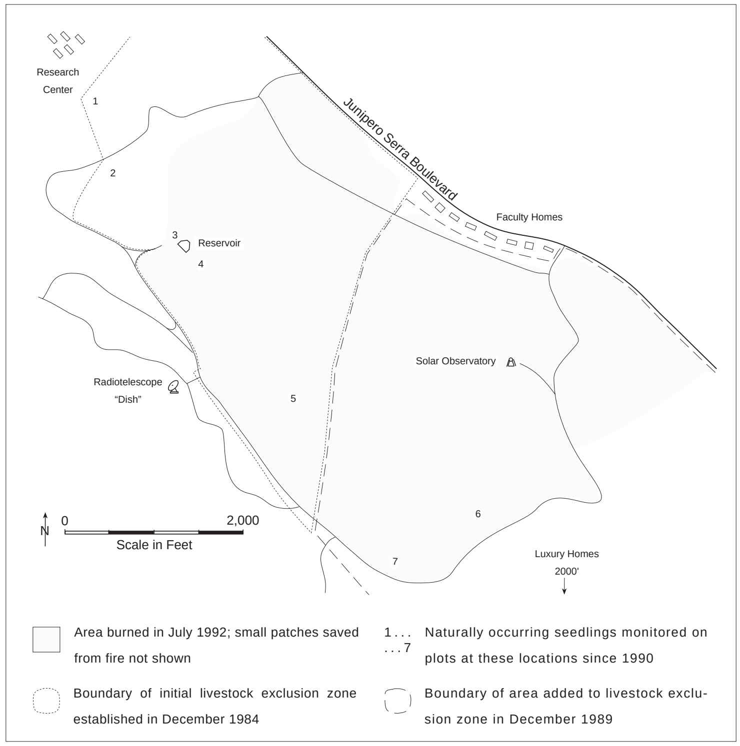

Figure 1—Map showing area burned in July 1992, including portions of livestock exclusion zones, homes and academic facilities at risk, and plots being monitored for natural regeneration.

To determine whether oaks released from grazing pressures were successfully regenerating, and to help determine when young trees might be able to withstand reintroduction of livestock, we selected seven plots for careful monitoring (*fig. 1*). The plots varied in slope, exposure, and vegetative cover and ranged in size from 0.1 acre to several acres. We mapped each plot to show the location, size, and species of juvenile oaks (i.e., oaks less than 10 feet tall). In the summers of 1990, 1991, 1993, 1994, and 1995, we surveyed all juvenile oaks in the sample plots, measuring their heights and noting their condition and vigor. In 1992, only the two plots that were not burned were surveyed.

University land managers had long acted to prevent and rapidly suppress fires, and in the several decades before 1992, only small (less than 1-acre) fires burned in the Reserve. Heavy rainfalls in the springs of 1991 and 1992 led to unusually lush growth of grasses, forbs, and other understory plants. In the absence of grazing, herbaceous vegetation grew densely and reached heights of 8-10 feet in some areas. When these plants dried, they created an exceptional fire hazard—extremely combustible material, with a high surface-to-mass ratio, which was well-aerated yet compact and reached into the edges of mature oaks' canopies.

Early in the afternoon of July 7, 1992, during a midsummer heat wave that saw temperatures climb above 90 °F, a wildfire began. Though quickly contained within a 500-acre area (*fig. 1*), the blaze burned through the night and into the next day, as brush accumulated over decades was consumed and large-diameter standing and fallen deadwood was reduced to ash.

Because five of our seven plots, holding 558 juvenile oaks, lay entirely within the fire zone, we were able to calculate rates of fire-related mortality and annual rates of growth before and after fire in these plots. Although some deaths would have been likely to occur even without fire, for purposes of our calculations, we defined fire-related mortalities to be monitored oaks which were last noted as alive in 1991. The mortality of oaks that were alive in 1993 but died in subsequent years was not considered to be fire-related. We applied *t*-tests to test the significance of mean differences between pairs of data sets. We used Chi-square tests to compare frequencies of fire mortality between species.

Results

Fire topkilled 22 percent of the 558 juvenile oaks in the five plots in the fire zone. Twenty-two percent of these resprouted from the root crown in the following 3 years. Thus, the fire killed 17 percent of the original 558 juvenile oaks. For comparison, 4 percent of monitored juvenile oaks died in the more typical year, July 1990 to July 1991, before the fire. Postfire survival and resprouting generally followed similar patterns across the three species. However, compared to *Q. douglasii* and *Q. lobata*, a significantly greater ($P < .001$) percentage of *Q. agrifolia* juveniles were topkilled (30 of 67) (*table 1*).

Table 1—Pre- and postfire annual growth of monitored juvenile oaks within and outside of burned area[1]

	Mean annual growth (sample size)		
	Q. douglasii	*Q. lobata*	*Q. agrifolia*
	inches		
Fire fatalities, 1990-91	1.4 (45)	2.0 (27)	1.0 (27)
Fire survivors, 1990-91	2.4 (214)	4.4 (132)	1.4 (34)
Fire survivors, 1993-95[2]	3.2 (170)	1.3 (105)	6.2 (28)
Unburned plots, 1990-91	7.3 (36)		
Unburned plots, 1993-95	2.0 (33)		

[1]For discussion of statistical significance, see text.
[2]Numbers in this row are not equal to those in second row because seedlings that died in 1994 or 1995 are not included here.

The likelihood of postfire survival generally improved with increasing prefire height of the juvenile oaks. Thirty-two percent of the juvenile oaks up to 10 inches tall died, whereas only 9 percent of those more than 10 inches tall died (*fig. 2*). Among topkilled trees, we found no significant association between resprouting rates and prefire height. The lack of correlation may reflect the fact that sample sizes were too small to reveal trends. Only 16 topkilled trees were taller than 20 inches, and only 27 trees of any height resprouted.

Prefire (1990-91) growth of juvenile valley, blue, and coast live oaks, taken as a group, was not significantly associated with postfire survival. When each species was analyzed separately, prefire growth was significantly related to survival ($P = .01$) only for juvenile valley oaks. *Q. lobata* juveniles that survived the fire grew, on average, 4.4 inches from July 1990 to July 1991; those that died in the fire grew only 2.0 inches during the same period (*table 1*).

Overall, pre- and postfire average annual growth of surviving juvenile oaks in the burned area did not differ significantly. The 479 juvenile oaks of all three species that had sprouted by July 1990 in the plots in the fire zone grew an average of 2.7 inches from July 1990 through July 1991. From 1993 through 1995,

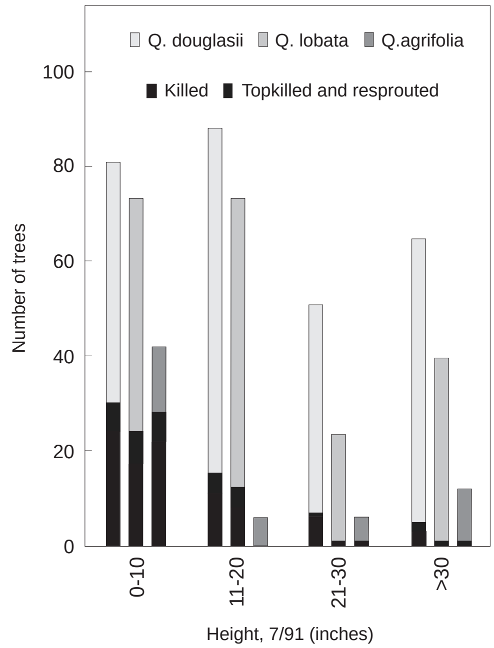

Figure 2—Juvenile oaks surviving, topkilled, and killed in 1992 fire, by 1991 size class and species.

juvenile oaks in the five plots in the fire zone grew an average of 3.6 inches annually. However, a breakdown of average growth rate by species shows that *Q. agrifolia* increased from 1.4 to 6.2 inches per year (significant at $P < .01$), *Q. lobata* declined from 4.4 to 1.3 inches (significant at $P < .01$), and *Q. douglasii* did not change significantly (*table 1*).

Growth rates of oaks within and outside of the fire zone are not strictly comparable. Only 49 juvenile oaks lay within the two plots beyond the fire zone, and they were, on average, older and taller than those inside it; their average height in 1991 was 41 inches, compared to 18 inches for those in the fire zone. Still, the trend in growth rates before and after the fire is strikingly different between burned and unburned plots. *Q. douglasii* in unburned plots grew an average of 7.3 inches in 1990-91 but only an average of 2.0 inches per year in 1993-95 (significant at $P = .002$); as noted above, juvenile blue oaks in burned plots showed no significant change in annual growth over that period (*table 1*). There were too few *Q. lobata* and *Q. agrifolia* on these plots to calculate meaningful growth rates.

Many young oaks of all species, across the entire Reserve, suffered partial or complete dieback due to rodent girdling (removal of bark and cambium layers around the base of the trees) in 1992 and 1993. The postfire drop in the growth rate of monitored blue oaks outside the burned area reflects the fact that many oaks in these plots declined in height between 1993 and 1995. When oaks that declined in height between 1993 and 1995 were removed from the sample, average annual growth for that period was 6.5 inches, not significantly different from 1990-91 growth. Unfortunately, we cannot calculate a comparable number for burned sites, since any declining heights may be due to either rodent damage or fire-related damage. Of 36 blue oaks in the unburned plots in July 1991, 8 percent died by July 1993 and 33 percent declined in height between 1993 and 1995. By comparison, 14 percent of juvenile blue oaks in burned areas died between 1991 and 1993, presumably because of the fire, and 15 percent declined in height between 1993 and 1995. Evaluators have observed that rodent damage has been the most common cause of large declines in seedling and sapling height on the parts of the Reserve from which livestock have been excluded.

No additional trends became apparent in either burned or unburned areas when growth rates of juvenile oaks were broken down by size class. Differences in survival and growth rates between plots were difficult to assess because no one species occurred in great enough numbers on all plots.

Discussion

The data we have collected about juvenile oaks, on a single reserve, responding to a single wildfire, is clearly limited in scope. Nevertheless, this case study is the first published report on fire-related growth and survival of California oaks in this size class. Several patterns are evident in the response of the juvenile oaks in our study to wildfire. First, a relatively small percentage of juvenile oaks taller than 10 inches perished. Second, comparisons of pre- and postfire growth within species on burned plots showed varied responses: coast live juveniles grew faster after the fire, valley oaks grew more slowly, and blue oaks showed no change.

Although overall growth of burned juvenile blue oaks was greater after the fire than that of blue oaks outside the fire zone, unburned blue oaks suffered significant rodent damage from 1993 through 1995. Thus, data on growth rates reflect the impact not only of fire but also of a sudden increase in rodent herbivory in the years of and following the fire. On the basis of the height data and field observations of rodent damage, we hypothesize that a causal relationship may exist between fire and rodent herbivory of juvenile oaks. As fire removes essential cover and food, rodents may overpopulate adjacent areas and increase herbivory of oaks there.

Q. agrifolia juveniles had lower fire survival rates but greater postfire growth than the other species. This could reflect a different, but not necessarily less successful, response to fire by juvenile live oaks compared with blue and valley oak juveniles. Alternatively, the apparent increase in *Q. agrifolia* growth might simply reflect the loss of most of the smallest (and perhaps slower-growing) coast live oaks from the sample. Further observations would be needed to test these hypotheses.

Our results generally support others' findings that a single wildfire may kill many of the smallest juveniles in an oak woodland but is unlikely to be devastating to the population as a whole. Haggerty (1991) found higher fire survival of blue oaks (93 percent compared to our 84 percent), but her sample consisted of both saplings and mature trees, whereas ours included only juveniles less than 10 feet tall. Allen-Diaz and Bartolome (1992) reported that prescribed burning had little impact on blue oak seedling recruitment, survival, or growth. However, they did not monitor individual seedlings before fire occurred, so their results are not readily comparable to ours.

On the basis of our data, we cannot draw firm conclusions about the relationship between fire suppression and native oak regeneration. So many human-mediated changes have been made to the ecosystem of our study site that it is very difficult to isolate the impact of any one. Extensive invasion of nonnative understory plants, decline of rodent predators such as fox, coyote, and bobcat, and falling water tables are all likely to contribute to an oak population's response to fire and its overall success or decline. Certainly, there will be some fire frequency at which oak regeneration will suffer. However, without further studies clarifying the effect of fire on seedling growth, we cannot weigh the costs and benefits of fire very precisely. Meanwhile, where intensive efforts are being made to restore a native oak population, particularly where artificial seeding has been deemed necessary, protection from fire damage may be desirable.

Land management implications of oaks' response to fire are further complicated by the fact that oak regeneration concerns typically compete with many other considerations—relative remoteness of the land, value of structures at risk, volume of public use, and livestock ranching concerns. On Stanford lands, proposals have been made to minimize fire risk via an integrated program of high-density, short-duration, rotational grazing; restoration of native understory plants; mowing; disking; spraying of herbicides; prescribed fire; and user education. Such a program faces formidable obstacles: animal management costs, air quality regulation, tenacity of established nonnative plants, steep terrain that is difficult to mow, community intolerance for herbicides, and growing year-round recreational use (500-1,000 visitors per day during peak use in 1995).

We have chosen a less controversial, less resource-intensive, and more seedling-specific approach to reducing fire risk to seedlings on the Academic Reserve. We have surrounded hundreds of naturally occurring and artificially planted seedlings with a 3-foot diameter piece of plastic landscape fabric, covered by a 4-inch thick layer of native rock. With this treatment, we aim to reduce the amount of readily burned fuel near the young trees and to provide a heat sink to prevent temperatures from rising to damaging or fatal levels if nearby understory plants and litter burn. We currently lack data to quantify these effects, but we have observed that the combination of rock over plastic does effectively suppress vegetation around young trees.

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References

Allen-Diaz, Barbara H.; Bartolome, James W. 1992. **Survival of *Quercus douglasii* (Fagaceae) seedlings under the influence of fire and grazing.** Madroño 39(1): 47-53.

Haggerty, Patricia K. 1991. **Fire effects in blue oak woodland**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, California. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 342-344.

Zebroski, Ortha; McBride, Joe. 1983. **Vegetation management plan**. Stanford, CA: Stanford University Planning Office; 61 p.

ECONOMICS, POLICY, AND PLANNING

VIII

Section Overview

Economics, Policy, and Planning[1]

Richard P. Thompson[2]

Throughout the symposium it seemed that whenever the toughest problems were mentioned, people and their growing impact on the oak woodland ecosystem were at the source. This refrain was heard from nearly every keynote speaker, many of whom claimed that the oak woodlands were currently under the greatest pressure from urbanization. The needs and demands of landowners, stakeholders, and society-at-large were the topic of the Economics, Policy, and Planning technical session.

Even though a wide variety of papers was presented, each one presented a different perspective on the key questions. What is a sustainable state? What values are at stake? Why are land use patterns changing so rapidly? What policies are we employing today, and are they effective? How do we develop sustainable policies? How do we mitigate impacts from the ever-increasing encroachment into the oak woodlands? Of course, we do not have ready answers to these questions today, but the following papers serve to give direction in looking for the answers.

To address the question on what is the current policy approach to oak woodlands management, Dr. Richard Standiford provided an overview of the Integrated Hardwood Range Management Program. This program is a partnership between University of California Cooperative Extension, California Department of Forestry and Fire Protection, and California Department of Fish and Game to conduct research, education, and monitoring in order to assist counties in establishing policies for the hardwood rangeland resources, the initial approach preferred by the Board of Forestry rather than regulation of those resources, as is similarly done for commercial timberlands.

Marcus Rawlings presented a case study on mitigation strategies for reservoir development. The important issues of potential net habitat displacement and the permanence of the mitigation/conservation easements were discussed in dialog with the audience. It is through such dialog and exchange between various stakeholders that progress toward sustainable policies is realized. This was the subject of Beth Greenwood's paper in which she presented the results of a facilitated, collaborative approach to designing sustainable management strategies—the Central Coast Sustainable Landscapes Project.

The focus of the next paper, presented by Sharon Johnson, was on the key stakeholder in the hardwood rangelands—the landowner. Hardwood rangeland owners are under extreme financial pressure to maintain their property as an oak woodland because of the low rates of return from grazing while facing rapidly rising land values for development uses. Attempts to keep the property intact and in the family are severely constrained by inheritance tax law. Ways must be identified to help landowners realize tangible benefits for maintaining the property as an oak woodland. Conservation rents or tradable habitat permits are being discussed as a means of meeting this need.

The paper by Jay Noel raised some even more basic questions such as: if efficient oak woodland management policies are to be designed, what desired future condition is being sought or, at least, what are the socially and economically acceptable courses to that future state? The means are available to

[1] Presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19–22, 1996, San Luis Obispo, Calif.

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model this policy process if we can quantify the current stocks (inventories of various oak woodland resources) and the bioeconomic system relationships (ecological functions, habitat responses to land use changes, etc.).

The last paper presented information that can be useful in assisting landowners in maintaining or restoring oak woodlands as one possible answer to the problems raised by Sharon Johnson. Joss Hanna described the results of a study conducted in the Lake Tahoe Basin which demonstrated quantifiable property value gains to managing trees on small acreages. The model and methodology used in this study offer a much broader applicability to other forest types including the oak woodlands which are experiencing perhaps the greatest impact from urbanization.

The Integrated Hardwood Range Management Program: Education and Research as a Conservation Strategy[1]

Richard B. Standiford[2] **James Bartolome**[2]

Abstract: *California's hardwood rangelands cover 10 million acres, providing wildlife habitat, esthetics, recreation, and watershed protection. About 85 percent of the area is privately owned, and private ranchers supply most of these open space values. The important public values from these privately-owned wildlands has created pressure for the state to regulate oak harvest and conversion. However, current policy calls for a program of intensive educational outreach. This program, started in 1986, is known as the Integrated Hardwood Range Management Program (IHRMP), and is a partnership between the University of California, California Department of Forestry and Fire Protection, and California Department of Fish and Game. The effectiveness of research and education as a tool for conservation of important environmental resources is discussed on the basis of the 9-year history of the IHRMP.*

Background

California's oak-covered rangelands, also known as oak woodlands or hardwood rangelands, occupy almost 10 million acres (Bolsinger 1988, Pacific Meridian Resources 1994). They provide habitat for 313 wildlife species, making them the most biologically diverse broad habitat type in California (Standiford and Tinnin 1996). Oak woodland values also include esthetics, recreation, and watershed protection . These large expanses of wildlands are somewhat unique in the western United States, with more than 80 percent in private ownership (Greenwood and others 1993). Livestock production is the dominant land use, and private ranchers supply most of these open space values (Huntsinger and Fortmann 1990).

The California State Board of Forestry (BOF) is a regulatory and policy-making body responsible for the state's forests and rangelands. A variety of interest groups have expressed concerns about oak woodlands to the BOF since the early 1980's. In response to these concerns, the BOF commissioned an Ad Hoc Committee on Policies for Forest Practice Regulation in California Hardwood Forest Types to clarify hardwood stocking criteria in the Forest Practice Rules. The Committee report in 1982, though focused primarily on hardwoods on commercial forest land, also discussed the importance of hardwoods on "non-commercial" land.

Three incidents resulted in continued concerns about hardwood lands: (1) Monterey and Santa Clara counties petitioned the Board to classify oaks as commercial species regulated under the Forest Practice Act because of concerns over hardwood harvesting; (2) a Timber Harvesting Plan (THP) in the Northern Sierra requested removal of most black oaks in a critical migratory deer corridor; and (3) the increase in the number of new biomass power plants held the possibility of severe impacts to hardwoods on commercial and non-commercial lands. In 1983, the Hardwood Task Force (HTF) was commissioned by the BOF to study all aspects of the state's hardwood resources. The HTF identified 19 issues affecting hardwoods and concluded that basic information about hardwood species and educational outreach were lacking. HTF recommended delineating

[1]An abbreviated form of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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hardwood areas into either conifer lands or hardwood rangelands and concluded that hardwoods on all lands should be considered commercial species requiring regulation (Pillsbury 1983).

On the basis of the issues raised by the HTF, the California Department of Forestry and Fire Protection (CDF), California Department of Fish and Game (CDF&G), USDA Forest Service (USFS), and University of California (UC) prepared a joint report to the BOF (Mayer and others 1985), and Board Staff outlined possible policy directions (Board of Forestry Staff 1986). The Board asked UC, CDF and CDF&G to develop a program of research, education, and monitoring on hardwoods responsive to these policy issues, which became the Integrated Hardwood Range Management Program (IHRMP) on July 1, 1986.

As discussion of hardwood issues became clarified, the BOF adopted a Resolution on Hardwoods on February 3, 1987. This resolution concluded that although the BOF had the authority and obligation under the Forest Practice Act to protect the hardwood resource, it was premature to declare hardwoods commercial under the Forest Practice Act. It was felt that an intensive educational program, problem-focused research, and frequent monitoring of the resource would be the most effective way to work with landowners and local governments to resolve hardwood issues. The IHRMP was the mechanism expected to accomplish the goals of this non-regulatory program. This policy has continued up to the present. IHRMP, through presentations and annual reports, has kept the BOF informed about the effectiveness of educational programs in accomplishing voluntary compliance with resource protection standards, results of research studies, and trends in resource use.

Development of IHRMP

Several guiding principles were used during development of the IHRMP:

- Was the research base on ecological and managerial factors affecting hardwood rangelands sufficiently well-developed to begin the design of an educational program?
- Could materials be developed for use in an educational program?
- Could UC's educational network of county-based Cooperative Extension offices deliver an educational program on hardwood rangeland conservation?

A survey of the literature and of researchers at various academic and public resource management institutions revealed that there was a very large base of research-based knowledge that could form the foundation for an educational outreach effort (Muick and Bartolome 1985). More than 113 different research studies, conducted between 1953 and 1985, were identified in this general survey. Given this base of knowledge, a general book, directed to landowners and resource management professionals, that summarizes the best available research-based information on hardwood rangelands was developed. The "Preliminary Guidelines for Managing California's Hardwood Rangelands" formed the basis for initial educational outreach efforts (Passof and others 1985). Finally, most of the hardwood rangeland counties in the state had a farm advisor with a strong educational and applied research effort directed at livestock producers and rangeland owners. New educational efforts were being developed for the influx of ranchette owners moving into California's foothills. This network of county advisors had already formed a Hardwood Workgroup to begin to organize and coordinate educational outreach to hardwood rangeland owners.

Since the elements for a research and educational program were in place, plans for the Integrated Hardwood Range Management Program were developed to build on this base (Passof and Bartolome 1985). One component of this effort called for increasing the staffing level of Cooperative Extension advisors and specialists working specifically on hardwood rangeland issues, to support delivery of local-based educational efforts through county extension offices. The second major component was to develop a competitive grants research program to address high-priority knowledge gaps on hardwood rangelands.

The IHRMP's mission is stated as follows:

> *"To maintain, and where possible expand, the acreage of California's hardwood range resource to provide wildlife habitat, recreational opportunities, wood and livestock products, high quality water supply, and aesthetic value."*

The initial goals and direction of the IHRMP were driven by statewide concerns about regeneration, wildlife habitat, and conversion pressure (IHRMP 1988). The initial focus of the educational and research effort was directed at a stand or single property level. As understanding of the ecological processes on these lands has increased, the IHRMP goals have broadened to include multi-ownership, landscape level considerations (IHRMP 1992). Although vast areas of hardwood rangelands still occur as interconnected large blocks, several impacts threaten to fragment these areas and reduce their ecological value. Historically, clearing for agricultural production and rangeland improvements resulted in the major source of loss (Bolsinger 1988). In recent years, however, the process of population migration from urban areas to rural foothill locations and conversion of hardwood rangelands to suburban and industrial development have been the predominant source of loss and fragmentation of hardwood rangelands (Bolsinger 1988). *Figure 1* traces this evolution of program goals in 1986 to the broader landscape-based considerations that are in operation today.

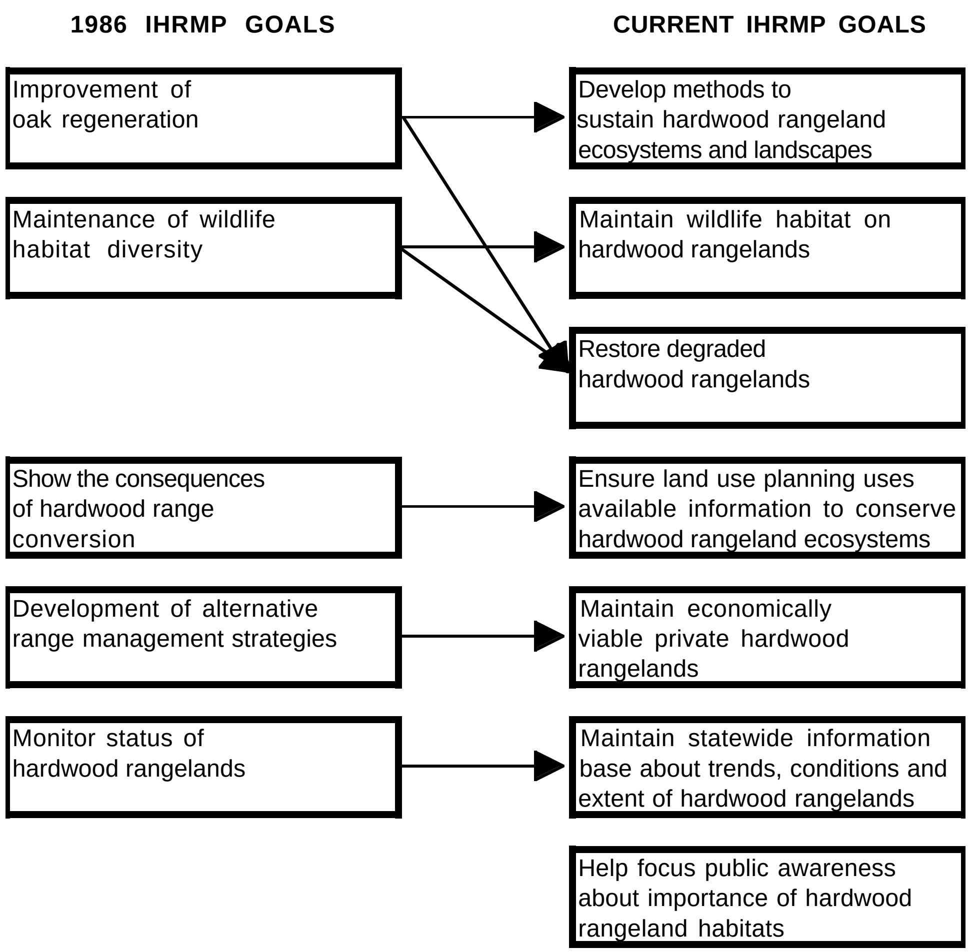

Figure 1—Evolution of IHRMP program goals.

The IHRMP has been administered as a collaborative effort between CDF, CDF&G, and UC. These organizations meet together at least quarterly for joint planning and priority setting. CDF has developed monitoring programs, UC has developed educational outreach programs, and CDF&G has had primary responsibility in assessing wildlife habitat values of the hardwood resource. UC and CDF jointly manage a competitive grants research program, ensuring that the highest priority problems are addressed, thereby eliminating duplication of effort. In recent years, the BOF has contracted with the California Oak Foundation (COF) to assist IHRMP efforts at urban public outreach and improve links with the development and planning communities. IHRMP effectiveness is monitored by contrasting current attitudes and management practices to baseline studies conducted early in the program. These surveys, combined with ecological monitoring, ensure program effectiveness and accountability.

Several criteria can be used to evaluate whether this coordinated educational and research approach to conservation of hardwood rangelands is successful. Each of these general criteria is considered in some detail in the sections below.

- Is new knowledge being developed?
- Are management practices that incorporate research-based knowledge being implemented by landowners and resource management professionals? Are management practices applied in such a way as to ensure sustainability of hardwood rangeland habitats?
- Are the trends of hardwood rangeland conversion being reversed? Are large-scale conversions due to range improvement, firewood harvest, and agricultural development reduced to a non-significant level? Does urban development maintain the ecological integrity of hardwood rangeland open space?
- Do conservation policies recognize the knowledge base on hardwood rangelands? Is the objective of these policies to sustain the ecological values of hardwood rangelands in an area?

Development of New Knowledge

Through UC and CDF funding, the IHRMP has funded 66 research studies over 10 years, which in turn has stimulated additional research on various aspects of hardwood rangelands. Specific areas investigated with IHRMP funding include: oak regeneration (20 projects); wildlife habitat (11 projects); soil, water, and land use issues (10 projects); hardwood rangeland management strategies (10 projects); and monitoring trends and status of hardwood rangelands (15 projects). This research has been conducted by investigators at various UC, California State University, and private university campuses, as well as at private research and consulting firms.

These research studies, resulting in more than 150 new scientific articles, contribute to the understanding of the extent of ecological and managerial processes on hardwood rangelands (IHRMP 1992). Research results have been disseminated in IHRMP-sponsored symposia and workshops and incorporated directly into educational documents and newsletters.

Research in oak regeneration has resulted in a better understanding of the ecological processes of natural regeneration (Gordon and others 1989; Swiecki and Bernhardt 1993). The high probability of achieving stump sprouting reduces the concern that a lack of sapling trees once suggested (McCreary and others 1991; Standiford and others 1996). Practical techniques for artificial regeneration have been developed, and oak seedlings are now widely available commercially (McCreary 1991). Genetic studies, underway to develop recommendations on oak seed sources for restoration projects, have shown large within-population variability (Riggs 1990). A new study has been started to evaluate the effects of hardwood rangeland fragmentation on the genetic diversity of oak species.

Studies on hardwood rangeland ecology have resulted in development of an ecologically based classification system (Allen and others 1991). IHRMP research has shown that extensively managed blue oak stands in wide areas of California have been quite stable over 60 years in the absence of land use changes (Davis 1995; Holzman and Allen-Diaz 1991). Pollen analysis of cores taken on hardwood rangelands suggests that current oak density on hardwood rangelands may be higher than at any time over the past several thousand years, possibly because of fire exclusion (Byrne and Mensing 1991). The importance of oaks for nutrient cycling on rangelands has been demonstrated (Dahlgren and Singer 1994; Firestone 1995; Frost and Edinger 1991). It has also been shown in one regional study that removal of up to one-third of the oak canopy has little effect on water quality and yield (Epifanio and others 1991).

Research on sustainable management practices has shown that diversifying enterprises on hardwood rangelands reduces risk and the need for oak clearing to offset livestock market fluctuations (Standiford and Howitt 1993). Recreational hunting programs provide an oak conservation incentive, and can increase ranch net present value by 30 to 50 percent (Loomis and Fitzhugh 1989; Standiford and Howitt 1993). Seasonal grazing practices have been developed to reduce moisture competition to oak seedlings (Hall and others 1992). Relationships between forage growth and oak overstory have been described for various regional locations (Bartolome and McClaren 1992: Frost and McDougald 1989). Combined with earlier studies (Holland 1980; Kay 1987), this relationship has helped to clarify when oak canopy enhances or suppresses forage production, and has resulted in the development of regionally based oak retention standards (Standiford and Tinnin 1996).

Hardwood rangeland wildlife studies have shown the value of different habitats for a variety of wildlife species, and models of habitat value have been developed and refined (Block and others 1990; Wilson and others 1991). Riparian zones in hardwood rangelands have been shown to be a particularly rich source of biological diversity (Tietje and others 1991). The effects of urbanization and fragmentation on wildlife habitat have been documented (Scott 1995).

Incorporating Knowledge into Management Activities

An important aspect of the development of educational programs is to characterize the demographics of the various audiences that have an impact on hardwood rangelands (Day 1987; Huntsinger and Fortmann 1990; McClaran and Bartolome 1985; Pillsbury and Oxford 1987; Whittington and Tietje 1993; Wright and Preister 1986). *Table 1* shows the wide variety of educational programs developed for the diverse audiences affecting hardwood rangelands.

A number of different surveys were implemented to evaluate the effectiveness of these various educational programs. A survey comparing participants in the IHRMP educational program to the population at large showed that ranchers, resource managers, conservation groups, and consultants, though diverse, have a strong set of shared values (Stewart 1991). Natural beauty and maintenance of wildlife diversity were the two most important values of hardwood rangelands to all audiences surveyed. Cooperative Extension (CE) has had some contact regarding oak woodland issues with 49 percent of the ranchers in California, and 69 percent of the resource managers. Of those who attended various IHRMP educational workshops, 74 percent of the ranchers and 70 percent of the resource managers have had some follow-up discussions with CE about oaks. Individuals who participated in IHRMP educational programs were more likely to carry out oak-enhancing management activities than non-participants.

Table 1—IHRMP educational methods addressed to various audiences

Educational methods	Audience addressed							
	Ranchers	Resource managers	Planners	Govt. officials	Devel-opers	Home-owners	Youth	Public
Workshops	x	x	x	x	x	x		
Field days	x	x				x		x
Symposia		x	x		x			
Organization in-service		x	x					
Consultation	x	x	x	x	x	x		
Associations/groups	x	x	x	x	x	x	x	x
Volunteers						x	x	
Publications	x	x	x	x	x	x	x	x
Newsletters	x	x	x	x	x			
News releases	x					x		x
Direct mailing	x	x	x	x				
Audio-visual	x	x				x	x	x
Curriculum							x	

The attitudes and management practices of hardwood rangeland owners were evaluated in 1985, just prior to the intensive educational outreach of the IHRMP (Huntsinger and Fortmann 1990). This same survey was repeated in 1992 to discern trends that resulted from the expanded educational programs (Huntsinger 1992). This follow-up research showed that education must be an ongoing process because at least 18 percent of hardwood rangeland properties had been sold in the 7-year period. The survey grouped owners into three categories: small (fewer than 200 acres); medium (200-5,000 acres); and large (more than 5,000 acres). In the 7 years between surveys, the only major change in demographics was that, in the small ownership class, average income increased dramatically and average parcel size decreased by 50 percent. This reflects exurban migration patterns into hardwood rangelands. Livestock grazing was still the dominant hardwood rangeland use after 7 years, occurring on 67 percent of all acres. The percentage of owners of large parcels who rely on livestock grazing as their major source of income declined from 70 percent in 1985 to 50 percent in 1992. Following the 7-year period of intensive educational outreach, oaks were more valued for wildlife habitat, soil protection, enhancement of property values, and for browse and mast production. The number of owners of large parcels selling firewood decreased from 40 percent in 1985 to 23 percent in 1992. The number of landowners of large parcels who cut living trees for forage enhancement declined from 58 percent in 1985 to 38 percent in the 7-year period. During this same time, the number of owners who conducted wildlife habitat improvements increased from 56 percent of the owners of large parcels to 64 percent. The surveys showed that owners who value oaks for wildlife, erosion control, and beauty were more likely to undertake oak promoting activities (protect sprouts, maintain fixed oak canopy levels, thin softwoods to promote oak growth, plant oaks). Owners who received advice from CE or other public advisory services were more likely to carry out oak-promoting practices. Strong attitudes against regulation of hardwood rangelands continued in the majority of all ownership classes.

Trends in Hardwood Rangelands

CDF has assumed responsibility in the IHRMP for monitoring changes in the availability and condition of hardwood rangelands. This included an effort to detect long-term changes on hardwood rangelands based on periodic statewide mapping. A baseline map was developed from aerial photos taken in 1981 and distributed to all county planning departments in California (Greenwood and others 1993; Pillsbury and others 1991). These maps are also available in digital format from the Teale Data Center in Sacramento. A second mapping project was completed in 1994 based on Landsat imagery (Pacific Meridian Resources 1994). This project showed errors of omission in the original mapping effort based on aerial photography. Ground checks of both the aerial photographs and remote sensing of satellite imagery showed underestimates of stand level canopy cover.

The USDA Forest Service Pacific Northwest Research Station has responsibility for regular inventory and assessment of hardwood rangelands in California. The first-ever statewide inventory was conducted in 1985 (Bolsinger 1988). These areas were resurveyed by field crews in 1994, and final reports are due in 1996. This inventory effort will provide the first detailed assessment of changes in stand structure over a 10-year period, form the basis for long-term evaluations of hardwood rangeland stands, and guide future education, research and policy efforts.

There has been no historical assessment of the acreage and volume of firewood harvested on hardwood rangelands. Annual reports of oak firewood harvest are made to the State Board of Equalization Timber Tax Division as the basis for yield tax payments; however, these reports may severely underestimate the extent of harvest on hardwood rangelands. To address the impact of firewood harvest on hardwood rangelands, CDF personnel monitored firewood harvesting annually by air from 1988 through 1992. Surveyors estimated acreage, intensity, and location of harvest sites on most of California's hardwood rangeland acreage. Approximately 27,000 acres had some firewood harvest in this 4-year period, yielding approximately 314,000 cords of firewood (Standiford and others 1996). There was a general downward trend in both acreage and volume harvested, consistent with the trends detected in the sociological survey (Huntsinger 1992). The harvest survey indicated that 0.1 percent of the total hardwood rangeland acreage was harvested annually. Although this is insignificant on a statewide basis, the survey showed that canopy retention after harvest was less than the recommendations in IHRMP and CDF&G educational materials in 96 of 120 areas observed in this 4-year period (Giusti and Tinnin 1993; Passof and others 1985).

The aerial monitoring showed significant regional impacts from firewood harvesting in Shasta and Tehama counties. Although they have less than 10 percent of California's hardwood rangeland, 50 percent of the total cords were harvested in these two counties (Standiford and others 1996). Harvest in these counties exceeded tree growth by about 10 percent over this 4-year period. This indicates that these harvest levels were not sustainable, and volume and canopy cover would gradually decline should this trend continue. These trend data were utilized by local decision-makers to develop local hardwood rangeland policies (see next section). No other counties had this harvest intensity, leading to the conclusion that firewood harvest was significant only in the northern Sacramento Valley region.

The assessment of California's hardwood rangelands by the Pacific Northwest Research Station showed that conversion of hardwood rangelands to urban uses was the largest single source of loss over the past decade (Bolsinger 1988). Given this trend, several efforts are underway to assess the extent of urbanization and to monitor the effect of hardwood rangeland fragmentation.

The CDF Strategic Planning unit evaluated various residential build-out scenarios in the Central Sierra Nevada region and showed a high probability of large-scale habitat change with the current county general plan in several areas (Doak 1989). CDF also spearheaded a project, known as the Sustainable Landscapes Project, in the Central Coast and Northern Sacramento Valley. This project was designed to assess the current landscape patterns and land use of hardwood rangelands, evaluate what patterns of landscape were necessary to sustain hardwood rangeland values into the future, and show how various land use alternatives affect this goal of landscape sustainability (Greenwood 1995). Several CE regional offices of the IHRMP are in various stages of setting up local information centers to assist in monitoring hardwood rangeland habitat and land use change. This effort has been closely coordinated with various bioregional planning groups.

Local Policy Initiatives

In May 1993, the Board of Forestry held hearings on hardwoods to evaluate the effectiveness of research and education as an approach to hardwood rangeland conservation. These hearings showed that there was strong support for the continuation of research, outreach, and monitoring, and that the kinds of threats facing hardwood rangelands vary greatly throughout California. Firewood harvesting was recognized as a concern in the northern Sacramento Valley, conversion to subdivisions was important in the central Sierra Nevada and southern California, and conversion to intensive agriculture was an issue in the North Coast. These findings confirmed that statewide regulations would not be able to effectively address the wide diversity of conservation issues. The BOF decided to intensify its outreach to local governments and encourage their participation in local policy development with the assistance of the IHRMP. Following a period of outreach, the Board will evaluate progress by local governments in providing policies which protect hardwood rangelands and determine where statewide policies might be needed to address continuing problems.

The IHRMP, consistent with the BOF resolution, has worked closely with local governments to encourage the development of local policies to conserve hardwood rangelands. At this time, 37 counties have adopted, or are in the process of developing, local oak conservation strategies. The different approaches fall into three general categories: voluntary guidelines, general planning process, and local ordinances. Each of these is discussed below.

County Voluntary Guidelines

At the 1993 BOF Hardwood Hearings, political and agricultural leaders from Tehama County volunteered to initiate a broad-based effort to address concerns about extensive firewood harvest in their area. This resulted in the appointment of a county oak committee composed of various resource agencies, environmental groups, agricultural groups, and CE. They developed a set of voluntary guidelines for oak retention designed to maintain economic viability of grazing and ecological values. This set of guidelines was passed by the county Board of Supervisors and mailed to all landowners in the county (Gaertner 1995). The success of this pilot project encouraged several other counties to develop voluntary guidelines. There are currently 12 counties in various stages of developing voluntary guidelines. The leadership for drafting guidelines varied in different areas of the State. Some were facilitated by the local chapter of the California Cattleman's Association, the County Board of Supervisors, the County Planning Department, or the Resource Conservation District. Each effort addresses important local issues and includes education and monitoring. For example, several of the voluntary guidelines in the northern Sacramento Valley addressed impacts from firewood harvest, whereas biomass harvest, fire protection, and soil erosion were important issues addressed in guidelines for the southern Sierra Nevada. Most of the guidelines also have general recommendations on urban development patterns.

General Planning Process

The county General Plan sets policies governing land use. The California Oak Foundation, working with the BOF, put together sample language on the importance of oak woodlands for the General Plan and mailed this to all county planning departments. Pilot educational activities have started in several Central Coast counties to utilize overlays of the CDF hardwood maps and parcel maps to implement landscape-based oak conservation strategies in the county planning process (Tietje and Berlund 1995). A Bay Area county compiled all existing oak policies for the county into a general booklet to be used for review of specific project plans which impact oak woodlands and to suggest mitigations. Another project between the county CE office and the planning department reports on the state of knowledge about riparian hardwoods in the county and develops project guidelines to implement the General Plan policy to protect and restore hardwood riparian habitats. In southern California, the IHRMP has worked closely with three county planning offices and Boards of Supervisors in the design of a corridor system to minimize the effects of habitat fragmentation. General regional and county-wide habitat conservation plans (HCP) have been coordinated with the goals of the IHRMP in southern California.

Ordinances

Some areas have used ordinances as a mechanism to protect oaks. Ordinances create a regulatory environment at the county or city level and usually involve a permitting process for the removal of any tree over a certain size class and mitigation standards where tree removal is allowed. Most tree ordinances have focused on the single tree rather than at a broad habitat scale. CDF has developed an educational book on ordinances which describes the importance of setting objectives for an area before writing an ordinance and monitoring whether the objectives have been accomplished (Bernhardt and Swiecki 1991). This book has been distributed to all counties in California. At this time, 11 counties have ordinances designed to protect oak trees.

Conclusion

Table 2 summarizes some of the important accomplishments of the IHRMP, current trends, and possible future considerations. Important information has been developed on the ecology and sustainable management of hardwood rangelands through activities of the IHRMP. Sociological and biological monitoring shows that diverse audiences have accepted and acted on information provided by IHRMP programs. A large number of counties have started the process of adopting local conservation strategies to conserve hardwood rangelands. It is quite clear that education and research have played a major role in conserving hardwood rangelands. Major accomplishments have been made in the more rural areas of California, where livestock and natural resource management are the predominant land use. Where individual landowners have the ability to implement management activities that affect large acreages, education and research have contributed to decisions that favor conservation of oaks.

However, the IHRMP activities have also shown that, for much of California, conversion of hardwood rangelands to urban or suburban land use is having the

Table 2—General overview of Integrated Hardwood Range Management Program accomplishments and future plans

Problem Area	Information Developed	Current Policy/Outreach	Trends	Future Considerations
Methods to sustain hardwood rangeland ecosystems and landscapes	• Ecology of natural regeneration • Ecological processes described • Oak genetic architecture	• Cost-share programs • Local groups develop landscape goals • Education to landowner groups	• Range watershed management plans • Stable stands over 60 years • Sapling recruitment gaps	• Expand cost-share participation • Develop landscape goals • Coord. with fire planning
Maintenance of wildlife habitat on hardwood rangelands	• Models of wildlife habitat relationships • Popular publications developed • Values of habitat components	• Oak retention guidelines • Develop local habitat goals • Wildlife habitat relationships (WHR) for general use	• Habitat fragmentation, from development • More wildlife consideration by landowners • Higher hunting values • Cumulative effects of previous conversions	• Evaluate retention guidelines • Develop landscape habitat goals • Refine WHR • Coordinated resource management process
Restore degraded hardwood rangelands	• Artificial oak regeneration techniques	• Outreach to restoration and nursery community • Develop community planting events	• 1 million seedlings yearly • Restoration professionals • Mitigation requires restoration	• Develop tree spacing goals • Low cost regeneration techniques • Restoration of native grasses and brush
Ensure that land use planning uses available information to hardwood rangeland ecosystems	• Effects of conversion on wildlife habitat • Open space conservation tools • *Planners Guide* publication • *Quercus* newsletter	• Input on local policies • Use taxation (Williamson Act, etc.) • Public acquisition funds • Tax incentives for conservation easements • Education for planners • Utilize General Plans for conservation goals	• 11 county tree ordinances • Residential development major impact • High population growth on hardwood rangelands • Land trusts as receivers for open space	• State-mandated tree ordinances • Oak conservation element in General Plan • Conversion permits • Coordinate Firesafe planning and oak conservation • Develop local oak land use goals
Maintain economically viable hardwood rangelands	• Sustainable management publications • Grazing strategies for oak regeneration • Relationship of oaks and forage production • Conservation incentives of diversified enterprises	• Local workshops for landowners, managers • Ranching for Wildlife • Monitoring by resource professionals • Work with associations • New markets for environmental products	• Decrease in large-scale firewood harvest • Localized impacts of firewood harvest • Decrease in landowner reliance on livestock as sole income source	• Expand participation in cost-share programs • Declare hardwoods commercial under Forest Practice Act • Develop sustainable landscape goals • Coordinate with range water quality planning • Certify management practices
Maintain statewide information base on hardwood rangelands	• GIS developed • Aerial harvest monitoring • Effective monitoring methods developed • Satellite imagery and change detection	• Hardwood maps available to counties • Coord. mapping with conservation groups • Coordination between state/local databases	• Increasing local use of GIS technology • Remote sensing may simplify monitoring	• Update geographic information system • Support regional landscape projects • Multi-agency monitoring effort • Continue aerial harvest observations • Notification of harvest

continued

Table 2, continued

Help focus public awareness about importance of hardwood rangelands	• Youth education curriculum on hardwood rangelands • Urban attitudes study	• News releases • Work with schools, 4-H, youth groups • Radio public service announcements • Coordinate with Calif. Oak Foundation	• Increasingly urban population • Environmental attitudes by urban populace • Poor understanding of private stewardship	• Expand media advertisement • Ties between urban and rural • General tax to internalize public values

largest impact on sustainability of resource values. The IHRMP has initiated education and research activities to address this concern. Growth in the application of geographic information system (GIS) technology and availability of oak resource data layers should help local planners and developers to assess impacts on oak woodland values. Educational materials developed for this issue have been widely accepted by professionals working in the land use arena. However, success will be demonstrated only by a significant effect on the rate or pattern of development. Conversion to residential and industrial uses is a land use decision that is determined through a political process involving action by elected officials with input from different constituencies. Political and economic forces vary greatly across California, and "success" in land use decision-making involves individuals agreeing on a political course of action. Conserving hardwood rangeland values in this kind of decision-making environment will present a new and important challenge for a research and education strategy. Program effectiveness must be evaluated very carefully over the next several years to determine whether education and research alone are sufficient to sustain the ecological values of hardwood rangelands.

References

Allen, B.H.; Holzman, B.A.; Evett, R.R. 1991. **A classification system for California's hardwood rangelands**. Hilgardia 59(2): 1-45.

Bartolome, J.W.; McClaren, M.P. 1992. **Composition and productivity of California oak savanna seasonally grazed by sheep**. Journal of Range Management 45: 103-107.

Bernhardt, E.A.; Swiecki, T.J. 1991. **Guidelines for developing and evaluating tree ordinances**. Report to California Dept. of Forestry and Fire Protection Urban Forestry Program; 76 p.

Block, W.M.; Morrison, M.L.; Verner, J. 1990. **Wildlife and oak woodland interdependence**. Fremontia 18: 72-76.

Board of Forestry Staff. 1986. **Policy options for California's hardwoods**. Report to State Board of Forestry. Sacramento, CA.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas**. Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Research Station, Forest Service, U.S. Department of Agriculture; 148 p.

Byrne, R.; Edlund, E.; Mensing, S. 1991. **Holocene changes in the distribution and abundance of oaks.** In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 182-188.

Dahlgren, R.A.; Singer, M.J. 1994. **Nutrient cycling in managed and non-managed oak woodland ecosystems**. Land, Air and Water Res. Paper 100028. Davis, CA: Univ. of Calif.; 91 p.

Davis, F.W. 1995. **Vegetation change in blue oak and blue oak/foothill pine woodland**. Report to California Department of Forestry and Fire Protection. Contract 8CA06673. Sacramento, CA: California Department of Forestry and Fire Protection; 34 p.

Day, N. 1987. **Study of urban attitudes towards oak trees**. Report by Polaris to the California Dept. of Forestry and Fire Protection. Sacramento, CA: California Department of Forestry and Fire Protection.

Doak, S.C. 1989. **Modeling patterns of land use and ownership**. Final report to California Department of Forestry and Fire Protection. Contract no. 8CA63967. Sacramento, CA: California Department of Forestry and Fire Protection.

Epifanio, C.R.; Singer, M.J.; Huang, X. 1991. **Hydrologic impacts of oak harvesting and evaluation of the modified universal soil loss equation**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 221-224.

Firestone, M.K. 1995. **Nutrient cycling in managed oak woodland-grass ecosystem**. Final report to the Integrated Hardwood Range Management Program. Berkeley, CA: University of California; 56 p.

Frost, W.E.; Edinger; S.B. 1991. **Effects of tree canopies on soils characteristics of annual rangeland**. Journal of Range Management 44: 286-288.

Frost, W.E.; McDougald; N.K. 1989. **Tree canopy effect on herbaceous production of annual rangeland during drought**. Journal of Range Management 42: 281-283.

Gaertner, S. 1995. **Local action to conserve California's oak woodlands**. In: Newsletter of Integrated Hardwood Range Management Program. Quercus 3(1): 1-7.

Giusti, G.A.; Tinnin P.J. 1993. **A planner's guide for oak woodlands**. Publication of the Integrated Hardwood Range Management Program, Univ. of Calif., Berkeley, 104 p.

Gordon, D.R.; Welker, J.M.; Menke, J.W.; Rice, K.J. 1989. **Competition for soil water between annual plants and blue oak seedlings**. Oecologia 79(4): 533-541.

Greenwood, B., ed. 1995. **The Central Coast sustainable landscapes project**. A report by the participants of the Central Coast sustainable landscapes project to the California Dept. of Forestry and Fire Protection. Sacramento, CA: California Department of Forestry and Fire Protection.

Greenwood, G.B.; Marose, R.K.; Stenback, J.M. 1993. **Extent and ownership of California's hardwood rangelands**. Prepared for Strategic Planning Program, California Dept. of Forestry and Fire Protection. Unpublished report.

Hall, L.M.; George, M.R.; McCreary, D.D.; Adams, T.E. 1992. **Effects of cattle grazing on blue oak seedling damage and survival**. Journal of Range Management 45(5): 503-506.

Holland, V.L. 1980. **Effect of blue oak on rangeland forage production in central California**. In: Plumb, Timothy, technical coordinator. Proceedings of the symposium on the ecology, management and utilization of California oaks. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 314-318.

Holzman, B.A.; Allen-Diaz, B.H. 1991. **Vegetation change in blue oak woodlands in California**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 189-193.

Huntsinger, L. 1992. **Impacts of education: Preliminary results of a follow-up survey**. In: Integrated Hardwood Range Management Program Fifth Progress Report. Berkeley, CA: Univeristy of California, Berkeley; 19-27.

Huntsinger, L.; Fortmann; L.P. 1990. **California's privately owned oak woodlands: owners, use, and management**. Journal of Range Management 42(3): 147-152.

IHRMP. 1988. **Integrated hardwood range management program: First progress report**. Berkeley, CA. 25 p.

IHRMP. 1992. **Integrated hardwood range management program: Fifth progress report**. Berkeley, CA. 47 p.

Kay, B.L. 1987. **Long-term effects of blue oak removal on forage production, forage quality, soil and oak regeneration**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources. Gen. Tech. Rep. PSW-GTR-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 351-357.

Loomis, J.B.; Fitzhugh, E.L. 1989. **Financial returns to California landowners for providing hunting access: analysis and determinants of returns and implications to wildlife management**. Trans. 54th North American Wildlife and Nat. Res. Conf. 54: 196-201.

Mayer, K.E.; Passof, P.C.; Bolsinger, C.; Grenfell, W.W.; Slack, H. 1985. **Status of the hardwood resource of California: a report to the Board of Forestry**. Sacramento: California Dept. of Forestry and Fire Protection; 126 p.

McClaran, M.P.; Bartolome, J.W. 1985. **The importance of oaks to ranchers in California foothill woodlands**. Rangelands 7: 158-161.

McCreary, D.D. 1991. **Artificial regeneration of native oaks in California**. Conference Proceedings, 1991 Society of American Foresters Annual Meeting, August 4-7, San Francisco, CA. Bethesda, MD: Society of American Foresters.

McCreary, D.D.; Tietje, W.D.; Schmidt, R.H.; Gross, R.; Willoughby, W.H.; Weitkamp, B.L.; Bell, F.L. 1991. **Stump sprouting of blue oaks**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 64-69.

Muick, P.C.; Bartolome, J.W. 1985. **Research studies in California related to oaks**. University of California Wildland Resources Center Report No. 7; 37 p.

Pacific Meridian Resources. 1994. **California hardwood rangeland monitoring final report**. Prepared for Strategic Planning Program, California Dept. of Forestry and Fire Protection. Unpublished report.

Passof, P.C.; Bartolome, J.W. 1985. **An integrated hardwood range management program**. University of California Wildland Resources Center Report No. 6; 18 p.

Passof, P.C.; Clawson, W.C.; Fitzhugh, E.L. 1985. **Preliminary guidelines for managing California's hardwood rangelands**. Univ. of Calif. Div. of Agric. and Nat. Res. Leaflet 21413; 92 p.

Pillsbury, N.H., chair. 1983. **California's hardwood resource**. Preliminary report of the Hardwood Task Force. State Board of Forestry, Sacramento, CA; 67 p.

Pillsbury, N.H.; DeLasaux, M.J.; Pryor, R.D.; Bremer, W. 1991. **Mapping and GIS database development for California's hardwood resources**. Report to California Dept. of Forestry and Fire Protection Strategic Planning Program. Contract no. 8CA63963; 63 p.

Pillsbury, N.H.; Oxford, J.K. 1987. **The hardwood management issue: county perceptions of use, change, problems, and regulation**. In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources. Gen. Tech. Rep. PSW- GTR-100. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 404-410.

Riggs, L.A. 1990. **Conserving genetic resources on-site in forest ecosystems**. Forest Ecology and Management 35(1): 45-68.

Scott, T.A. 1995. **Initial effects of housing construction on birds in an oak woodland along the wildland urban interface**. In: Proc. Symp. The Wildland Urban Interface. Occasional Papers of the Southern California Academy of Sciences.

Standiford, R.B.; Howitt, R.E. 1993. **Multiple use management of California's hardwood rangelands**. Journal of Range Management 46: 176-181.

Standiford, R.B.; McCreary, D.; Gaertner, S.; Forero, L. 1996. **Impact of firewood harvesting on hardwood rangelands varies with region**. California Agriculture 50(2): 7-12.

Standiford, R.B.; Tinnin, P., technical coordinators. 1996. **Guidelines for managing California's hardwood rangelands**. University of California Division of Agriculture and Natural Resources Leaflet no. 3368; 180 p.

Stewart, W. 1991. **Monitoring values and practices of oak woodland decision makers on the urban fringe**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 174-181.

Swiecki, T.J.; Bernhardt, E.A. 1993. **Factors affecting blue oak sapling recruitment and regeneration**. Report to California Dept. of Forestry and Fire Protection Strategic Planning Program. Contract no, 8CA17358.

Tietje, W.D.; Barrett, R.H.; Kleinfelder, E.B.; Carre, B.T. 1991. **Wildlife diversity in valley-foothill riparian habitat: north central versus central coast California**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 120-125.

Tietje, W.D.; Berlund, T. 1995. **Land-use planning in oak woodland**. In Newsletter of Integrated Hardwood Range Management Program. Quercus 3(2): 1-9.

Whittington, J.; Tietje, W.D. 1993. **Oak management in California municipalities**. California Agriculture 46(2) 20-23.

Wilson, R.A.; Manley, P.; Noon, B.R. 1991. **Covariance patterns among birds and vegetation in a California oak woodland**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 126-135.

Wright, J.; Preister, K. 1986. **Steaks and stakes: extension's linkages on the hardwood range**. Report to the Integrated Hardwood Range Management Program; 42 p.

An Ecosystem-Based Approach to Valley Oak Mitigation[1]

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***Abstract**: The Contra Costa Water District's (CCWD's) Los Vaqueros Reservoir Project will inundate 180 acres of valley oak habitats. Instead of using replacement ratios to identify mitigation needs, we designed an approach that would efficiently replace lost ecological values. We developed a habitat quality index model to assess the value of lost wildlife habitat and effectiveness of mitigation options. Application of the model indicated that restoration of 238 acres of woodland and savanna would fully replace lost habitat values in 75 years.*

Our mitigation planning process was effective because it provided demonstrable benefits to CCWD and resource agencies. The planning processes could be adopted for use in other habitat restoration, mitigation, or mitigation banking projects.

In 1988, Contra Costa Water District (CCWD) proposed construction of the Los Vaqueros Project, a 100,000-acre-foot reservoir in eastern Contra Costa County, California. One of the few major, unavoidable consequences of the project is the loss of a large number of mature valley oaks (*Quercus lobata*) along and adjacent to Kellogg Creek within the reservoir inundation area. To secure the required permits, CCWD prepared an environmental impact report and environmental impact statement and supporting documents that identified environmental impacts associated with the project and appropriate measures that would be implemented to mitigate those impacts (Contra Costa Water District and U.S. Bureau of Reclamation 1992).

During early planning phases of the Los Vaqueros Project, CCWD committed to its ratepayers and the involved state and federal agencies that it would fully mitigate for significant impacts of the project on biological and other resources. CCWD also committed to its ratepayers to mitigate at a reasonable cost. Consequently, CCWD sought to develop a method for assessing project impacts on valley oaks and developing a mitigation program that is biologically defensible and economically efficient.

CCWD elected to use an ecosystem approach to planning the mitigation program. The approach established the primary mitigation goal as the replacement of the ecological values of the valley oak community. We believe this approach to establish mitigation needs is better than using typical tree or habitat acreage replacement ratios because it is based on sound ecological principles, is equitable, and satisfies requirements of regulatory agencies. It is also applicable to projects that affect other important ecosystems, including wetland and riparian habitats. The goal of this paper is to describe this approach to mitigation development using the Los Vaqueros Project planning process as an example.

The Planning Process

We used a phased planning process that resulted in three separate documents: a conceptual mitigation plan, a detailed mitigation plan, and a bid specifications and plan drawings package. Each of these documents addressed valley oak

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mitigation issues with progressively greater specificity. The first two documents were used for interagency discussions, and the third was used by CCWD to contract for the construction and initial maintenance of the mitigation.

Conceptual Mitigation Plan

The conceptual mitigation plan described and quantified the project impacts, identified and justified goals for mitigating those impacts, and identified potential areas for implementing valley oak mitigation.

Impact Assessment

To assess the project's impacts on valley oaks, it was necessary to describe the valley oak habitats and the wildlife habitat functions and values provided by each valley oak habitat that would be affected by the project.

Description of Valley Oak Habitats

Two valley oak habitat types were readily distinguishable in the project area, based on landscape position and canopy density: woodland and savanna. Valley oak woodland supports a relatively dense canopy (typically greater than 65 percent) formed by narrow bands of trees that grow in and adjacent to intermittent drainages at lower elevations in the project area. Valley oak savanna occurs on valley floors away from creek channels and supports a sparse canopy (typically less than 5 percent) with an extensive understory dominated by annual grasses.

A standardized method was used to delineate woodland and savanna polygons on aerial photographs and determine habitat acreage. First, several criteria were established to describe the readily observable differences in spatial (i.e., distance between trees) and structural characteristics (i.e., landscape position and canopy cover) of woodland and savanna. Second, field surveys were conducted to determine the number and diameter at breast height (dbh) of trees in each valley oak habitat affected by the project. Approximately 830 woodland and 140 savanna trees would be affected by the inundation and dam footprint. The mean dbh of savanna trees was 43 inches; 95 percent of savanna trees exceeded less than 10 inches. The dbh of woodland trees averaged 28 inches, and 90 percent exceeded 10 inches.

Establishing a clear methodology for defining and mapping habitat acreages was important because boundaries between the two habitat types are not distinct. The acreage of valley oak savanna, in particular, could vary substantially depending on whether the mapping criteria used included or excluded open grassland that occurred between the sparse oak overstory. Affected acreage also could vary depending on where polygon boundaries are drawn in relation to canopy edge. These mapping criteria could ultimately affect mitigation acreage requirements and design.

Mean canopy width (43 feet, determined by measuring canopy size for a representative sample of trees from aerial photographs) and distance from stream channels were the basis for mapping distinct woodland, savanna, and grassland polygons. Woodland and savanna types were defined as follows.

Valley Oak Woodland—Areas with two or more trees growing within two mean canopy widths of each other and within one mean canopy width of stream channel banks. Areas of annual grassland within one mean canopy width as measured from the canopy edge also were mapped as valley oak woodland.

Valley Oak Savanna—Areas with three or more trees farther than one mean canopy width from stream channel banks and within at least four mean canopy widths of each other. Annual grassland within four mean canopy widths from the canopy edge also was mapped as savanna.

Valley oak trees that did not fit the criteria for woodland or savanna were considered as single trees within annual grassland habitat. Because loss of valley oak trees was considered a significant impact of the project, removal of single trees also required mitigation. Consequently, single trees were assigned an impact acreage area representative of the average per tree in savanna habitat.

Application of this method indicated that approximately 50 acres of woodland and 130 acres of savanna habitat (including single trees) would be affected by the project. The method also allowed for comparison of habitat acreage under four scenarios:

- current conditions,
- future conditions with no project,
- future conditions with project implementation and no mitigation, and
- future condition with project implementation and mitigation.

Wildlife Habitat Functions and Values

We developed and applied a habitat quality index (HQI) model to quantify the wildlife habitat functions and values of woodland and savanna that would be lost with project implementation. The HQI model is designed to represent the range of habitat values that are characteristic of woodland and savanna. The model uses a formula structure similar to the species-specific habitat suitability index (HSI) models of the U.S. Department of the Interior, Fish and Wildlife Service's habitat evaluation procedures (HEP) methodology (1980, 1981) that combines quality ratings for a set of habitat characteristics that are important in determining habitat quality. The HQI model quantifies wildlife habitat value based on two structural characteristics of valley oak habitats: mean tree dbh and mean percent canopy cover (Jones & Stokes Associates 1991).

The HQI variables were selected because they represent most wildlife habitat values provided by valley oaks and are easily measured. Mean percent canopy cover was determined from aerial photographs and represents wildlife habitat values associated with foliage (e.g., leaf surface area for foraging birds and for nesting cover). Mean dbh was determined from direct field measurements of all trees in the project area and represents habitat values associated with tree size (e.g., acorn production [Garcia and others 1991, Koenig and others 1991], bark furrowing [Jackson 1979], and the availability of nesting cavities [Wilson and others 1991]).

The model provides a per-acre quality value by combining ratings for percent canopy cover and dbh variables. Quality ratings for each variable are determined by assigning a numerical value of 0.0-1.0, with a value of 1.0 representing the highest quality attainable for that characteristic. The per-acre HQI value is multiplied by the number of acres of habitat to produce an overall quality rating in habitat units (HUs). Average annual habitat units (AAHUs) are the average number of HUs annually produced from target year (TY) 0 (the year that project construction is initiated) to any specified future TY. Changes in preproject and postproject AAHU values reflect the magnitude of habitat quality change that can be expected with project implementation and the amount of mitigation necessary to offset those impacts. Application of the model indicated that a total of 48 woodland AAHUs and 87 savanna AAHUs would be lost with project implementation.

Historic trends in woodland and savanna conditions were used to predict future habitat extent and condition if the project were not implemented. Aerial photographs of the project site taken between 1939 and 1987 were analyzed to determine historical densities of valley oaks in the project area and the mean annual net rate of tree loss during that period. During this period, the number of woodland trees remained stable while the number of savanna trees declined (from mortality and lack of regeneration) at a rate of about 0.6 percent per year. This rate of decline is similar to the 0.45 percent per year rate observed elsewhere for valley oak by Brown and Davis (1991). The HQI model was used to quantify the resulting decline in wildlife habitat value expected in the future without project implementation, assuming continuation of the tree loss rate observed between 1939 to 1987 (*fig. 1*). Application of the HQI model indicated that 12 savanna AAHUs would be lost during the next 75 years.

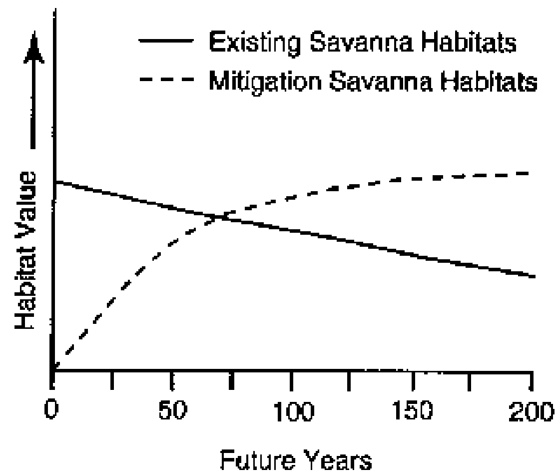

Figure 1—Predicted habitat value of existing valley oak savanna without project implementation and mitigation valley oak savanna with project implementaion in future years.

Mitigation Goals

Four goals were established in interagency discussions to guide the process of valley oak impact mitigation.

1. Use Restoration Techniques That Are Economically Efficient and Can Be Sustained on a Long-Term Basis—This goal was adopted to recognize that funding and staffing resources are limited and must be effectively applied in the mitigation process. The use of methods that require substantial funding and staffing may be appropriate initially, but mitigation stands should be sustainable without intensive, long-term maintenance (e.g., continuous irrigation).
2. Preferentially Replace Habitats That Have Been Most Detrimentally Affected by Regional Land Uses—Analysis of historic aerial photographs of undeveloped lands in the surrounding region and distribution of trees by dbh class showed that savanna was declining while woodland remained intact. The savanna type, therefore, appeared to be in the greatest need of augmentation as a regional landscape component. Restoration of savanna to mitigate for some of the losses of woodland was recommended and accepted.
3. Protect Mitigation Sites in Perpetuity—This goal was adopted to ensure long-term management and protection of mitigation sites from future habitat loss or effects of adjacent land use. This goal was achieved by using mitigation site selection criteria that ensured the selection of only the land that could reasonably be afforded long-term management and protection.
4. Design Mitigation Plans to Replace Lost Wildlife Habitat Values—This goal directed the pattern of planting to ensure that the structure created in the mitigation areas would correspond to the structure typical of healthy native habitats. For example, the canopy closure level chosen to represent the highest quality of savanna habitat was

15 percent (higher than the 5 percent observed at the site) to account for past canopy reduction.

To achieve these goals, the HQI model was used to identify mitigation acreage requirements and the growth period necessary to replace lost habitat values. To apply the HQI model, growth projection curves were developed (using tree dbh and canopy width data collected from the project area) to predict future mean canopy and mean dbh of valley oak trees planted for mitigation. HQI model results indicated that approximately 240 acres of valley oak must be planted to replace lost wildlife habitat values (i.e., 135 woodland and savanna AAHUs) within 75 years (*fig. 1*).

The HQI model incorporates an explicit mechanism to allow some tradeoff between habitat quality and quantity in determining total habitat values for existing and mitigation stands. Trees planted as acorns in the mitigation areas cannot achieve the same characteristics, and hence wildlife value, as the older trees for several hundred years. The model, however, attempts to explicitly quantify judgments of agency and consultant biologists regarding the relative tradeoffs between habitat quality at various points in time and habitat quantity (i.e., acreage) and thereby encourage consensus on the appropriate mitigation acreage.

Creation of some of the habitat characteristics of older stands (e.g., nesting cavities and down wood) will also be accelerated by installing and maintaining bird nest boxes and brush piles in mitigation areas to replace some of these values until they can be provided by the maturing mitigation stands.

Mitigation Site Selection

A three-step process was developed and implemented to identify, evaluate, and select potential mitigation sites.

First, a large regional area, consisting of CCWD project lands and eight valley bottomlands immediately to the north, was initially evaluated, which provided a wide range of potential mitigation site choices. The second step in the process was to identify soil types in potential mitigation areas that were suitable for valley oak establishment and growth and to rate them as having a low, moderate, or high capability for sustaining valley oaks.

The last step in the process was to select final mitigation sites. Several ecological and economic criteria were applied to lands possessing suitable soil types. The criteria and their rationale included:

- Proximity to the project impact area (resource agencies preferred that mitigation be established as close to the impact area as feasible),
- The amount of mitigation achievable at the site (larger areas of mitigation would be more cost effective to implement and provide greater wildlife habitat values than smaller areas),
- Proximity to other protected lands (establishment of valley oak habitats adjacent to existing protected habitats would increase overall habitat values by contributing to creation of a larger protected area of habitat and would reduce the likelihood of potential future adverse effects on mitigation habitat from adjacent land uses),
- Apparent health of existing onsite trees (as an indicator of a site's suitability for valley oak establishment),
- Depth to groundwater,
- Availability of irrigation water sources, and
- The estimated cost for land and mitigation implementation.

Application of this process resulted in selection of three different mitigation sites located within and immediately adjacent to the Los Vaqueros watershed.

After completion of the draft conceptual mitigation plan, CCWD presented the mitigation concept to permitting and resource agencies for comment. The conceptual mitigation plan provided background information and ecological justification for the proposed mitigation approach. The conceptual planning process enabled CCWD to clearly justify land requirements, including some lands that needed to be purchased specifically for mitigation. The plan also identified the procedures that could be used to meet interagency requirements.

Detailed Mitigation Plan

Following agreement by agencies with CCWD's conceptual mitigation approach, a detailed mitigation plan was developed (Jones & Stokes Associates 1993). The detailed plan described the "what, where, when, and how" of the mitigation program. Six major program elements were described in the plan:

- A detailed description of project impacts, mitigation goals and objectives, and selected mitigation areas;
- A planting plan that described the source and type of planting material, planting densities and layout, planting methods, and site maintenance;
- A mitigation implementation schedule that described the period over which mitigation would be implemented relative to the project implementation schedule;
- A mitigation monitoring plan and schedule that described how and when mitigation sites would be evaluated to determine the mitigation's success;
- Mitigation performance standards, established for future years, that must be met if mitigation is to be considered successful. (CCWD established performance standards to achieve at least 60-percent and 50-percent plant survival at years 5 and 10, respectively, following implementation of mitigation. Performance goals also were established for interim years to enable CCWD to determine whether plant survival was sufficient to ensure that the year 5 and 10 performance standards would be met.); and
- A description of potential remedial measures (e.g., replanting unsuccessful portions of mitigation sites or acquiring and planting additional mitigation lands) that could be implemented if any of the plantings do not achieve performance standards.

The first step in preparing the detailed mitigation plan was to conduct site-specific investigations of selected mitigation sites to confirm the presence and boundaries of suitable soil types and to identify potential constraints that were not identified in earlier evaluations.

At the request of permitting agencies, we evaluated "natural management" and "active management" approaches as options for implementing mitigation. The natural management approach relies on using management practices to increase the likelihood for natural reestablishment of valley oaks. Active management involves active, direct cultivation of oaks. Management actions using a natural approach can include changing grazing patterns that may be suppressing valley oak regeneration, improving hydrologic conditions for valley oak establishment by enhancing stream channels, or modifying other ecological factors (e.g., gopher control).

CCWD adopted an active management approach and rejected the natural approach because its dependence on natural regeneration to replace lost habitat values in the 75-year mitigation period could not be reasonably ensured. To increase the likelihood that mitigation goals will be achieved, CCWD's approach includes planting acorns and seedlings, providing irrigation for at least 2 years, removing livestock during seedling establishment, installing tree shelters to reduce herbivory, and initiating a 2-year weeding program. Using this approach requires greater initial costs than using less intensive management methods (e.g., planting acorns without irrigation or other maintenance) but is expected to achieve mitigation objectives more quickly and avoid the long-term costs of remediation associated with the less intensive method.

CCWD is also implementing the phases over time. The first phase was implemented in December 1995 on the mitigation site with the least favorable site conditions. The remaining mitigation sites will be planted after completion of dam construction, which is likely to be in winter 1997-1998. Monitoring of the initial plantings will allow mitigation techniques to be evaluated without risking potential failure at all the sites. The rationale for this phased approach is that methods proven successful on the least favorable site will ensure the success of the remaining, better sites. If one or more elements of the program are unsuccessful, however, this phased approach allows CCWD to adjust the program before investing in the remaining mitigation sites.

Following completion of the draft detailed mitigation plan, CCWD again met with the agencies involved to ensure that the proposed mitigation implementation and followup procedures were sufficient to reasonably ensure that mitigation goals agreed to in the conceptual mitigation plan could be achieved.

Detailed Bid Specifications and Plan Drawings

The final planning element was preparation of detailed bid specifications and plan drawings. Bid specifications and plan drawings provide sufficient detail for a habitat restoration contractor to construct and maintain the mitigation. These documents also provide the basis for competitive bidding by prospective contractors. Major elements of CCWD's specifications package included:

- Detailed descriptions of materials required for installation,
- The irrigation system layout,
- The planting layout and methods, and
- Mitigation maintenance requirements.

Mitigation Implementation

Mitigation implementation was an unencumbered and straightforward process because all mitigation issues had been resolved in the planning process. CCWD initiated Phase 1 of its mitigation in winter 1995, which consisted of planting approximately 1,000 acorns and seedlings on 55 acres. Monitoring survey results of the planting area may require slight adjustments to techniques used to establish subsequent mitigation phases.

Conclusion

We believe that the mitigation planning process developed and implemented for the Los Vaqueros Project is applicable to a variety of other projects and habitat types. The process can achieve a more ecologically meaningful and economically efficient result than is obtained under typical formula-based oak mitigation approaches. The process benefits project proponents by:

- Reducing mitigation costs;
- Increasing the certainty of mitigation success; and
- Ensuring that mitigation requirements are realistic, equatable, and scientifically based.

Involving resource agencies in a sequential planning process also reduces potential for delays during permit approval. Agencies, which frequently lack sufficient staff for detailed project evaluation, recognize benefits from development of clear, defensible methods to assess project impacts and identify project-specific mitigation. This should reduce reliance on the expedience of using predetermined tree or habitat acreage replacement ratios to establish mitigation requirements, which may not replace affected resource values.

We also believe that this planning process or a modified form of it can be used by a wide variety of landowners, land management agencies, and planning departments for habitat enhancement and restoration programs. The process may also provide the basis for establishing regional mitigation banks to replace oak woodland and other habitat types.

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References

Brown, Rodney W.; Davis, Frank W. 1991. **Historical mortality of valley oak (*Quercus lobata*, Nee) in the Santa Ynez Valley, Santa Barbara County, 1938-1989**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 202-207.

Contra Costa Water District and U.S. Department of the Interior, Bureau of Reclamation. 1992. **Final Stage 2 environmental impact report/environmental impact statement for the Los Vaqueros Project**, SCH #91063072, Volume I. September 27. Concord and Sacramento, CA. (JSA 90-211.)

Garcia, Sergio L.; Jensen, Wayne A.; Weitkamp, William H.; Tietje, William D. 1991. **Acorn yield during 1988 and 1989 on California's central coast**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 161-163.

Jackson, J.A. 1979. **Tree surfaces as foraging substrates for insectivorous birds**. In: Dickson, J.G.; Conner, R.N.; Fleet, R.F.; Kroll, J.C.; Jackson, J.A., eds. The role of insectivorous birds in forest ecosystems. New York: Academic Press; 69-94.

Jones & Stokes Associates, Inc. 1991. **A conceptual plan to mitigate impacts on valley oak habitat for the Los Vaqueros Reservoir project**. December. (JSA 90-211.) Sacramento, CA. Prepared for Contra Costa Water District, Concord, CA.

Jones & Stokes Associates, Inc. 1993. **Valley oak and riparian woodland habitat mitigation plan for the Los Vaqueros Project**. September. (JSA 92-078.) Sacramento, CA. With technical assistance from James A. Montgomery, Consulting Engineers, Inc., Walnut Creek, CA. Prepared for Contra Costa Water District, Concord, CA.

Koenig, Walter D.; Carmen, William J.; Stanback, Mark T.; Mumme, Ronald L. 1991. **Determinants of acorn productivity among five species of oaks in central coastal California**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 136-142.

U.S. Department of the Interior, Fish and Wildlife Service. 1980. **Habitat evaluation procedures (HEP)**. Ecological Services Manual 102. Washington, DC: Fish and Wildlife Service, U.S. Department of the Interior.

U.S. Department of the Interior, Fish and Wildlife Service. 1981. **Standards for the development of habitat suitability index models**. Ecological Services Manual 103. Washington, DC: Fish and Wildlife Service, U.S. Department of the Interior.

Wilson, Ralph A.; Manley, Patricia; Noon, Barry R. 1991. **Covariance patterns among birds and vegetation in a California oak woodland**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 126-135.

Factors Contributing to Land-Use Change in the Hardwood Rangelands of Two Central Sierra Nevadan Counties[1]

Sharon G. Johnson[2]

Abstract: *In many parts of California, the rate and progression of land use change in the hardwood rangeland depend upon the decisions of ranchers. As major landowners in these regions, a rancher's decision to subdivide or sell for development are significant moves toward land use change. In many instances, a single landowner decision may effect the disposition of thousands of acres of hardwood rangeland. This study seeks to identify factors that contribute to the sales or subdivisions of ranches in two rapidly developing counties in the Central Sierra Nevada: El Dorado and Amador. Area ranchers were surveyed through personal interviews and questionnaires in an effort to identify and examine factors creating difficulties for ranch operations. Instability factors identified by other land use change researchers were also explored.*

Research to date has established that the direct loss of woodlands to subdivision remains the greatest, most immediate threat to the viability of California's oak woodlands and the wildlife nurtured there (Doak and others 1991), (Allen-Diaz and Holzman 1993). Bolsinger (1988), for example, shows that since the 1970's suburban development has been the primary reason for woodland loss. He also estimates that current pressures for development threaten to claim another quarter million acres by the year 2010.

In much of California, the vanguard for new growth and development is largely focused on rangelands. Once characterized by low use and low value, the past 20 years have brought intense pressure for development and rising land values to much of California's hardwood rangelands. The foothill counties of the Central Sierra Nevada, for example, are among the fastest growing regions of the state. Between 1970 and 1990, the Sierra Nevadan population expanded more than 130 percent—that is over two and a half times as fast as the rest of the state. Most of this growth occurred in the central Sierra Nevadan foothill counties, with El Dorado County alone accounting for more than 28 percent—by far the highest in the region (Griffiths 1992). There is no question that growth must and will continue to occur in many of these areas, but questions as to how and whether traditional land uses, such as agriculture and livestock ranching, can persist in these evolving landscapes are concerns of many resource managers.

This study focuses on a fundamental aspect of land use change: the rancher. In many rural parts of California, the rate and progression of land use change in the hardwood rangeland depend upon the decisions of landowning ranchers. As major land holders in these regions, a rancher's decision to subdivide or sell for development may be a significant move toward regional change. In many instances, a single landowner decision may effect the disposition of thousands of acres of hardwood rangeland. Factors that contribute to rancher decisions to sell, whether they be difficulties in the modern business of livestock ranching or difficulties with increasing suburban neighbors—become the building blocks of change. This research seeks to identify and examine these keystones of change—those factors that contribute to ranchers' decisions to sell.

[1] An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Methods

The data reported in this paper were gathered in a series of in-depth, personal interviews with ranchers in El Dorado and Amador Counties during 1994 through 1996. The findings reported here are preliminary and reflect the first phase in a series of planned interviews. For each county, a list of active ranchers was obtained from the farm advisor. These lists were compared to Assessor's property records to determine if the ranchers or their families were also landowners in the county. The resulting list of landowning, ranching families became the source list for the interviews.

Interview techniques evolved somewhat during the first stages of this research. The first interviews were predominantly open-ended, guided by a list of questions derived from the literature on land use change and from issues identified during previous interviews with county staff. As themes emerged in these early interviews, they were included as questions for later interviews. The question list soon evolved into a draft questionnaire, intended to be used as a future mail survey.

The draft questionnaire guided the majority of interviews including all those taking place after June 1995. In fact, these interviews were also designed to "test" the draft questionnaire, as it was assumed that the interviewees at this stage were typical of the target group intended to be sampled in the mail survey to follow. Although the questionnaire guided much of the interview, time was always taken for more open-ended conversation both before and after the questionnaire was completed.

It is the results of these interviews, from the earlier, less directed contacts through those directed by the testing of the draft questionnaire, that are reported here. Not all questions were answered by all ranchers. Some declined answers on personal questions in such face-to-face settings, and some issues did not emerge until later interviews. For these reasons a descriptive approach has been taken in this paper. Where available and appropriate, numbers of respondents and answers are included.

Interview Participants

A total of 17 ranchers were interviewed, including 14 El Dorado and Amador County ranchers and three Sacramento County ranchers whose ranches were located near the Amador/Sacramento county line. Spouses participated in the conversations in three instances. All ranchers were from multigenerational ranching families. Six were third generation and five were fourth generation. In 11 cases, the ranch lands, or portions of them, had been in the family more than 60 years; six of these had been in the family for more than 100 years.

All participants were over 30 years of age. Six were 30 to 49 years old, three were 50 to 64, five were over 65, and ages of three were unknown. All had spent most of their lives within their county. School and military accounted for most time away. Of the eight participants who volunteered educational background, all had some college, several had Baccalaureate degrees, and two had graduate degrees.

Eight called themselves "full-time" ranchers whereas five had full-time jobs off the ranch. Three were retired from full-time jobs. Eight claimed that most of their family income came from the ranch, two said it contributed less than half their family's income, and two others others said all profits from cattle were reinvested in building their herds.

Issues Identified in the Literature of Land-Use Change

Land-use-change researchers have documented and described the process of change from rural/agricultural uses towards suburban uses in many parts of the country. The term "the urban-rural interface" is often used to describe regions surrounding growing urban areas where the propensity for land use change is high. In this zone, land value, land use, and rural economy are all affected by the dynamics of growth. It is as if the urban center casts an economic shadow across the nearby landscape.

The zones of the urban-rural interface have been described by a number of scholars. John Fraser Hart (Hart 1991) likened this vanguard of expansion around urban areas to a bow wave spreading before a moving boat. Land planners speak of an "urban shadow" in which the intensity of agricultural practices diminishes and scatterings of urban-type buildings or businesses appear. Economists describe an "impermanence syndrome" that discourages investment in agriculture in the urban fringe (Heimlich and Anderson 1987) Characteristics of land use change within these zones have also been detailed by researchers such as Bradley (1984), Huntsinger and Hopkinson (1996), and Healy and Short (1981).

A number of investigators, including Healy and Short (1981), Bradley (1984), Clawson (1971), Hart (1991), and others have examined various elements of land use change on agricultural and forest lands. Causal mechanisms such as demographic change, land market conditions, and speculation have been examined. But land use change on these lands may not be directly analogous to change in California's oak woodlands. Furthermore, other than work by Huntsinger and Hopkinson (1996), Forero and others (1992), and McClaran and others (1985), little work has been done on the progression of land use change on rangeland, especially in California.

The research reported in this paper takes factors and processes identified by other land-use-change researchers and investigates their relevance to the hardwood rangelands of the Central Sierra Nevada. Specific factors explored in interviews and questionnaires include:

- The parcelization of large rural properties
- Land speculation
- Increased land values (reflecting urban values rather than agricultural values)
- Disintegration of the farm economy (leading to increased farming costs for remaining farmers)
- Breakdown of farm infrastructure (increasing costs and business complexities for remaining farmers)
- Conflicts with urban neighbors

Parcelization and Speculation

Many of the above processes are already evident in the rangelands of the Central Sierra Nevada. Subdivision of large properties exists in a somewhat helter-skelter pattern across existing rangeland. All ranchers interviewed, for example, identified their home ranch as less than 5 miles from a subdivision or development. As one drives through the remaining undeveloped areas of these two counties, enclaves of subdivision are commonly encountered.

Land values in this area have also been affected by development potential. Values ranging from $1,000-$2,300 per acre, as cited by the ranchers themselves, are now beyond the price of land that can be purchased for livestock grazing alone. These high values create specific problems for ranchers wishing to continue their traditional livelihoods and will be addressed in detail later in this paper. Analysis of assessor's property records suggest that much land ownership is speculative in nature. Development companies are major landowners in both counties, especially in El Dorado County where the top three private land owners are development companies. Ranchers also feel the advance of speculation as all ranchers queried say they have been contacted by developers or real estate agents interested in their property. Several ranchers commented that such contact occurs "all the time."

Disintegration of the Farm Economy and Infrastructure

A number of questions were asked in an effort to gauge changes in the farm—ranch, in this case—economy. Ranchers were asked about changes in their herd size: whether their numbers were generally stable or had they increased or decreased. Four ranchers say they are actively increasing herd size now. Three ranchers reported the number of animals in their herds as remaining fairly stable during the past decade, with some fluctuation due to drought or market conditions. The situations of two of the three ranchers claiming a decrease in herd size will be discussed in some detail in the Public Land Policy and Private Land Management section. The other ranch reduced its stock numbers when the family member primarily responsible for ranch operations died.

Ranchers were also asked about the nature of their operations, specifically whether they were primarily cow/calf or stocker operations. "Stockers," also called feeder cattle, refers to weaned calves usually bought in the fall and sold in the spring (actual timing varies by operation.) Stockers require only a single season of investment and can be a more speculative investment. A cow/calf operation, on the other hand, implies a longer period of investment. A cow is held for 8 to 12 years depending on her health and fertility, and her calves are the product that is sold. A herd of cows is an important part of ranchers' investments in their future operations. A trend change away from cow/calf toward stocker operations might indicate a reduction in long-term ranch investment in an area and a turn toward operations that are more speculative.

No clear trend was evident from answers to these questions. Except for the one instance to be described, in which a rancher sold his cow herd and invested in stockers as he planned for change, the nature of most operations remained fairly steady under each rancher's management. Cow/calf operations dominated, with some ranchers making additional purchases of stockers. Because of the generally steady nature of operations, these stocker purchases suggest a diversified business strategy of the rancher/businessman rather than a change.

As an indicator of change in the farming infrastructure, questions were asked regarding how ranchers sold their crop of calves. Most ranchers remember a time during which there were numerous packing houses in the area, and representatives would come out to the ranch to buy or inquire about buying animals—often well before the calves were ready to be sold. Today, a few ranchers still maintain the contacts to have buyers come to the ranch, and video sales are becoming more common. But the primary outlet for sales today is the auction. Although several auction yards are within a few hours' drive of most ranches, the number of auctions is less than it was just a few years ago.

None of the ranchers reports the diminishing opportunity of sales as a critical problem. Most felt that animals could be sold when needed. One mentioned, however, that being restricted to auction sales, having a bad day at the auction, and low prices hurt the rancher more than situations with more competition.

The breakdown of farm infrastructure and possible increased costs and difficulties for ranchers were also explored through questions regarding the availability of veterinarians and suppliers. Aside from one rancher who noted that veterinarians who treat large animals are harder to find, medical treatment and supplies are generally adequately available to all operators.

Questions were also asked about the ability to hire help on the ranch. All ranchers asked said that the financial and administrative burden of hiring help—because of withholding, social security taxes, and disability and compensation insurance—is a definite disincentive for ranchers. Most work today is performed by family members and friends. One rancher said that if it were not for the help of a son, he would sell his cow herd. Another commented that his children can earn more driving trucks than by working the family cow herd.

Although the literature on land use change suggests that a breakdown of the social fabric in agricultural communities can contribute to change in fringe areas (Smith and Martin 1972), the ranchers interviewed do not consider this a problem. Nearby family and ranch friends may be fewer these days, but those that are left "stick together more." There is a general awareness, however, that the neighbors moving in now have different lifestyles and values, and livestock operators often do not feel understood by their more suburban neighbors.

Conflicts with Urban Neighbors

The literature on land use change suggests that conflict between agricultural operators and suburban residents increases as a region develops. These conflicts typically take the form of traffic problems, trespass, vandalism, complaints from urban neighbors, and problems with dogs.

Some conflicts are indirect. For example, in past decades ranchers would drive their stock to pasture on public roadways. Even the long drive from the home ranch in the foothills to the summer range in the mountains involved driving the herd up public highways, such as Highway 50. But as population has increased and traffic and congestion with it, the cattle drive has essentially disappeared. Transport by trucks, involving higher operating costs, have taken their place.

Other conflicts with urban residents are more direct. Vandalism, damage to fences, trespass, poaching, and problems with dogs are common occurrences. Fences are commonly damaged inadvertently by vehicle accidents, but they are also purposefully cut, broken, or driven over by trespassers wanting to get motorcycles or other vehicles onto the rangeland. Such problems are not just an inconvenience requiring the expense of repair, they are also a liability concern. Regardless of the reason cattle get out, ranchers bear full responsibility for accidents caused by cattle that stray onto roadways.

Marauding dogs are another persistent problem for all ranchers. It is not just the loss of stock or the inconvenience of "dealing" with the problem (ranchers in both counties are entitled to kill dogs that are found chasing stock); the disbelief of suburban residents regarding what their dogs do when they are not home does not help relations between ranchers and their newer neighbors. Dead dogs do not help these relationships either.

Aside from the killing of stock by dogs, poaching on the home ranch within these two counties has not been a major problem to date. Several ranchers are concerned, however, about unexplained losses of calves on their summer ranges in the mountains, leased from the USDA Forest Service.

Many ranchers have had some personal experience or know of someone who has had to deal with complaints from urban neighbors. Complaints typically focus on animal noise or stock bells, especially during early morning hours. But ranchers in both of these counties are protected by "Right to Farm" ordinances which allow all agriculturists to continue normal operations in spite of complaints. Ranchers uniformly feel these ordinances are critical to the future of agriculture in the area. Unfortunately, issues that cause complaints, although carrying no force of law, do not lead to better understanding or improved relationships between ranchers and their increasingly suburban neighbors.

Although the literature suggests that conflicts with urban neighbors do contribute to further change in use, such conflicts did not appear to be significant in these two counties. The ranchers themselves refer to them as "irritations" or "hassles" but consider them surmountable. Instead, ranchers identified a number of other factors they consider more threatening to their continued operations. These are what one rancher described as the "insurmountable" problems.

Critical Problems Identified by the Ranchers

From the first interview, ranchers themselves identified problems they believe are the most difficult to overcome. These include the economics of cattle raising, estate taxes, what will be referred to as the "pyramid of heirs," and the inflexibility of assets. Each is discussed in some detail below.

The Economics of Livestock Ranching

Livestock ranching is a land-intensive activity with a low dollar yield per acre. It is best suited for locations where land costs are low and competition for competing higher-income land uses is nonexistent. This was the case for most of the Central Sierra Nevadan rangelands until recent decades.

Certain economic parameters shape the profitability of livestock operations. As a rough figure, a cow can produce a calf that brings in $100 to $200 profit a year. This figure takes into account that not all cows calf each year, half of those born are females that cannot be considered income-producing in the same way, and that all costs of operations come out of the income calves produce. The market price of beef, which is currently very low, also dramatically affects profitability.

A herd must be supported by land—how much land depends upon the land's productivity. In the foothill hardwood rangeland of El Dorado and Amador Counties, year-round carrying capacity varies from about 10 acres per cow in the better areas to 20 acres in other areas. Land values typically range from $1,000 to $2,300 per acre depending on area. A simple example here can help illustrate the difficult economics ranchers face: Assuming a 15-acres-per-cow carrying capacity and a low land value of $1,000 an acre, a $15,000 land investment is required to support a cow that produces $100-200 profit a year. This is a return of around one percent per year. On the basis of these figures, land worth $1.5 million is needed to support a 100-cow herd.

Another way to look at the problem is the rent value of land. One acre of land worth $1,000 at current prices, if rented out as pasture, would earn only about $10—again a return of only one percent. It is not surprising that ranchers now say they cannot afford to buy land for cattle production. With the agricultural earning power of land such a small percentage of its value—its value for development—it no longer makes sense to buy land for livestock. All ranchers interviewed already owned land. Given current economics the most likely future buyers of rangeland will be speculators.

The Need for Summer Range

The above figures also do not consider the need for summer range. *All* ranchers interviewed seek additional pasture during the drier times of the year, from about May to November, depending upon the elevation and climate of the home ranch. This additional pasture may be at higher mountain elevations either owned by the rancher, leased from other land owners, or leased from Federal land management agencies. Some ranchers lease pasture—sometimes improved with irrigation— from other land owners near the home ranch. The need for summer range adds expense and complexity to the livestock operation.

Estate Taxes

For those families who have been able to pass the ranch on to subsequent generations, the very ownership of land—the fact that land that does not need to be purchased at today's prices—allows for the continuation of the family livestock business. But high land values return to haunt the family when a ranch passes from one generation to the next. The Williamson Act may provide some tax relief in the form of lower annual property tax rates for enrolled agricultural lands, but federal estate taxes, which must be paid at the death of a landowner before assets are distributed to heirs, are based on the full market value of the land. Although California does not currently have estate taxes, the federal bite is fierce enough. Estate taxes allow only $600,000 of value to be passed on to heirs tax free. For estates worth more than this amount, the tax rate ranges from 37 to 55 percent, depending on the value of the estate. We have already seen that a herd of 100 cows requires the support of land worth an estimated $1.5 million. As one rancher said, "The profit from our herd is not enough to pay the interest on the loan we took out to pay federal estate taxes."

Incorporating the family livestock business offers some mechanisms to pass on the family ranch, but incorporation is complicated and requires planning decisions that are difficult for many families to make. Legal assistance is also required which adds a burden of cost and complexity to the process. About this situation another rancher commented, "No one wants to talk about death and lawyers." Even with estate planning, there is no guarantee that heirs can or will continue the family business.

The Pyramid of Heirs

Even if a family is able to manage the financial planning to enable a ranch to pass on to the next generation, another problem often awaits: the expanding pyramid of heirs. If a family has a single heir, the ranch can more simply pass on in one piece. If a family has multiple heirs, the assets must somehow be divided. Even in the case of an incorporated family ranch that can stay intact, problems emerge if some heirs do not want to participate in the family business or if heirs do not get along. Property settlements brought on by divorce can especially ravage the family ranch. Splitting assets or buying out heirs presents a multitude of problems to estate planning for ranching families. Even if a ranch can be passed on intact for one generation, circumstances for the next generation may be much more complicated. The expanding pyramid of heirs in these counties has already caused the splitting, sale, and later development of a number of foothill county ranches.

Inflexibility of Assets

For most urban residents, dipping into savings accounts is a major way to finance education, retirement, or unexpected medical expenses. For these ranchers their ranch lands or their cow herd itself are their major assets. The non-liquidity of these assets presents major problems to ranch families for any of the above-mentioned needs and are especially restrictive when it comes time to handle estate taxes or distribute assets among heirs. Selling some land or stock to meet financial obligations directly lowers the ranch's earning ability, thus compounding financial problems. Selling off a portion of land is further complicated by the costs of surveys required for any subdivision. The survey costs of splitting off a 40-acre piece, for example, range from $10,000 to $12,000.

Most ranches are composed of a number of individual assessor's parcels, each of which is a legal entity and capable of being sold. But the selling of any such piece could threaten the economic viability of the remaining ranch. Similarly, if land is divided among heirs, the individual pieces may not be large enough to run a cattle operation. Williamson Act status—which most ranchers feel is critical to their operations—may also be threatened if the ranch becomes smaller. County review is required for any piece with Williamson Act designation. A piece cannot qualify if it is no longer economically viable for its designated agricultural activity. Ranches are not viable if they become too small. Thus, the inflexibility of a rancher's major assets—the ranch lands or the herd itself—adds to the instability of ranching in the region. If financial needs become too great, either to meet family needs or the settlement of an estate, the likely result is the sale of the entire ranch. Since land prices are now too high for the purchase of land for ranching or agriculture, development is most probable.

Federal Land Policy and Private Land Management

Much is said and written today about the potential impacts of changes in federal grazing policies. This issue is much larger than can be considered here, but experiences related in these interviews suggest an important connection between public land policy and private land management decisions.

All ranchers interviewed seek additional pasture for the summer. Of 16 ranchers queried, 13 have relied on USDA Forest Service grazing leases on mountain land at one time or another. Eight still rely on these leases, two take their cattle to Oregon, and the rest graze on rented pasture closer to the home ranch. Many mountain leases have been in the same family for generations. Of the ranchers who have used federal grazing leases, a number interviewed related incidents of losing or giving up these leases. These losses have important consequences best illustrated with examples.

Two ranchers interviewed lost their grazing leases when a dam was built on the land they leased. These ranchers began trucking stock to Oregon for summer range. One of these ranchers has recently sold his cow herd, invested in stockers for the time being, and intends to phase out ranching. He claims that current costs of trucking on top of other ranching economics now makes his operations unfeasible. Much of his land is now in Williamson Act nonrenewal—a process requiring 9 years. Development, at least on a portion of his property, is the most probable future disposition of these lands. As a major landowner in his area, any change in use will be widely felt. This is one case in which the loss of a lease appears to have contributed to the eventual phasing out of the family ranch.

Another rancher who lost a grazing lease is now renting improved pasture near his home ranch in the foothills. Since rented pasture is hard to find, he has reduced the size of his herd. Several other ranchers in the same area just abandoned their mountain leases because of difficulties in dealing with staff in their Forest Service District. They will also be looking for private pasture in the same area for the first time this summer.

One of the ranchers interviewed cited a shortage of rentable pasture as the major problem facing the livestock industry in these two counties today. Considering that much of the pasture currently available for rent is in unstable ownership dispositions (leased by retired ranching families who no longer run their own cows, leased by land-holding development companies with development plans, or leased by absentee landowners), the future availability of rentable pasture is highly questionable.

Every rancher who loses a lease on high-country pasture and seeks rentable pasture near the home ranch is heightening competition for a commodity already in short supply. These problems could well encourage ranchers to cut back herd size or just go out of business. Because livestock returns are such a small percentage of land value, it is unlikely land will be purchased for new ranches or purchased to be rented out for pasture; thus, development is the most likely future of land that is abandoned for ranching. In this way federal land policies regarding grazing leases in high-country locations can easily influence landowner management decisions on the home ranch miles away.

Conclusion

This research suggests that the "urban shadow" has already affected ranches in El Dorado and Amador Counties in many ways. Processes observed by other land-use-change researchers, such as land speculation, parcelization of large properties, the breakdown of farm infrastructure, and conflicts with urban neighbors, are all present to some degree. But interviews with 17 ranchers suggest that in the Central Sierra Nevada the most important effect of the urban shadow—an effect that may well encourage further change—is increased land value.

Hargrave (1993) found that El Dorado County ranchers had a higher return from land appreciation than from livestock production during the past decade. But returns in the form of higher land values exacerbate all the problems ranchers identified: it increases the discrepancy between land value and agricultural earnings, making the purchase of land for ranching a poor investment and thus weakening the stability of livestock grazing as a major land use. High land values also generate high estate taxes, and the inflexibility of land assets makes it difficult for ranch families to meet financial contingencies, settle estate taxes, or settle claims of heirs.

Perhaps the most critical juncture for the future of any ranch is when a ranch passes from one generation to the next . At this time, all problems that ranchers identified—the economics of ranching, inflexibility of assets, estate taxes, and the pyramid of heirs—are particularly exacerbated by high land values. For these reasons, much actual land use change in the suburbanizing counties of the Central Sierra Nevada may be initiated by the very mortality of the land owner. Summarized in another way, the loss of family ranches in this region may ultimately be traced to two facts of life familiar to us all: death and taxes.

References

Allen Diaz, Barbara; Holzman, Barbara. 1993. **Resampling VTM plots in Blue Oak cover type series.** Forest and Rangeland Resources Assessment Program, California Department of Forestry and Fire Protection; 73 p.

Bolsinger, Charles. 1988. **The hardwoods of California's timberlands, woodlands, and savannas.** Paper PNW-RB-148. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 148 p.

Bradley, Gordon A. 1984. **The urban/forest interface.** In: Bradley, Gordon A., ed. Land use and forest resources in a changing environment. Seattle and London: University of Washington Press; 3-16.

Clawson, Marion. 1971. **Suburban land conversion in the United States: an economic and governmental process.** Baltimore: The Johns Hopkins Press. Published for Resources for the Future, Inc.

Doak, Sam; Green, Kass; Fairfax, Sally K.; Johnson, Sharon G. 1991. **The legal environment for hardwood lands in California.** In: Proceedings of the symposium on oak woodlands and hardwood rangeland management. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 242-245.

Forero, Larry; Huntsinger, Lynn; Clawson, W. James. 1992. **Land use change in three San Francisco Bay area counties: inventing the urban ranch.** Journal of Soil and Water Conservation 47(6): 475-480.

Griffiths, Phil. 1992. **The Sierra now: a compendium of social and economic statistics on the Sierra Nevada Region**. Berkeley: University of California, Department of City and Regional Planning, professional report submitted for the M.C.P. degree.

Hargrave, T. 1993. **The impact of a Federal grazing fee increase on land use in El Dorado County, California.** Berkeley: University of California, Energy and Resources Group; 68 p. Master's thesis.

Hart, John Fraser. 1991. **The perimetropolitan bow wave.** The Geographical Review 81(1): 35-51.

Healy, Robert G.; Short, James L. 1981. **The market for rural land trends, issues, policies.** Washington, DC: The Conservation Foundation.

Heimlich, R.E.; Anderson, W.D. 1987. **Dynamics of land use change in urbanizing areas: experience in the Economic Research Service.** In: Lockeretz, W., ed. Proceedings of the symposium on sustaining agriculture near cities; Nov. 20-21, 1986; Boston, MA. Ankeny, IA: Soil and Water Conservation Society; 135-154.

Huntsinger, L.; Hopkinson, P. 1996. **Sustaining rangeland landscapes: a social and ecological process.** Journal of Range Management 49: 167-173.

McClaran, M.P.; Romm, J.; Bartolome, J.W. 1985. **Differential farmland assessment and land use planning relationships in Tulare County, California.** Journal of Soil and Water Conservation 40: 252-255.

Smith, A.H.; Martin, W.E. 1972. **Socioeconomic behavior of cattle ranchers, with implications for rural community development in the West.** American Journal of Agricultural Economics 54: 217-225.

Management of California Oak Woodlands: Uncertainties and Modeling[1]

Jay E. Noel[2] **Richard P. Thompson**

Abstract: *A mathematical policy model of oak woodlands is presented. The model illustrates the policy uncertainties that exist in the management of oak woodlands. These uncertainties include: (1) selection of a policy criterion function, (2) woodland dynamics, (3) initial and final state of the woodland stock. The paper provides a review of each of the uncertainty issues. The final section of the paper describes a modeling approach that can be developed to assist policy makers in evaluating alternative oak woodland policy actions.*

The management of natural resources is the topic of numerous academic journals, and hundreds of books and popular articles. Natural resource management has different meanings to different groups of people. Natural resources can be viewed as environmental assets which provide value to society in any number of ways. This value can be gained from using the natural resource as an input into the productive process, as a sources of raw materials, as a provider of life-sustaining services, and as a provider of esthetic and recreational amenities. The management of a natural resource is further complicated by various uncertainties. Uncertainty exists in determining the exact composition or stock (size) of the natural resource, in understanding the ecological dynamics of the natural resource, and with respect to whether the resource can be managed to achieve some socially preferred state.

It is then not surprising that, when one suggests that we need to better manage our natural resources, controversy erupts concerning how the natural resource should managed and for whose benefit. One segment of society may wish to have natural resources managed to improve their short-run and/or long-run productivity (e.g., range management for livestock) while another group may wish to have the natural resource managed to sustain or improve its amenity qualities (e.g. wildlife habitat).

Ideally, the highest value of the natural resource to society could be attained by maximizing the discounted net social value of the resource. This can be a difficult natural resource management problem since it requires information on the prices and costs of differing natural resource uses. Some of these have market values and cost (e.g. firewood), and other uses may have observable costs, but not have observable market prices (e.g. open space). These uses must have values measured through non-market evaluation techniques. Nevertheless, management of a natural resource requires that choices be made between competing resources uses and over time and space. These choices will not only affect differing groups in society but also potentially affect the ecological dynamics of the natural resource system. Effects on natural resource systems are typically valued in terms of their ultimate impact on human society although this is not universally accepted.

Commoner (1972) presents a principle of minimum interference, which suggests that there should be minimal to no management of natural resource systems by society. However, the obvious is that society does attempt to manage natural resource assets and that the outcome of that management is judged by whether it is consistent with collectively desired outcomes.

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A California natural resource that is subject to such complex debate over its allocative uses is the oak woodlands. There are about 10 million acres of oak woodlands (also known as hardwood rangelands) in California. Oak woodlands provide a number of valuable economic uses. These include cattle grazing, water resource development, wildlife habitat, open space, hardwood lumber and firewood, and land for urban development. There is a long history of concern about the public and private management of California's oak woodlands. These concerns include conflicts over changing land use, rights and responsibilities of ownership, and the extent and character of urban forces reshaping the oak woodlands, and the long-run sustainability of these woodlands.

Local, state, and federal agencies are under increasing pressure to deal with a wide diversity of private and public interests in a comprehensive and economically sound manner. To achieve this goal, improved oak woodland management guidelines are needed for land use planning and for ecologically and economically sustainable management practices in water production, grazing, wildlife, hardwood lumber, and housing. The California Department of Forestry and Fire Protection has summarized the policy issues and objectives for state action (California Dept. of Forestry 1988).

The broad objectives of this paper are to provide an overview of the problems associated with managing California's oak woodlands as a natural resource management problem and the development of a comprehensive oak woodlands control model that could assist policy-makers in achieving collectively desired outcomes. The modeling approach takes a systems view of the oak woodland's management problem. The model is intended to be an evaluative, not prescriptive, tool.

Oak Woodlands Management: The Uncertainty Problems

The following control problem is a mathematical representation of the oak woodlands management problem. It is presented to facilitate discussion of the uncertainty that exists in establishing oak woodland management policies.

Maximize or Minimize $\int_{t_0}^{t_1} I\big(S(t), U(t), t\big)$, subject to:

$\dot{S}(t)=f(S(t),U(t),t)$, the oak woodland ecosystem dynamics,

$(t_0) = S_0$, initial state of the oak woodlands,

$S(t) = Gt(S(t))$, the final state or terminal value of the oak woodlands,

$ht(S(t), U(t), t)$ (0, oak woodland constraints.

S(t) is the state of the oak woodlands at any given period of time between t_0 (current time period) and t_1 (future time period). The state describes those attributes that compose a specific oak woodland. For example, acres of land suitable for cattle range, volume of wood available for firewood and other hardwood uses, acres available for housing development, acres suitable for amenity purposes, acres suitable for wildlife habitat, and water development potential could characterize a specific oak woodland state. U(t) represents the control variables which affect the state of the oak woodlands from one period of time to the next. These controls could include the amount of cattle grazing in some specified time period, amount of oak harvested for firewood, amount of land utilized for wildlife habitat or housing. X(t) are the random disturbances that can affect the oak woodland state and include natural phenomena such as drought, fire, wind, and plant diseases and insect infestations.

The oak woodland management problem can now be stated as follows. Maximize or minimize I, some real valued policy criterion function, which has as its arguments S(t), the state of the oak woodlands in any time t; U(t) the uses of oak woodlands in any time t; and t time. This maximum or minimum is subject to $\dot{S}(t)$, the oak woodland ecosystem dynamics known as equations of motion; S(0), the initial state or value of the oak woodlands; $G_t(S(t))$, the final state or terminal value of the ending state; and h(S(t), U(t), t), specific ecological and policy constraints on the controls and states of the oak woodlands.

This oak woodland management problem is dynamic and stochastic and can be characterized as a closed loop control problem. This implies that resource allocation policies are conditional upon learning more about the ecological and economic dynamics and the impact that resource uses of and policies for have on the dynamics.

This model illustrates that managing oak woodlands is subject to varying degrees of uncertainty in the decision-making process. Uncertainty arises from (1) specification and selection of a policy criterion function and its parameters, (2) oak woodlands dynamics including the evolution of oak woodland ecology over time and the impacts that management decisions and random disturbance have on that evolution, and (3) the initial stock and final oak woodland stock or value. The next four sections discuss these uncertainties from the perspective of an investigator who is interested in developing a model to assist public policy-makers in evaluating different oak woodland management policies.

Policy Criterion Functions

Policy criterion functions provide the basis for evaluating the desirability of management policies and actions which lead to specific outcomes. These outcomes can be viewed as the state of the oak woodland ecosystem in some given time period. Public-policy decision makers must choose between alternative management strategies (policies) and actions that influence different sectors of the society in various ways and have different welfare connotations to these segments of society.

The uncertainty that must be addressed is the choice of a specific policy preference function and the estimation of its parameters. A number of researchers have attempted to address this issue including Theil (1968), Prescott (1972) , and Fromm (1969). Rausser and Freebairn (1974) discuss the issues associated with the selection of preference functions and estimate a preference function for United States beef import quotas.

Policy preference functions can be viewed as the objective function of the public agency which has the management responsibility for the natural resource. This means that the public policy entity must combine its legal mandates with its perceptions of society's wishes into a societal welfare function, which becomes its objective function. An attempt is then made to maximize this function given various constraints. Rarely, if ever, is the public agency certain as to what the societal welfare function looks like or whether, upon selecting a specific societal welfare function, it is the one which will maximize societal welfare.

There are two basic approaches to the development of a policy preference function. The first approach is to develop an explicit objective function. The formalization of an explicit objective function and its optimization allows for the endogenous (internal to the system) determination of the control parameters and thus the time-dependent resource states. The controls and resultant states are then reviewed by the policy-maker for management feasibility. If the optimization set of controls and states is not considered practical by the policy-maker then another objective function is selected and the process begins over again. This process would continue until a workable set of policies is determined.

The policy-maker would determine which is the more practical from a policy perspective.

An example of this type of policy preference function is the maximization of a social welfare function. The function is composed of the benefits and costs that accrue to differing uses of the natural resource over time and space. A number of studies have used the optimization of an explicit objective function to evaluate natural resource issues. Noel and McLaughlin (1983) use this approach to address the problem of groundwater overdraft problem in the San Joaquin Valley.

The second approach to the development of a policy preference function is an implicit approach. Such an approach assumes that the public policy decision-maker has implicitly optimized a societal welfare function and has chosen a set of management options that targets specific state outcomes. These targets become the ideal levels the public-policy decision maker has for the natural resource system. A deviation from them is considered a loss or cost to societal welfare.

The optimization criterion is to keep the evolution of the natural resource system as close to the target levels of controls (e.g., timber harvesting levels) and states (e.g., cubic feet of unharvested forest) as possible. An example of this type of policy criterion function is the quadratic tracking function (Athans 1972). The optimization of this function results in a minimization of the deviation of the targeted levels of states and controls. The deviation costs are measured by the relative weights placed on achieving a specific state versus achieving a specific control. The policy maker thus has the option of placing a greater weight on achieving a specific targeted state than control or vice versa. The optimization of the tracking function then is a minimization problem, which finds the minimum cost path of targeted state and control deviations. Dixon and Howitt (1979) use this type of policy preference function to evaluate an intertemporal forest harvesting problem.

The choice of what type of policy preference function to use is a subject of theoretical and empirical debate. Rausser and Freebairn (1974) list six points, which should be considered in the selection process. They conclude that the explicit function approach is preferred to the implicit approach since the arbitrariness of the former is less than that of the latter. Their view is not universally accepted (Naylor 1970).

Whatever approach is taken, a policy preference function must be estimated. This is a three-step process involving: (1) selection of the relevant variables as arguments, (2) determination of the appropriate mathematical structure, and (3) obtaining an estimate of a set of values for the parameters of the function.

Uncertainty in Dynamics of Oak Woodland Systems

Management of oak woodlands is subject to ecological uncertainties. The areas of uncertainty that are important to both the modeler and decision-makers are structural uncertainty and functional uncertainty. Structural uncertainty is caused by a lack of knowledge concerning the exact mathematical form that represents the ecosystem dynamics and a lack of data to estimate the form even if it were known. Functional uncertainty is concerned with changes in structure arising from sampling and measurement error. Structural and functional uncertainties create a stochastic set of natural resource system parameters, which essentially means that decision-making is done with incomplete information. This implies that selection of a policy is conditional upon current information concerning the structural and functional aspects of the ecosystem. However, new data assist in updating knowledge, creating a sequential policy-making process. Thus, the oak woodlands management problem has a dual nature. The policies chosen to manage the system affect both the value of the objective function and quality of future information on the structural parameters of the ecosystem. This is an active learning problem, which recognizes the stochastic nature of the ecosystem and represents a closed loop control problem, which seldom has an analytical solution (Aoki 1967).

Given the structural and functional uncertainty problems associated with natural resource management, the modeling of complex ecological systems has received a considerable amount of attention from biologists, ecologists, engineers, and economists. The modeling efforts have been concentrated in two areas: those models whose purpose it is to provide an understanding of complex biological systems and those models which are directed to biological system control. Central to both is the difficulty in inferring the true model from the phenomena being modeled. An example of the research being done in this area is provided by Mees (1990).

The second source of uncertainty in the mathematical modeling of natural resource systems is that of random disturbances, which can change the ecosystem parameters over time and space. These random disturbances include lightning-caused fire, floods, drought, erosion, disease, and insects. The impact of these disturbance processes on ecosystem management is discussed in detail by Averill and others (1994). The authors argue that these random disturbances can have both positive and negative effects on an ecosystem. It is not a question then of whether these disturbances can be ignored, but of finding a way to characterize these disturbances in physical and economic terms. Several tools are available to assist in this process including global positioning systems (GPS), geographic information systems (GIS) and geo-statistical technologies.

Certainty equivalence is an approximation approach to the stochastic (uncertainty) problems created by both the structure and function issues and random disturbance issue discussed above. The certainty equivalence approach uses expectation of the stochastic parameters of the biological system functions. A number of restrictive assumptions underlie this approach (Chow 1975). However, it is likely that researchers and decision-makers will continue to approximate the complex, dynamic biological systems with linearized versions of models that use certainty equivalency to handle structural and functional uncertainty problems. Standiford and Howitt (1992) use certainty equivalency in their bioeconomic model of California's hardwood rangelands. They derive production functions for forage, hunting, cattle, and oak firewood. A near optimal control was used to solve for state and control variables to give optimal time paths for oak density and cattle stocking.

The Initial State of the Oak Woodland System

This section discusses the biological, socio-political and economic criteria needed to adequately describe the initial state of the oak woodland ecosystem in California. This modeling phase should be the most straightforward to design and measure, but it is greatly complicated not only by the large amount of information needed on the parameters of the ecosystem but the more difficult problem of quantifying the relationships between the parameters. For example, one might be able to measure with reasonable accuracy the number of acres of various oak woodland types delineated by composition and structure. However, describing the habitat potential of each structural-composition type for various wildlife species is far more difficult.

Another important issue to address in defining the initial state is the scope or scale of the ecosystem. As the scale of the model increases to statewide, for example, information must necessarily be more generalized, which increases the uncertainty and thereby reduces the model's evaluative power. The result is either no feasible solution or a general one that is useless.

On the other end of the spectrum, the project area could be scoped down to as small as a watershed scale where more detailed information could be (and has been to varying degrees) collected, reducing uncertainties but providing solutions that disregard important landscape level concerns.

Figure 1 briefly summarizes that state of knowledge necessary to develop a oak woodlands policy model. By no means is the summary exhaustive nor is it sufficiently detailed to show the distinction between studies related to state or control issues. It is basically designed to illustrate, in one glance, where past efforts have focused and where the major gaps in knowledge exist.

Figure 1—Description of the current state of oak woodland research. Literature cited in this figure is not cited in the references section of the paper. For complete citations, please contact the authors at California Polytechnic State University, San Luis Obispo, California.

Silvics and Silviculture

Composition & Structure	Productivity	Regeneration
Allen, et al., 1991 Bolsinger, 1988 Byrne, et al., 1991 Davis, 1995 Holzman & Allen-Diaz, 1991 Mayer, et al., 1985 Pillsbury, et al., 1983, 84, 85, 91 Riggs, 1990	Bartolome & McClaren, 1985 Jameson, 1967 Jensen, 1987 George & Jacobsen, 1987	Muick & Bartolome, 1987 McCreary, et al., 1991 Swiecki & Bernhardt, 1993 Plumb, unpublished

Ecological Processes

Fire	Water	Nutrient Cycling	Pathogens & Insects	Wildlife Interactions
Rothermal, 1983 Zavon, 1982	Epifanio, et al., 1991 Gordon, et al., 1989 Duncan & Woodmansee, 1975 Murphy, 1970 Smith, 1977	Dahlgren & Singer, 1994 Firestone, 1995 Covington, 1981	IMPACT, 1987	Block, et al., 1990 Wilson, et al., 1991 Barrett, 1979 Verner, 1980 Bertram & Ashcraft, 1983

Land Use & Effects

General	Range/Grazing	Homesites	Habitat	Urban-interface
Doak, 1989 Greenwood, et al., 1993 Huntsinger, 1990, 91, 92 Pillsbury & Oxford, 1987 Tietje & Berlund, 1995 Doak & Stewart, 1986 Heady & Pitt, 1979 Clawson & George, 1985 Fortman &Huntsinger, 1985	Hall, et al., 1992 Holland, 1973, 80 Kay, 1987 Pacific Mer. Res., 1994 Bartolome, et al., 1980 Hooper & Heady, 1970 Rosiere & Torell, 1985 Frost & Edinger, 1991 Duncan, 1967	Whittington & Tietje, 1993	Tietje, et al., 1991 Airola, 1988 Graves, 1977 Ohmann & Mayer, 1987	Scott, 1995 Stewart, 1991

Resource Demands & Values

Grazing	Game	Row Crops	Fuelwood/Products	Ecological/Conserve
Wright & Preister, 1986 Alden & Mayer, 1984 Bowie & Watson, 1986 McClaren & Bartolome, 1987 Reed, 1974	Loomis & Fitzhugh, 1987, 89		Standiford, 1989 Standiford, et al.,1996	

Socio-political

Tree Ords./Prop. Rights	BMPs	Education/Extension
Bernhardt & Swiecki, 1991 BOF, 1982 Cox, et al., 1982	BOF, 1986 Gaertner, 1995 Passof, et al., 1985 Standiford & Tinnin,1996 Gingrich, 1971	IHRMP, 1990-95 Wright & Priester, 1987

This summary of past research indicates a reasonably good understanding of many of the management components for the oak woodland ecosystem, especially with regard to land use effects of different practices on the ecosystem and vice versa. It also appears that research has been done on the current structure, composition and ecological processes of the oak woodland ecosystem to begin such policy modeling. Nevertheless, to adequately define a desired future condition (final state), it is essential that more research be done on the natural range of variation in structure, composition, and ecological functions.

Figure 2 is illustrates the concept of a natural range of variation in structure and fire occurrence. Like all North American ecosystems, the oak woodland resource developed under the influence of humans for millennia. In order to assure that a sustainable policy is designed, it is essential that the final state fall within the natural ranges of variations before the impact of humans. Once defined these natural ranges of variation are defined, one is ready to specify the final state in the policy model.

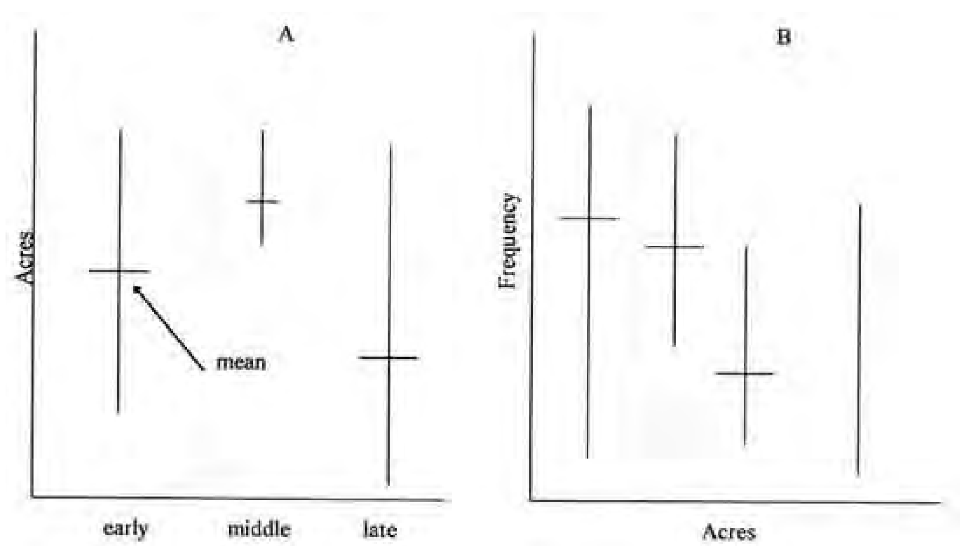


Figure 2—Natural ranges of variation in structure (A) and fire occurrence (B). Height of lines represents the distribution range.

The Final State of the Oak Woodland System

The management of oak woodlands requires that the public agencies who have management responsibility to evaluate societal interests in the form of a policy preference function, gain or have knowledge concerning the ecosystem dynamics, and determine the initial and desired final states of the oak woodlands.

The California Department of Forestry has as one of its goals the achievement of such a sustainable state (Calif. Dept. of Forestry 1988) This raises a question of controllability. Controllability is the ability of a policy instrument to modify the initial oak woodland ecosystem over a specific time horizon to achieve the final state. Aoki (1973) shows that the controllability condition is a necessary and sufficient condition for achievement of specific policy goals within a specific time period.

The real issue from a management perspective is whether this potential final state can be defined so as to be achievable. That is, is there a set of policies that will allow the initial oak woodland ecosystem state to converge to a sustainable state? The answer to these questions lies in the stability and controllability of the system in question. A completely controllable system is stabilizable regardless of its asymptotic stability properties (Aoki 1974). From an ecosystem management perspective, it is more important to know the controllability properties of the system than its asymptotic stability properties.

It is unlikely that complete controllability and, hence, stability in the oak woodland can be achieved or that it is even desirable. The same random disturbances previously mentioned, even if predictable, are not totally controllable. The very desirability of controlling such disturbances is brought into question by Averill and others (1994) who note, "Efforts to suppress (manage) disturbances, such as lightning fires, floods, drought, diseases and insects, which have been perceived to be in conflict with economic interests, have resulted in reduced biodiversity and ecosystem health. The more we attempt to maintain an ecosystem in a static condition, the less likely we are to achieve what we intended. We must be willing to bear both the economic and biologic consequences of such management."

The more preferred policy prescription from both a controllability and desirability perspective is to allow for a range of final states. Such a range would allow for a flexibility in establishing management polices and would add reality to modeling. The modeling problem would then be to find a minimum set of policies that addresses the critical question of timeliness of policy outcomes and curb the excessive expectations of policy or management actions.

The Modeling Process

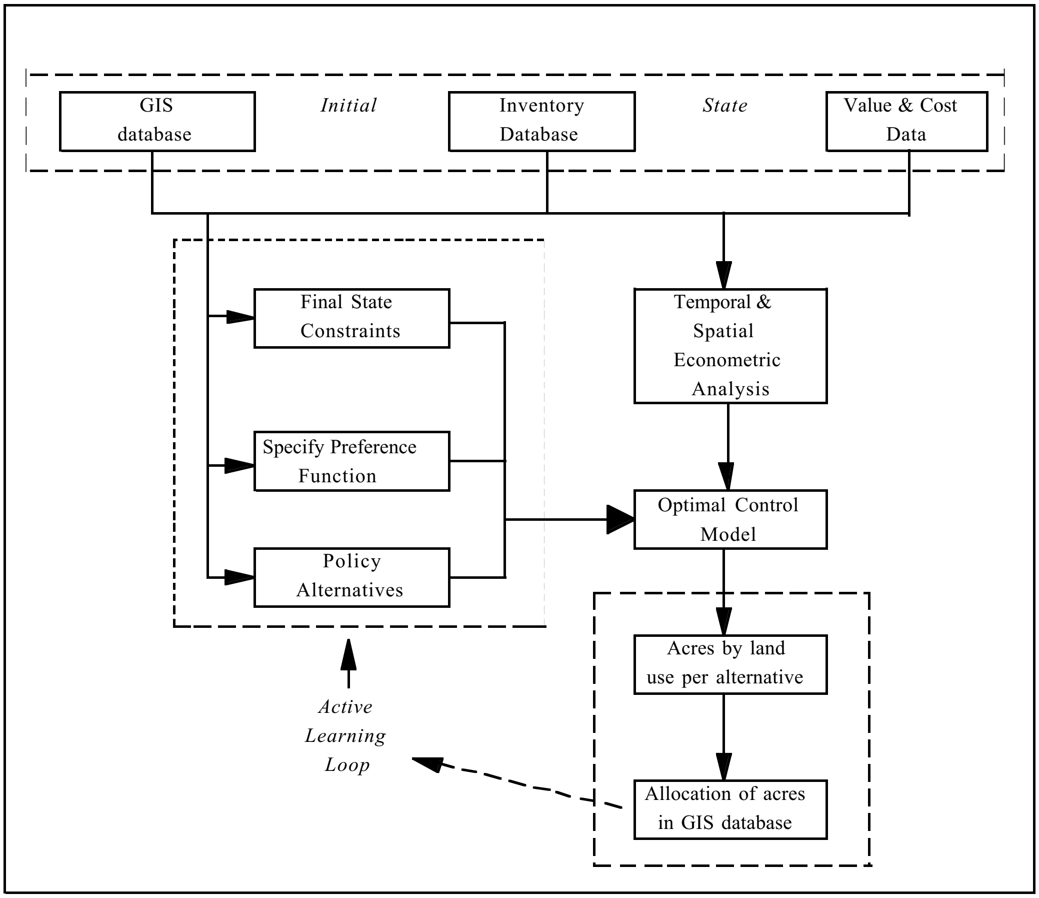
Thus far we have discussed various key issues that influence efforts to model policy governing the management of the oak woodland ecosystems. Now it is time to summarize these issues in a comprehensive modeling system that is useable as a policy analysis tool. *Figure 3* illustrates the process of modeling various policy alternatives relying upon a similar process developed by Covington and others (1988), which they called a "Terrestrial Ecosystem Analysis and Modeling System" (TEAMS). *Figure 3* illustrates the necessary component of an interactive oak woodland's policy evaluation model. Each of the problem variables in oak woodland management is connected and allows the decision-maker the opportunity to observe the bio-economic responses that may occur under differing policy scenarios. The model stresses the importance of the interactive learning process in evaluating differing oak woodland policies.

This type of model is useful for running any number of policy scenarios under changing economic and biological system conditions. GIS and inventory data bases are used to establish an initial state. Economic benefit-and-cost data for differing uses of the oak woodlands are used along with input from public policy officials to estimate a policy preference function. The GIS and inventory data are also used to estimate the biological system equations of motion. A final state can be specified or determined endogenously to the model, and differing policy constraints can be specified. These parameters are then combined in an optimal control model. The policy preference function is optimized given the various biological and policy constraints and the resulting land use allocations are observed.

The model can be used to evaluate tradeoffs. For example, very restrictive and directive management policies could be put into the model as constraints. This could shorten the time to achieve the final state, but such a course may not maximize the policy preference function. Alternatively, one could pursue a course that increases the value of the policy preference function, but extends the time to achieving the final state, even to a point where the final state is never achieved.

Another important use of this type of modeling framework is assessing the value of information. Earlier, the problem of uncertainties, especially in the biological system equation estimation, was discussed. As additional information about the different parameters making up the management problem becomes available, the model's parameters can be re-estimated. This allows for a re-

Figure 3—Oakwood Land Policy Modeling System.



examination of existing policies or new policies given additional information. Additionally, under certain circumstances, the value of new information can be estimated from the model. This type of modeling could provide the justification for obtaining new information or refining existing information.

This interactive learning process of estimating and refining the important parameters of the oak woodland management problem, trying alternative management policies, and observing the model's response enables the policy-maker to undertake final policies that are reasonable and defensible.

Conclusions

The oak woodlands of California are a valuable resource, but one that is in jeopardy from competing land uses. Policies must be designed that promote actions leading to the highest net benefit to society of the oak woodland resource while retaining the structure, composition, and ecological functions to ensure their sustainability. There are several approaches to designing these policies. One is incrementalizing existing policy, also known as "tweaking," or just "muddling through." This approach probably best describes the development of California's de facto oak woodland policy. Policy-making in this manner may minimize controversy, but has a much lower chance of achieving a desired future condition of the oak woodland ecosystem.

Another approach would be to clearly specify a desired future condition and undertake a rational analysis of the forces that are shaping the oak woodland resource. Assuming that the necessary information were available, policies could be identified that would constrain land uses and practices so as to achieve the desired future condition. There are potentially numerous policy paths to this desired future state, some socially and economically aggressively direct, others more gentle and circuitous. Whatever the course, at least society and policy-makers would be more certain that proposed policies would achieve a sustainable state.

The authors submit that this later approach is superior as a means of setting policy. We have attempted to clarify how one might design a model to aid policy-makers in pursuing this policy approach. The research problem becomes one of identifying the arguments, and relationships and obtaining the data to minimize the uncertainties that influence construction of such a model.

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References

Aoki, Masanao. 1967. **Optimization of stochastic systems.** New York: Academic Press.

Aoki, Masanao. 1973. **On sufficient conditions for optimal stabilization policies.** Review of Economic Studies 40(1): 131-138.

Aoki, Masanao. 1974. **Local controllability of a decentralized economic system**. Review of Economic Studies 41: 51-63.

Athans, Michael. 1972. **The discrete time linear-quadratic-gaussian stochastic control problem.** Annals of Economics and Social Measurement 1(4): 449-491.

Averill, R.D.; Louise, L.; Saveland, J.; Wargo, P.; Williams, J. 1994. **Disturbance processes and ecosystem management.** www.fs.fed.us/research/disturb.html

California Department of Forestry and Fire Protection. 1988. **California forest and rangelands: growing conflict over changing uses**. Sacramento: California Department of Forestry and Fire Protection; 348 p.

Chow, Gregory. 1975. **Analysis and control of dynamic economic systems**. New York: John Wiley & Sons.

Commoner, Barry, 1972. **The closing circle**. New York: Alfred Knopf.

Covington, W.W.; Wood, D.B.; Young, D.L.; Dykstra, D.P.; Garrett, L.D. 1988. **TEAMS: a decision support system for multiresource management**. Journal of Forestry 86(8): 25-33.

Dixon, Bruce L.; Howitt, Richard E. 1979. **Uncertainty and the intertemporal forest management of natural resources: an empirical application to the Stanislaus National Forest.** Giannini Foundation Monograph Number 38. Berkeley: University of California.

Fromm, G. 1969. **The evaluation of economic policies**. In: Naylor, Thomas H., ed. The design of computer simulation experiments. Raleigh, NC: Duke University Press .

Mees, A.I. 1990. **Modeling complex systems.** In: Vincent, T.L.; Mees, A.I. Jennings, L.S., eds. Dynamics of complex interconnected biological systems Boston: Birkhauser.

Naylor, Thomas H. 1970. **Policy simulation experiments with macro-economic models: the state of the art.** American Journal of Agricultural Economics 52: 263-271.

Noel, Jay E.; McLaughlin, Dennis. 1983 **San Joaquin Valley hydrologic-economic modeling study.** Unpublished research report. Sacramento: California Department of Water Resources.

Prescott, E.C. 1972. **The multi-period control problem under uncertainty**. Econometrica 40: 1043-1058.

Rausser, Gordon C.; Freebairn, John W. 1974. **Estimation of policy preference functions: an application to U.S. beef import policy**. Review of Economics and Statistics 56: 437-449.

Standiford, Richard B.; Howitt, Richard E. 1992. **Solving empirical bioeconomic models: a rangeland management application.** Journal of Agricultural Economics 74(2): 421-433.

Theil, Henri. 1968**. Optimal decision rules for government and industry.** Amsterdam: New Holland.

Estimating Value Contribution of Tree and Stand Condition[1]

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Abstract: *Key issues in encouraging forest management at the interface level in the oak woodlands are fire abatement, stand improvement, infection reduction, and hazard tree removal. The development of effective management prescriptions for stand improvement and economic returns provide guidance for homeowners, appraisers, and realtors. The purpose of this research project was to determine the effects of stand characteristics (e.g., structure, density and health) on the value of urban/interface forested properties. In this study, the forest characteristic coefficients were statistically significant with an estimated value contribution of about $30,000 each, or over 22 percent of the median property's value ($262,079).*

El Dorado and Placer Counties are two of the fastest growing counties within California and have undergone continued urbanization since the 1800's. The population of El Dorado County has almost tripled in 20 years, from 43,833 in 1970 to 125,995 in 1990. In Placer County the population has more than doubled, from 77,632 in 1970 to 172,796 in 1990 (San Francisco Examiner 1995). This explosive growth has created an urbanization of "traditional" wildlands into suburban communities. California's forests are a desirable place in which to reside and will continue to succumb to urbanization far into the future. Objective recognition of the beneficial economic and ecological qualities of a property's forest character will encourage improved management that incorporates the necessities of the natural environment.

The forests of the Lake Tahoe Basin today are overstocked and contain heavy infection levels of parasitic higher plants as agents of tree diseases (Tahoe Daily Tribune 1994). The suppression of fire, coupled with an increasing population base, has further reduced the health, composition, structure, and stocking of the Lake Tahoe Basin forest (hereinafter referred to as LTB). Drought, disease, and beetles respect no property boundaries when a forest's natural defense mechanisms are weakened. These threats have changed a once unbridled vigorous forest into an infected urban forest on both public and private land in California.

The existing literature on the implicit price of trees and their presence on residential property summarizes either the interrelationships between condition and associated health of the forest or the economic contribution from the absolute presence of trees on residential property. Literature on the value contribution of trees on urban, suburban, and rural property includes work by Magill (1989), Anderson and Cordell (1985), Chadwick (1980), and Neely (1979). Studies by Standiford and others (1987), Anderson and Cordell (1985), and Colorado State Forest Service/Colorado State University (1979) have attempted to identify the optimum number of trees on a property to enhance the value. These studies utilized both realtors and appraisers to estimate the value contribution or reduction in varied stocking levels from photographs, if all other site conditions were held equal.

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We attempted to design a more comprehensive model that reflects not only the esthetic value contribution of the number of trees per acre but also the effect of average tree size and the health of the trees. In this paper, a brief description of this model using sample data from the LTB will be presented. Finally, we will discuss the applicability of this modeling approach to other forested property markets, specifically the oak woodlands.

Methods

The approach used in this study rests upon hedonic theory wherein the value of any "property" is the cumulative result of the values of the characteristics which comprise the property. This study adds to the current body of knowledge by estimating the contribution to property value through a very comprehensive measure of tree and stand esthetic incorporating the size, infection level, and number of trees per acre.[6] The structural relationships of this model can be described as follows:

$$V_t = f(SQFT_{it}, VIEW_{i1994}, NS_{it}, LNDSCP_{it}, \mathbf{Z}_{i1994})$$

$$\text{where } \mathbf{Z} = f(SDI^*, INFECT_i^{\gamma}),$$

$$SDI_i^* = TPA_i^{\phi 2}\left[\frac{DBH^{\phi_1}}{10}\right]^{-1.6}$$

(see *table 1* for variable definitions)

Here, the value of any characteristic is imputed by the strength of the relationship between the property's value (V_t) and the quantity/quality of the characteristic, referred to as an implicit price of the non-market characteristic. The hypothesis was that tree condition, defined as structure, composition, density and health, in the LTB of California affect property value. In the above equation $\mathbf{Z}_{i1994}$ represents the forest vector, defined by the size and number of trees (SDI_i*) and their vigor ($INFECT_i$). In this hedonic model the estimated implicit price

Table 1—Rating guide for near and far viewsheds

Rating	Meaning
Near Viewshed	
1	NO VIEW possibly along major road or heavy-use area.
2	VERY POOR, surrounding property has heavy overstocking and poor condition
3	POOR, characteristics of 1 and 2 but in a modest degree
4	BORDERLINE, more (3) attributes than (5)
5	FAIR, on side of overgrown or undermanaged
6	INDETERMINATE, mild effort necessary manage condition
7	IMPROVING, more (6) attributes than (8)
8	GOOD, possibly hilltop and well stocked forest adjacent
9	VERY GOOD, near lake with wide view or open space
10	EXCELLENT, surrounding property is possibly lake-front or park-like; Forest Service land adjacent
Far Viewshed	
1	NO VIEW, possibly along major road or heavy-use area
2	VERY POOR, surrounding property heavily overstocked and in poor condition
3	POOR, characteristics of (1) and (2) but in modest degree
4	BORDERLINE, more (3) attributes than (5)
5	FAIR, on side of overgrown or undermanaged
6	INDETERMINATE, mild effort necessary to manage condition
7	UNENCUMBERED, more(6) attributes than (8)
8	GOOD, possibly hilltop and well stocked forest in the distance
9	VERY GOOD, near lake with wide views near mountains or open space
10	EXCELLENT, outlying property is possibly lake-front or views of mountain ranges in the distance and/or ski slopes

[6]A complete description of the theoretical and empirical model presented in this paper is presented in a thesis by R. Joss Hanna (1995).

contribution of the stand characteristics to the value of a property was the primary research interest, and the phi (Φ) and gamma (γ) vectors are for transformation to functional form.

Field Data Collection

Time-series empirical data were collected and constructed for the hedonic model and applied to sample home sales from 1989 to 1994. In July 1994, exactly 100 transactions of improved sites (defined as improved property, owned in fee) were randomly selected through public records at the El Dorado and Placer County assessors' offices. Collection of transactions evidence was equally divided between El Dorado and Placer Counties, fulfilling a range of price stratum identified by realtors and appraisers from the area.

Upon selection, permission to enter the property was obtained, and data were collected and verified on site. The silvical characteristics evaluated were: (1) tree size, (2) number of trees, (3) species, (4) form class, (5) locational attributes to the home, (6) presence of pathogens and insect infestation, (7) tree mortality, and (8) evidence of previous tree management. Other variables that could significantly affect a property's sale price are those that reflect the condition of the neighborhood and community where it is located. In order to capture and separate those impacts from forest characteristic differences, near-view and far-view variables were evaluated, along with 31 cross-sectional data items from each sample property comprising the house and property characteristics, typically found in a multiple listing service's description.

The variables used to represent forest characteristics are size and density of trees; position in the crown; evidence of management; mortality and infection rating incorporating needle, top crown, twig, branch, trunk, and root condition, as well as lean of tree (*tables 1, 2*). These measures are proxies for the esthetic impact, physical setting, and health of the individual portion of the forest contained on the property. Along with the extensive recording of data, all sites and plant aggregates were photographed for confirmation of the particular evaluations to complete the refined range of variables for repeatability and documentation.

Econometric Analysis

Tests for the best functional form indicated that a log transformation of the price, power transformations of infection, and stand density using an autoregressive process best fit the data. The variable transformations and statistical procedures improved the model and increased the efficiency in estimating the value contribution from the tree and stand characteristics to property value. The dependent variable is the selling price of a single family residence, varying in size from one-third to five acres and covering sales from 1989 through 1994, while the impact of forest attributes on the property value is our principal interest.

In determination of the "best" model two primary goodness-of-fit criteria were employed, the log likelihood function and the adjusted R^2. Through the iterative process, we examined the adjusted R^2 and predicted beta's significance. Each iteration involves different values for the phi (Φ) and gamma (γ) vectors and will yield alternative functional forms in the estimation of contribution from forest characteristics to property value.

Detection of error problems were conducted through the model's specification. Respecification of the model may alter the error term conditions; therefore, finding an acceptable specification for the model involves simultaneously altering the functional form and remediating the error problems. If the empirical design is correct, then the iterative processes should converge on a model whose coefficients and error have the correct properties and for which there is a high degree of "goodness-of-fit" (Judge and others 1985).

*Table 2—Variable definitions and source**

Variable	Definition	Unit /Example	Source
PRICE:	Full transaction amount recorded	Real price	MS
Date:	Date the transaction was consummated	Day/Mo./Yr	MS
Size:	Acreage or portion thereof	Acres	MS
Year built:	Year home was built	Year	MS
SQFT:	Square footage of heated living area	Actual	MS
Bedroom:	Number of bedrooms	Actual	MS
Bathroom:	Number of bathrooms	Actual	MS
Stories:	Number of stories of home	Actual	OS
Garage:	Presence of garage	0 = none 1 = 1 car 2 = 2 car	OS
Location:	Access variable will measure nearest tenth of a mile distance from main arterial road.	1 = 0-.5 mi. 2 = >.5-1 mi. 3 = >1-1.5 mi. 4 = > 1.5-2 mi. 5 = > 2 mi.	OS
VIEW:	Average of the Near and Far View value	0 -15	OS
NS	County dummy variable (also a proxy for forest type: Jeffrey Pine, Mixed Conifer, respectively).	1 = El Dorado 2 = Placer	
Stand Data			
DBH	Avg. measured in each plant aggregate	measured	OS
Height	Avg. measured in each plant aggregate	measured	OS
TPA	Trees/acre in each plant aggregate	measured	OS
P.A.	Size of plant aggregate (PA) in relation to the total property	1 = 0 -10 pct 2 = >10-20 pct 3 = >20-30 pct 4 = >30-40 pct 5 = >50 pct	OS
P.A. weight:	Size of plant aggregate in relation to the other aggregates	1 = 0-20 pct 2 = >20-40 pct 3 = >40-60 pct 4 = >60-80 pct 5 = >80 pct	OS
Pathogens*:	Pathogens detected that are presenting problems to stand and affecting health of trees	1 = none 2 = moderate 3 = definite 4 = heavy	OS
Insects*:	Insects detected that are presenting problems to stand and affecting health of trees	1 = none 2 = moderate 3 = definite	OS
INFECT	Risk Class based on Tahoe Regional Planning Agency Hazard Guide (source: M. D. Hansen, TRPA)	1 = no risk 2 = 1 -4.5 3 = 5 - 7.5 4 = 8 +	OS
LNDSCP:	Effort in managing to natural surroundings	1 = no 2 = yes	OS
SPCS:	Species present on property	Actual	OS
LAYER:	Layers present in canopy (D, CD, I, S/S, & Sup.)	Actual	OS

* Other data were collected but not described in this table. For a full listing of all data and variables constructed, contact the authors.

OS = Data collected on site. MS = Data provided through metro scan.

Stand Density Index and Value Contribution

Reineke (1933) found that a consistent relationship existed between log(TPA) and average DBH. The slope of the stand density index was approximately -1.6 for many species. The stand density index value is not strongly correlated with age or site and therefore can be used as a comprehensive measure of stand density condition. This quality of independence of age or site makes the stand density index an additional valuable parameter in describing a stand (Husch and others 1982); thus a composite variable is formed using Reineke's definition of stand density.

$$SDI = TPA \bullet \left(\overline{DBH}/10\right)^{-1.6}$$

It was further hypothesized that **Z** variables of tree size, density, condition, height, diversity, and species would significantly influence forest property values. These are typical stand measures and as such have well-established methods of data collection. Reliance upon "tried and true" sampling measures promotes the applicability of this modeling approach.

The **Z** vector is a composite term that contains forest characteristics of the property that have been hypothesized to influence value. The specification of **Z** is the primary interest in the identification of the hedonic model. Alternative specifications for **Z** range from a very specific representation to a general composite variable representing several tree and stand attributes. The two expressions for **Z** presented below represent the final two competing specifications:

$\mathbf{Z_1} = f$(DBH, TPA, SPECIES, LAYERS, HEIGHT, INFECT, LANDSCAPE, NS)

$\mathbf{Z_2} = f$(SDI, INFECT, LDSCP, NS), where SDI = f(DBH, TPA)

The correlation matrix in *table 3* is composed of Pearson correlations between all candidate independent variables. The first data column shows the relationship between all the independent variables and the dependent variable (P log). It was hypothesized that the relationship between a property's characteristics and its price is positive. The correlations between P log and the independent variables (SPECIES, LAYER, SDI, INFECT , NS, VIEW, LNDSCP, SQFT, TPA, DBH) appear to be frequently highly correlated, a positive sign for further empirical analysis.

Table 3—Pearson correlation matrix

Variable	Log P	SPCS	LAYER	SDI	INFCT	N/S	VIEW	LDSCP	SQFT	TPA
SPCS	**0.326**									
LAYER	0.173	**0.515**								
SDI	0.255	**0.315**	**0.342**							
INFECT	**-0.652**	-0.031	0.032	0.05						
N/S	0.152	-0.023	0.075	-0.06	0.065					
VIEW	**0.786**	**0.343**	**0.331**	0.22	**-0.536**	-0.091				
LDSCP	**0.265**	0.242	-0.037	-0.11	-0.209	0.002	0.134			
SQFT	**0.577**	0.168	0.088	0.14	**-0.43**	0.096	**0.335**	**0.302**		
TPA	**0.358**	**0.429**	**0.408**	**0.631**	-0.076	0.140	0.233	-0.017	**0.287**	
DBH	-0.094	0.047	0.117	**0.620**	0.231	-0.204	0.013	-0.115	-0.13	-0.1

Correlations in bold are considered to be sufficiently high to be relevant, using the following t-test at $\alpha = 0.05$ and $n = 76$, $t = r\,((n-2)/(1-r^2))^{0.5}$ (Snedecor 1957). See *table 1, 2* for explanation of variables.

In *table 3*, the correlation between SDI and DBH, and between SDI and TPA, are important to note for the development of Reineke's stand density index. Analysis of the correlation matrix and initial ordinary least squares (OLS) linear regressions point to a clear weakness in the $\mathbf{Z_1}$ specification relative to $\mathbf{Z_2}$. Poor model fit and little significance of the independent variables were due, at least in part, to loss of degrees of freedom, high multicollinearity, and probably serial correlation. Therefore, evidence exists to reject the $\mathbf{Z_1}$ specification and to aggregate or design instrumental variables as in the $\mathbf{Z_2}$ specification.

The variables SPECIES and LAYER appear to be highly related to other independent variables, particularly the composite measure, SDI. Important correlations are between LAYER and TPA, SPECIES and TPA, VIEW and SQFT and LDSCP. Clearly, some of the intercorrelations may be unintelligible, such as INFECT with VIEW and TPA with SQFT, and such spurious correlations can still create degrading multicollinearity.

Throughout the analysis and development to the final model, many alternative forms for the specification of $\mathbf{Z}_2$ were conducted. When all of the aforementioned forest variables were regressed together at the plant aggregate level, against the log of the final transaction price, the adjusted R^2 was 76 percent. Trees per acre and the diameter at breast height variables were on the borderline of significance. However, when the transformed stand density index value (SDI*) was employed in the final model, the adjusted R^2 increased to 83 percent and the tree and stand coefficients had a higher significance (*table 4*). It is important to note that the predicted beta ($\hat{\beta}$) remained quite stable as various forms of $\mathbf{Z}_2$ were tested by iterating values of the parameters (d, F_1, F_2). This stability is indicative of the absence of multicollinearity and gives confidence in our well behaved model and in the specification of our model.

Table 4—Results of the hedonic price generalized least squares model

Variable	Coefficient estimate	| *t*-value |	Confidence interval @ 90 pct	Marginal implicit price
	Log(PRICE)			
constant	11.556**	51.270		
SQFT	0.00014**	2.2785	$221,299-$317,924	$ 34
LDSCP	0.13974**	2.2584	$250,727-$280,609	$36,860
VIEW	0.06224**	6.2964	$232,296-$302,873	$23,784
NS	0.20289	1.0253	$225,376-$312,173	$53,979
SDI*	0.02235*	1.8004	$234,055-$300,598	$ 5,804
INFECT	0.07985*	1.7961	$234,103-$300,656	$20,745
rho	0.71152**	8.9289		
F-value	70.089			
Adj. R^2	0.8336			
Log L.F.	15.616			
n 76				

Notes: Mean property price was $262,079.
Confidence Intervals were calculated at the mean of each variable and then evaluated at the mean property price.
Marginal Implicit Prices were calculated as the change in predicted prices for the lowest and highest values of the variable divided by the range of that variable.
** indicates 1-tailed *t*-value significant at the $\alpha = 0.01$ level
* indicates 1-tailed *t*-value significant at the $\alpha = 0.05$ level

Results

The generalized least squares results for the following final functional form of the empirical hedonic model are presented in *table 4*:

$$\log(P_i) = \beta_0 + \beta_1 \, SQFT_{i\,t} + \beta_2 \, VIEW_{i1994} + \beta_3 \, LDSCP_{i1994} + \beta_4 \, NS_{i\,t} + \beta_5 \, SDI^*_{i1994} - \beta_6 \, INFECT_{i1994}^{1.3} + e_i$$

where: i = 1, 2, . . ., 76 sample properties, and each argument is potentially a vector characteristic.

t = years 1989–1994

$$SDI^* = TPA^{0.7} \left[\frac{DBH^{0.6}}{10} \right]^{1.6}$$

(The signs of the β coefficients represent the hypothesized relationships.)

The estimated coefficients were derived through the regression equation, and their *t* values were tested for significance. The SQFT, VIEW, and LNDSCP coefficients were statistically significant at $\alpha = 0.01$ (given that the alternative hypothesis indicated the direction of the relationship, a 1-tailed *t*-test was applied). The coefficient with the highest *t*-value was VIEW at 6.2964. The coefficients of the forest characteristics, INFECT and SDI*, were also statistically significant at $\alpha = 0.05$. The only variable deemed as having an insignificant relationship to log(P) was the locational proxy for forest type (NS).

It is more informative to interpret these statistical relationships in more meaningful terms, i.e., dollars. For the forested properties within the LTB, the estimated mean contribution of altering stand density (SDI*) is between $234,055 to $300,598, about the mean of $262,079, with 95 percent confidence. It is further concluded that with 95 percent confidence the mean value contribution from the INFECT variable to property value is $20,745 to the average home price of $262,079. As hypothesized, the infection rating had a significant inverse relationship to price.

Discussion

The development of an empirical hedonic model permits the valuation of forest and stand esthetics. The most striking outcome of this analysis was that easily measured stand condition variables accounted for a significant property value contribution. In our analysis we developed an *ex-post* model that effectively estimates forestland esthetics' economic contribution to property value.

As the traditional "wildland" forests succumb to urbanization, more information will be needed regarding the value contribution of the remaining forest stands to the new home sites. The results of this study should be helpful in understanding which forest characteristics create value and in quantifying these relationships. The following points summarize the results of our study:

- The specification presented here is only one of a multitude of possibilities based upon the current forest condition and other socio-economic factors.
- A significant portion of the variation (83 percent) in property sales price is explained by our independent variable set in the empirical model.
- All but one of the variables in the final empirical model are significant at $\alpha = 0.05$.
- All selected variables behave in a manner to be expected in their relationship to the dependent variable.
- Coefficients appeared to be quite stable in magnitude in all models tested, providing confidence in our data items.

It must be recognized that a higher SDI* does not imply an increase in TPA. In reference to the LTB, a rise from increasing average DBH while holding constant or increasing TPA will likely yield a higher value. The fastest and most proven method for increasing the average stand diameter for a given site is to thin out the weakest trees. This could be consistent with Anderson and Cordell (1985) because TPA alone was used to derive value and SDI was not tested. However, the final empirical hedonic model, not functional form, should be applicable to similar urban interface issues in other regions.

On the basis of our findings, the private landowners in the LTB will recognize that the present value of the gains in expected property value would clearly justify current out-of-pocket costs to improve stand health and esthetics. Implications from the empirical analysis led to the following statements relating to the primary objective of the study:

- Empirical results support the hypothesis that forest condition does influence property price in the LTB of California.
- Increasing SDI leads to gains in property value through increasing DBH by thinning.
- Unhealthy or dead trees diminish property value.
- Stagnated stands not only pose a hazardous threat but are also a value deflator.

These results should encourage landowners in the LTB to invest in the management of the stands. Because the majority of the urban forest is privately owned, the benefits must outweigh the costs for the small non-industrial private landowners to maintain their portions of the interface forest in a sound manner. With findings such as ours, there is significant support for the sustained management of the forest through economic returns in property values. Silvical prescriptions need to incorporate existing characteristics of the specific groups of vegetation. Because of the diversity of the composition and structure, it is not possible to identify one single best approach to meet management objectives.

Implications for Oak Woodlands

Just as with the Lake Tahoe area, the esthetic created from the current forested environment in the oak woodlands of California can be characterized as in decline because of urbanization. The multiple uses of the oak woodlands for ranches and suburban development have fragmented the forest cover type to a point that serious efforts in forest management are needed to rectify these problems and to promote improved property values. The fundamental approach to valuing the urban interface forest through this type of econometric analysis is sound. It is anticipated that as the forest types under inspection change, so will the significant property and stand characteristics.

Adjustments to the hedonic model might include the stocking, view, efforts in management, infection, and mortality in a different relationship to the property value than in the Sierra Nevada mixed conifer and Jeffrey pine forest types. Multiple uses would also be able to be modeled into the hedonic equation, incorporating uses for cattle and horse pastures. Another potentially important influence is the general forest condition in a particular forest property market, i.e., the cumulative effect of individual property stand conditions. To incorporate these influences, use of geographic information systems (GIS) and geo-statistical modeling techniques may help. Such research will help us to better understand and describe the value of the urban forest and assist policy makers direct land use.

References

Anderson, L.; Cordell, H. 1985. **Residential property values improved by landscaping with trees**. Southern Journal of Applied Forestry 9 (3): 163-166.

Chadwick, L.C. 1980. **Review of guide for establishing values of trees and other plants.** Journal of Arboriculture 6(2): 48-50.

Colorado State Forest Service / Colorado State University. 1979**. Dollars and sense about your trees**. Fort Collins: Colorado State Forest Service. 17p. Unpublished document.

Hanna, R. Joss. 1995. **Economic contribution of forest attributes to property value in the Lake Tahoe Basin of California**. San Luis Obispo: California Polytechnic State University; 117 p. Master's thesis.

Husch, B.; Miller, C.; Beers, T. 1982. **Forest mensuration**. 3rd ed. Malabar, FL: Krieger Publishing Company; 402 p.

Judge, G.; Griffiths, W.; Hill, R.; Lutkepohl, H.; Lee, T.-C. 1985. **The theory and practice of econometrics**. John Wiley and Sons, Inc.

Magill, Arthur W. 1989. **Searching for the value of a view**. Res. Paper RP-193. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 9 p.

Neely, D. 1979. **Guide for establishing values of trees and other plants**. Urbana, IL: International Society of Arboriculture.

Reineke, L. H. 1933. **Perfecting a stand density index for even age forests**. Journal of Agriculture Research 46: 627-638.

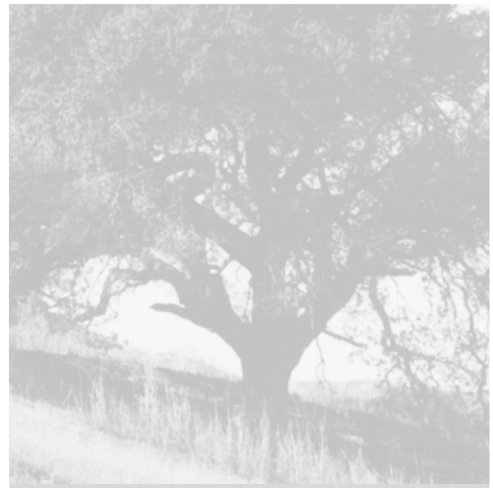
San Francisco Examiner. 1995. **Population explosion hits the Sierras**. San Francisco Newspaper Agency. May 7, 1995.

Snedecor, G. 1957. **Statistical methods**. Ames: Iowa State College Press; 172-177.

Standiford, R.; Diamond, N.; Passof, P.C.; LeBlanc, J. 1987**. Value of oaks in rural subdivisions.** In: Plumb, Timothy R.; Pillsbury, Norman H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; November 12-14, 1986; San Luis Obispo, CA. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 156-160.

Tahoe Daily Tribune. 1994. **Tahoe's tinder box**. Tahoe Daily Tribune, Inc. August 6, 1994.

POSTERS



Overview—A Bird's-Eye View of the Poster Papers

John M. Bryant, Technical Chair

Thirty-one posters were displayed during the symposium. These covered a wide range of topics in highly creative and informative ways. Fifteen of these are presented here as extended summary papers. Topics are:

Poster Papers

Huntsinger—Changes in ownership, land use, and management in the oak woodlands from 1985 to 1992.

Shelly—A comprehensive profile of the hardwood industry in California.

Lubin—State and federal regulations, potential product contaminants, seasonal consideration, and sustainable harvesting issues related to production of special forest products.

Lawson, Zedler, and Seiger—A 5-year study of growth rates and mortality in two oak species.

Narog, Paysen, Corcoran, and Zavala—Explores stand vigor of canyon live oaks in relation to thinning and prescribed burning.

Fuchs, Krannitz, Harestad, and Bunnell—Considers the importance of Steller's jays in dispersal and regeneration of oaks.

Hubbell—A study of intercropping of valley oak and alfalfa during initial restoration efforts.

Scott and Pratini—Describes benefits of adding mineral soil from beneath mature Engelmann oaks to soil around seedlings planted in an irrigated field.

Weitkamp, Yoshida, and Tietje—A pilot study to guide planning for research on the effects of the Conservation Reserve Program on oak regeneration.

White—Statistical analyses of growth rings vs. stem diameters to estimate age of interior live oak in the San Bernardino Mountains.

Barry, Knight, and McCreary—Concludes that pruning of oak resprouts to enhance growth is not worth the effort.

McDougald and Frost—Evaluates the impact on vegetation of a 400-acre prescribed burn in Madera County in 1987.

Munton, Johnson, Steger, and Eberlein—Describes diets of California spotted owls at low elevations, in foothill riparian hardwood habitats.

Motz, R.W.—A nurseryman presents procedures and advice on establishment of native oaks without supplemental irrigation.

California's Oak Woodlands Revisited: Changes in Owners, Use, and Management, 1985 to 1992[1]

Lynn Huntsinger[2]

Introduction

A 1985 statewide survey of the goals, characteristics, and management practices of owners of California oak woodlands was instrumental in developing the research and extension components of the University of California's "Integrated Hardwood Range Management Program" (IHRMP) (Huntsinger and Fortmann 1990). The survey was based on a random selection of properties in the oak woodlands, instead of the more typical random selection from a list of names. In 1992, the owners of the same properties were resampled (Huntsinger and others 1997). Because this land-based sample was surveyed at two different times, it offers a unique opportunity to answer at least two kinds of questions central to the conservation of oak woodlands: What is the rate and nature of woodland land use change? Since Program implementation, have landowner practices and values changed? This brief summation compares some results of the second survey to those of the first, and addresses these questions for the years from 1985 to 1992.

The oak woodland can be thought of as an ecosystem at risk. Much of its value and character has to do with its being large and contiguous. Unsuited to crop or forest production, the foothill woodlands remain a vast, often interconnected acreage running through 38 of California's 52 counties—home to more wildlife than any other major habitat type in the state (Mayer and others 1986). Today there are two major forces that most threaten the extensive and overwhelmingly privately owned oak woodland. In the early decades of the century millions of hectares of oak woodland in valley bottoms were converted to cropland. Today, conversion for residential use is gobbling up woodland (Bolsinger 1988). Land values in many areas are far higher than those justifiable by range livestock production (Hargrave 1993, Johnson 1996). Incentive programs that reduce property taxes, like the California Land Conservation Act (CLCA or Williamson Act), require the support of firm land-use zoning designations that are often lacking (McClaran and others 1985).

The second major risk to oak woodlands is a perceived lack of regeneration of oak species in the woodlands (Muick and Bartolome 1987). Scientists and lay people alike have noted a lack of sapling-sized oak trees in many areas. Concerns that some parts of the woodland will eventually disappear because of attrition are exacerbated by the harvest of oaks for fuel and for increasing forage production. In 1985, when the Integrated Hardwood Range Management Program (IHRMP) was conceived, it was believed that this kind of oak removal was a serious problem in the woodlands.

[1] Presented as a poster at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Comparing 1985 to 1992

Overall, oak woodland landowners still fall into the archetypes described as a result of the 1985 study (Huntsinger and Fortmann 1990) *(table 1)*. However, there have been changes in land status, owner characteristics, management, and attitudes about oaks.

Landownership Is Dynamic

During the period between surveys, an average of almost 4 percent of oak woodland properties were sold each year. According to database and assessor records, about 11 percent of ownerships in the original sample were subdivided during the 7 years between sampling periods. According to survey responses, over the past 5 years 9 percent of the ownerships and 7 percent of the woodland has been subdivided (Huntsinger and others 1997). Results of various field surveys conducted in the woodlands show an exponential rate of decline (Huntsinger and Hopkinson 1996). Holzman (1993) found that conversion rates over the past 60 years varied regionally, with more than a third of the woodlands developed in one region and an average conversion loss of 20 percent among the five regions studied. Ranchers interviewed in a Central Sierra study tended to believe that high land values and the estate and property taxes that go with them, coupled with irregular and low investment return from ranching, are major obstacles to the long-term future of ranching in areas where development pressures are high (Johnson 1996). Hargrave (1993) found that in El Dorado County, investment returns from land appreciation often exceeded those from livestock production. Landowners report that subdivisions are closer than ever to their own properties, and with subdivision, management conflicts between agricultural producers and urban refugees also become part of the scene (Huntsinger and Hopkinson 1996).

Landowner Goals Are Changing But Grazing Is Still the Major Land Use

There is a consistent trend away from using the land to produce products of any kind. But although the data show a general reduction in the use of oak woodlands for grazing and in the participation of landowners in livestock groups and economies, grazing is still, in fact, the major activity and the major underlying goal of oak woodland landowners *(table 2)*. This is especially true of larger parcels. This and other studies have indicated that about three-fourths of California's oak woodlands are grazed by livestock (Bolsinger 1988, Holzman 1993) and that, although fewer than half of ranches are solely supported by ranching (Richards and George 1996), ranching is the most important source of household identity for the majority of ranchers (Bartlett and others 1989, Richards and George 1996). Conservation of oak woodlands on any large scale will require the participation of the livestock industry. Trends among livestock grazers and other oak woodland landowners were the same: none of the results reported here were different when those who do not graze livestock were excluded from the analysis *(table 2)*.

Values and Practices Targeted by the IHRMP Were Affected

Although this type of survey cannot "prove" that the Program caused people to act differently, changes in values and behavior can be linked to program goals. Considerable IHRMP research was targeted to finding out how wildlife management could offer incentives to landowners to keep oaks through the marketing of hunting opportunities and habitat management, and in 1992, more landowners were aware of the value of oaks as wildlife browse *(table 2)* and were actively engaged in improving wildlife habitat.

IHRMP-sponsored research testing overstory-understory relationships in oak woodlands showed that, particularly in drier parts of the state, oaks at mid-canopy levels do not reduce forage production and, in some cases, extend the availability of green feed by increasing the species and phenological diversity of the grassland (Frost and McDougald 1989, McClaran and Bartolome 1989). This information was promoted through educational materials and workshops, and

Table 1—Two oak woodland archetypes identified as characterizing respondents in the 1985 and 1992 surveys.

Owner of small property	Owner of large property
Does not sell products from land	Sells products, most often livestock
More often absentee	Resident owner
More recent arrival	Long-term owner
Relatively amenable to oak use regulation	Anti-regulation
Less than half cut living oaks	Most cut living oaks
Growing in numbers	Relatively stable in numbers

although removing oaks for increased forage production was the major reason large landowners gave for removing healthy oaks in 1985, today it is one of the least important reasons and is seldom done. Program efforts directed at owners of smaller properties have also apparently paid off. Owners of small properties tend not to cut oaks for economic reasons such as increasing forage production, but instead cut them for home use as firewood. Since 1985, the frequency of firewood cutting has decreased significantly, particularly for owners of small properties. Landowners are also much less likely to sell firewood than they were in 1985 *(table 2)*, perhaps reflecting program efforts to increase awareness that oak harvest may not always be sustainable. In fact, landowners in 1992 were far more likely to agree that "oaks are being lost in California" than they were in 1985. Landowners who valued oaks for browse, shade, wildlife habitat, soil conservation, and/or had contact with an advisory agency were significantly more likely to carry out oak-promoting activities such as planting oaks and protecting oak sprouts ($P < 0.1$, *t*-test).

Landowners Are Not Receptive to Regulation

As also indicated by this and other studies, ranchers and oak woodland landowners are not fond of regulatory options (Ellickson 1991, Huntsinger and Hopkinson 1996) *(table 2)*. However, they are apparently receptive to education and information programs, as well as to incentive programs like the Williamson Act that reduce the costs of high land values for producers, because about half of them have their land contracted under the Act. A dramatic increase in landowner awareness of the threat to California's oaks has occurred in the past seven years, and landowners have voluntarily responded with reduced cutting and increased protection of oaks *(table 2)*. Stewart (1991) indicates that ranchers are more willing to accept "carefully crafted oak related ordinances" than is apparent in the general response to regulation of oak use found in this study.

Conclusions

Several of the behaviors targeted by the IHRMP, including cutting of oaks for forage production enhancement and home firewood use, have shown dramatic reductions since the program began in 1985 *(table 2)*.

The owners of both large and small properties have demonstrated a receptiveness to the Program's education efforts. Ranching and livestock production, by maintaining large open space areas in private, productive ownerships, can play a critical role in conserving California's natural resources. If well managed, privately owned woodlands linking reserve areas and parks can magnify reserve effectiveness in protecting wildlife populations many times. Landowners, however, tend to be adamant about protecting their own rights to use their land as they see fit, including selling the land at a profit for real estate development (Huntsinger and Hopkinson 1996). Often the land represents the majority of a family's financial assets and landowners feel threatened by any public tendency to view the state's remaining open space as having an implicitly "public" character. Balancing the economic needs of the landowner and conservation goals will challenge Californians concerned about their landscape in decades to come.

Table 2—Change in landowner attitudes and management, 1985 to 1992

Percent of landowners who…	1985 (n=126)	1992 (n=115[1])	$P < (\chi^2)$
Cut living oaks[3]	70	50	0.04
Thin oaks	35	26	0.1
Cut oaks to increase forage	45	28	0.01
Poison oaks	7	2	0.05
Value oaks for natural beauty	82	88	ns
Value oaks as browse	51	67	0.02
Sell firewood	20	11	0.04
Believe oaks are being lost	59	79	0.004
Believe oak use should be regulated	32	39	ns
Graze livestock on land[4]	76	66	0.07

[1] About 30 percent of 1992 respondents participated in 1985 survey. There was no significant difference between their responses and those of new respondents. Response rates were 75 percent in 1985 and 1992.
[2] Chi-square analysis.
[3] Includes owners who cut only one oak.
[4] An estimated 71 percent of the woodland in 1992. Results reported in this table were no different when those who do not graze livestock were excluded from the analysis.

Although a program of research and extension can help reduce land use change by contributing to the economic well-being of ranchers through better or more diverse management, and to the enjoyment of oak woodlands by owners of small properties through enhanced wildlife and esthetic values, it cannot hope to prevent massive land use change as California's population expands into rural areas. Research and extension efforts must be complemented by some effort to influence the course of land use change in the oak woodlands we wish to conserve in California.

References

Bartlett, E.T.; Taylor, R.G.; McKean, J.R. ; Hoff, J.C. 1989. **Motivation of Colorado ranchers with federal grazing allotments**. Journal of Range Management 42: 454-456.

Bolsinger, Charles L. 1988. **The hardwoods of California's timberlands, woodlands, and savannas**. Resour. Bull. PNW-RB-148. Portland, OR: Pacific Northwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 148 p.

Ellickson, R.C. 1991. **Order without law: how neighbors settle disputes**. Cambridge, MA: Harvard University Press.

Frost, W.E.; McDougald, N.E. 1989. **Tree canopy effects on herbaceous production of annual rangeland during drought**. Journal of Range Management 42: 281-283.

Hargrave, T. 1993. **The impact of a federal grazing fee increase on land use in El Dorado County, California**. Berkeley: University of California; 68 p. Master's thesis.

Holzman, B. 1993. **Vegetation change in Californian oak woodlands**. Berkeley: University of California; 215 p. Ph.D. dissertation.

Huntsinger, L.; Buttolph, L.; Hopkinson, P. 1997. **California hardwood rangelands revisited: owners, use, and management in the nineties**. Journal of Range Management 50: 423-430.

Huntsinger, L.; Fortmann, L.P. 1990. **California's privately owned oak woodlands: owners, use, and management**. Journal of Range Management 42(3): 147-152.

Huntsinger, L.; Hopkinson, P. 1996. **Sustaining rangeland landscapes: a social and ecological process**. Journal of Range Management 49: 167-173.

Johnson, Sharon. 1996. **Factors contributing to land use change in the hardwood rangelands of two central Sierra Nevadan counties**. [These proceedings].

Mayer, K. E.; Passof, P.C.; Bolsinger, C.L.; Grenfell, W.W., Jr.; Slack, H. 1986. **Status of the hardwood resource of California: a report to the Board of Forestry**. Sacramento: California Department of Forestry and Fire Protection.

McClaran, M.P.; Bartolome, J.W. 1989. **Effect of *Quercus douglasii* (Fagaceae) on herbaceous understory along a rainfall gradient**. Madroño 36: 141-153.

McClaran, M.P.; Romm, J.; Bartolome, J.W. 1985. **Differential farmland assessment and land use planning relationships in Tulare County, California**. Journal of Soil and Water Conservation 40: 252-255.

Muick, P.C.; Bartolome, J.W. 1987. **An assessment of natural regeneration of oaks in California: a report to the Forest and Rangeland Resources Assessment Program**. Sacramento: California Department of Forestry and Fire Protection; 100 p.

Richards, R.; George, M. 1996. **Evaluating changes in range management practices through extension education**. Journal of Range Management 49(1): 76-80.

Stewart, William. 1991. **Monitoring values and practices of oak woodland decision makers on the urban fringe**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 174-181.

Profile of the California Hardwood Industry[1,2]

John R. Shelly[3]

Abstract: *The hardwood industry in California is not well documented and often is described as fragmented. An analysis of hardwood interests in the state reveals a wide gap between hardwood consumption and the supply of native hardwood lumber. A recent survey of individuals, companies, and agencies involved in hardwood utilization provides the data for profiling the hardwood industry. A questionnaire mailed to these contacts uncovered 22 hardwood mills in the state that produced an estimated 11 million board feet of hardwood lumber in 1995, and 38 suppliers that offer native hardwood lumber. A telephone survey of furniture manufacturers in California identified 860 companies that utilize hardwoods. The information obtained from this survey provides a comprehensive profile of the hardwood industry in California.*

The hardwood industry can be broken into three major segments: producers, suppliers, and secondary manufacturers. The producers, or primary manufacturers, are the sawmills that manufacture lumber. The suppliers are the wholesale/retail companies that supply lumber to the secondary manufacturers which make the finished goods. The major goods manufactured from hardwood lumber include: furniture, cabinets, and flooring. Previous studies by other researchers have identified a large secondary manufacturing industry in California; one recent survey reported 860 companies (Cohen and Goudie 1995). The project reported in this paper was undertaken to determine the size of the hardwood producer and supplier community and to identify the secondary manufacturers that use hardwoods. Information was gathered by a variety of methods including mailed questionnaires and telephone contacts which resulted in a directory of enterprises involved in the hardwood industry in California (Lubin and Shelly 1995).

Survey Methods

Companies and individuals were identified as potential constituents of the hardwood industry from a variety of sources. The starting point for the list was the hardwood mailing list of the University of California Forest Products Laboratory which was developed through personal contacts and attendance at workshops. Added to this mailing list were companies found in the following directories.

- 1995 Directory of the Wood Products Industry, Miller Freeman, Inc., San Francisco, CA.
- 1991 California Manufacturers Directory: Wood Products & Furniture, The California Hardwood Foundation, San Francisco, CA.
- 1994-95 California Furniture Manufacturers Association Membership Roster & Buying Guide, California Furniture Manufacturers Association, Los Angeles, CA.
- 1990 High Sierra Resource Conservation and Development Area: Hardwoods Directory Producers to Users, Sierra Economic Development District, Auburn, CA.
- 1992 California Forest Products Marketing Directory, California Department of Forestry and Fire Protection, Sacramento, CA.
- 1994 Markets Analysis and Marketing Strategy for CA Hardwoods, Supplement 1: Secondary Wood Products Manufacturers, U.S.

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[2]Partial funding for this project was provided by contract with the California Department of Forestry and Fire Protection and an award from the U.S. Department of Commerce Economic Development Administration (EDA Project No. 07-19-04005).

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Department of Commerce Economic Development Administration, Sacramento, CA.

From the various sources, 265 potential lumber producers and/or suppliers and 1,022 potential secondary manufacturers using hardwoods were identified. The producers and suppliers were mailed a survey to confirm that they worked with hardwoods and to determine the characteristics of the enterprise. Those that did not reply to the mailed survey were contacted by phone. The secondary manufacturers were contacted by phone to confirm the information reported in the other directories.

Survey Results

Ninety-two of the 265 enterprises identified as potential producers and/or suppliers responded to the mailed survey; the remaining 173 were contacted by phone. Of the 32 percent of the contacts that were familiar with native California hardwood species, 22 of the enterprises were identified as lumber producers, 27 as suppliers, and the remaining 37 reported an interest in native hardwoods but no active involvement (Lubin and Shelly 1995).

Twenty-three percent of the secondary manufacturers were eliminated from the database because they exclusively used softwoods. Forty-five percent of the remaining 782 could not be reached with the addresses and phone numbers available, and no forwarding information could be obtained. It was verified that the remaining 429 companies used hardwoods. This information, along with the species used, is listed as an appendix in the *California Hardwoods and Nontimber Forest Products Directory of Producers and Suppliers* (Lubin and Shelly 1995). No further analysis was performed on the secondary manufacturers.

Lumber Producers

The native hardwood lumber producers were concentrated in northern California (*fig. 1*). Only one producer, of the 22 identified, was found south of the greater San Francisco Bay Area. The survey was likely biased towards northern California producers because they were the easiest to find. Undoubtedly there are small mills in other parts of the state processing urban and woodland species,

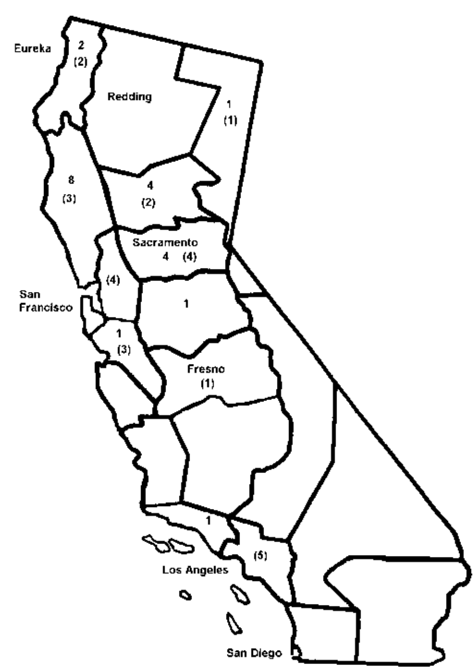

Figure 1—Location of native hardwood lumber producers and suppliers in California grouped by 3-digit postal ZIP code. The numbers represent the number of companies in a particular zone; suppliers are shown in parenthesis.

and an ongoing effort is focused on adding them to the survey database. It was known that a few medium-sized softwood mills in northern California have experimented with a limited hardwood production over the past few years, but they did not respond to the survey and were not included in this profile. However, it is worth noting that because of their size, these mills are capable of having a large impact on production figures.

A profile of the industry indicated mostly small companies working with a wide variety of species. *Figure 2* illustrates the range of species being used. Nearly all of the producers processed at least one of the main timberland species (California black oak, *Quercus kelloggi*, tanoak, *Lithocarpus densiflorus*, and madrone, *Arbutus menziesii*). Seven of them worked exclusively with timberland species, but the remainder also processed many woodland and urban species.

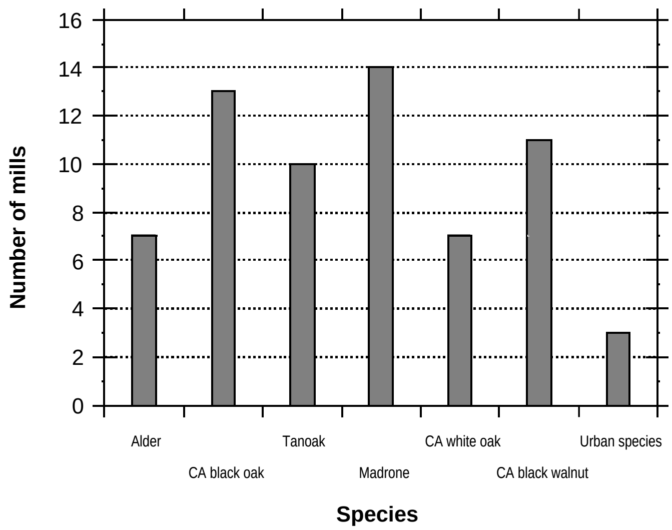

Figure 2—Summary of the number of mills that process various species of hardwood lumber. CA = California.

Most of the producers are small enterprises; only 5 of the 22 have an annual production greater than 50 thousand board feet and more than 5 employees (*fig. 3*). Although information on the type of milling equipment being used by each producer was not requested in the survey, it is believed from personal knowledge that almost all, except the two largest mills, use only portable sawmills.

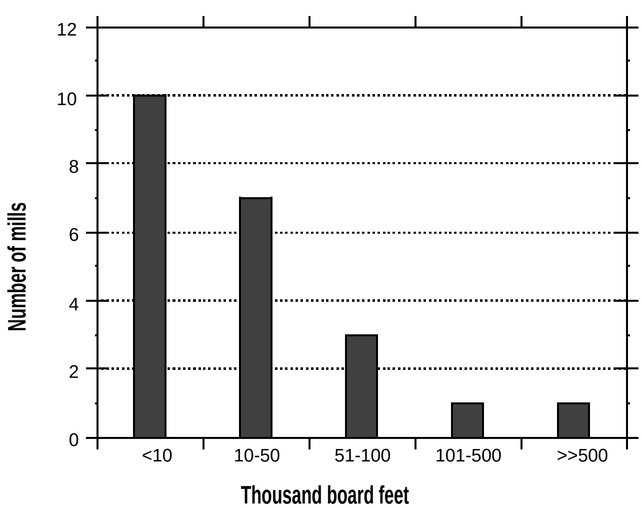

Figure 3—Summary of mill size based on the estimated annual production of hardwood lumber.

Lumber Suppliers

Twenty-seven suppliers were found throughout the state that confirmed they dealt with at least some of the native hardwood species. Although most of the lumber producers also supply lumber directly to manufacturers and individuals, they were not considered suppliers for the purposes of this survey. The suppliers identified in this survey tended to be concentrated near the major manufacturing centers of the State (*fig. 1*). Alder was the species most frequently supplied, but at least 12 suppliers indicated that they supplied the main timberland species of California black oak, tanoak, and madrone (*fig. 4*). California white oak and black walnut were also commonly carried (10 and 16 companies, respectively). Eight of the suppliers also indicated that they carried some native woodland species (listed as "other" in *fig. 4*). One supplier also carried lumber produced from a variety of urban species.

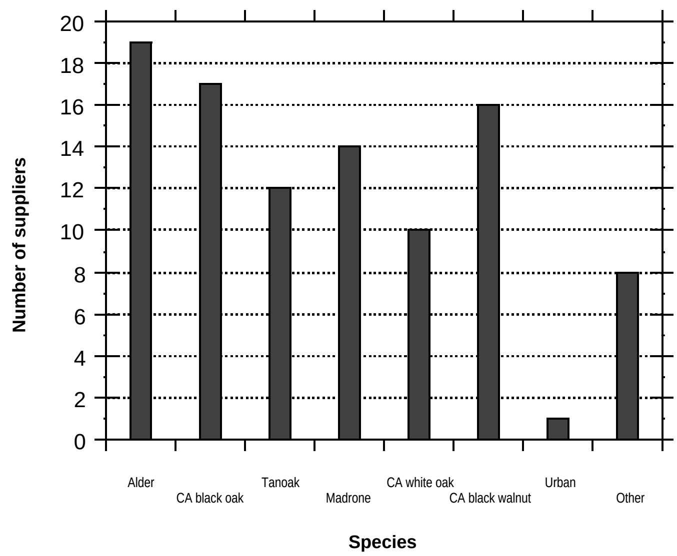

Figure 4—Summary of the number of suppliers that carry various species of California-grown hardwood lumber. CA = California.

Drying Capacity

Most of the lumber producers (64 percent) had only a passive lumber-drying capability (*table 1*) of either air drying or solar drying. Of the remaining eight producers, six had a dehumidification drying system, one had a conventional steam-heated kiln, and one had a vacuum drying system. The total producer-drying capacity was only 126 thousand board feet capable of a yearly production of about 1.3 million board feet, or only about 1 percent of the demand for west coast hardwood lumber. In addition to the kiln capacity of the hardwood lumber producers there is a sizable softwood-drying capacity in the state, and at least three suppliers have an additional 225 thousand board feet of dry kiln capacity. Some of this softwood capacity could conceivably be used to kiln dry partially air-dried hardwoods.

Table 1—Hardwood drying capacity available from lumber producers and suppliers in California.

Drying method	Number of mills	Total capacity in board feet
Passive		
Air	12	Unknown
Solar kiln	2	2,000
Active		
Dehumidification	6	69,000
Steam heat	1	50,000
Vacuum	1	5,000

Concluding Remarks

The survey identified 22 lumber producers and 25 suppliers that deal with native hardwood lumber and 429 secondary manufacturers that use hardwoods. The producers are mostly small enterprises using portable sawmills with only two having an annual production greater than 500 thousand board feet. These small producers tend to work with a wide variety of species, primarily including the timberland species of alder, California black oak, tanoak, and madrone, but also many woodland species such as valley oak (California white oak, *Quercus lobata*) and black walnut. Three enterprises indicated that they also use urban species such as elm and sycamore.

Lack of drying capacity is a serious shortcoming to developing a vital hardwood industry. The estimated 1.3 million board feet of annual hardwood lumber kiln capacity in California is only about 1 percent of the west coast hardwood lumber demand.

The hardwood industry is best described as fragmented. There is a mature, well-developed supplier and secondary manufacturing segment but the producer segment is in its infancy. As interest increases in finding higher-value uses than the present pulp chips, boiler fuel, and firewood for California's native hardwood resource, the producer segment is certain to grow. Some well-established softwood sawmills are experimenting with hardwood lumber production on a limited basis. Their input into the hardwood lumber supply would have a dramatic impact on the industry.

References

Cohen, David H.; Goudie, Derek. 1995. **Profile of the California furniture industry: structure, product types, and wood use**. Forest Products Journal 45(6): 31-37.

Lubin, Dorothy Mockus; Shelly, John R. 1995. **California hardwoods and nontimber forest products: directory of producers and suppliers**. Richmond, CA: University of California Forest Products Laboratory; 69 p.

The Utilization of Nontimber Forest Resources to Create Special Forest Products[1]

Dorothy Mockus Lubin[2]

Abstract: *Historically, our forest resources have been viewed primarily as a source of timber and wood products, such as lumber, plywood, and veneer. Compared to all that has been written about timber management and traditional timber products, discussion of the incredible variety of nontimber, or special, forest products has been almost nonexistent. This work provides a closer look at our forests and woodlands as complex systems capable of sustaining a wide diversity of special forest products. Most regions of the country possess the forest resources that represent opportunities for rural entrepreneurs to supplement their incomes. Many of the special forest products businesses have developed as cottage industries, utilizing an easily obtained or accessed resource to create a specialty product for a niche market. The category of special forest products includes such varied commodities as aromatics, berries and wild fruit, cones and seeds, forest botanicals, transplants and floral products, mushrooms, nuts, and weaving and dyeing materials. Though many of these special forest products originated as a specific cultural tradition, others are the result of a creative market analysis.*

State and federal regulations, potential product contaminants, seasonal considerations, and sustainable harvesting are some of the important issues related to the production of special forest products. Products can be categorized as those based on wood, such as aromatics, charcoal, animal bedding, and soil amendments, or as non-wood products, encompassing the product groups of edible fungi, forest botanicals, and floral products. The harvesting, marketing, and environmental considerations were explored for each of these major categories. It is important to note that these considerations can be unique to each product and continue to change as markets develop.

The range of products included in the special forest products label is too great to attempt to provide a comprehensive reference. The focus of this paper will be on those special forest products that are, or show potential to be, of the most economic significance for California's forests and woodlands.

Wood-Based Products

Charcoal

Charcoal is a form of highly porous, amorphous carbon, produced when wood or other carbonaceous substances are heated in the presence of little or no air, a process known as destructive distillation. The market for charcoal is mainly that of recreational activities and restaurant use. A small percentage of charcoal is utilized in certain metallurgical processes and as a filter to remove organic compounds, such as chlorine, gasoline, pesticides, and other toxic chemicals, from air and water. Many cities utilize high-quality filter charcoal to remove leachate from their landfills. Natural charcoal utilizes native hardwoods and fruitwoods, and the best product results from a raw material that is low in sulfur content. Hickory, mesquite, oak, and maple are all species used in charcoal production (Baker 1985).

[1]Presented as a poster at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Natural charcoal, if marketed aggressively and creatively, can compete with large briquet producers in certain market areas. The advantages of the natural charcoal—an all natural, 100 percent hardwood product, no additives, no lighter fluid needed, reuse potential, more fuel efficiency than briquets—must be stressed to overcome the few disadvantages: irregularity of shape and size, tendency to flake and break, and cost (Baker 1985). It may prove strategic to link up with a grill company and focus on a regional market rather than attempt to break into a national market with a line of natural charcoal.

Flavor Enhancers

Many species of wood are used as flavor enhancers in grill cooking (*table 1*). Both restaurants and individuals take advantage of wood as a natural flavor enhancer. Wood in the form of chips and chunks is used by the residential consumer; roundwood is used by the restaurant trade; and sawdust is primarily used in the smoking and liquid smoke industries (Thomas and Schumann 1993).

Table 1—Woods used in grill cooking as natural flavor enhancers

Alder	Hickory	Sugar maple
Apple	Madrone	Tanoak
Bigleaf maple	Mesquite	Vine maple
Cherry	Oak	

Particle-Based Products

Chips, shavings, and bark are byproducts of a region's sawmills and wood processing plants. They may also be produced directly from biomass material. However the material is procured, it does provide an abundance of opportunities for supplemental income. This "residue" can be used as animal bedding and litter products, soil conditioners, amendments and mulches, landscaping and packing materials (Schumann 1979). It can also be used in a host of secondary wood products such as particleboard, fireplace logs, fuel pellets, and molded wood composite products (Hamilton and Levi 1987).

Non-Wood Products—Forest Botanicals, Forest Greenery, and Mushrooms

Forest Botanicals

Contained in the forests and woodlands are an abundance of plants that have market potential in culinary uses and medicinal and pharmaceutical purposes (Craker and Simon 1987; Miller 1988). The resulting products all require different processing and packaging procedures. Communication with a buyer is essential to ensure that the product is harvested, processed, and packed correctly.

Culinary Uses

Herbs and spices, edible greens, roots or tubers, and edible flowers are all categories of culinary forest botanicals. The herbs and spices are used as seasonings, to add aroma or color to foods and as ingredients in beverages such as herbal coffees, teas or soft drinks. The utilization of botanicals as natural food preservatives will no doubt increase over time, because the harvesting of edible greens, roots, tubers, and flowers has steadily risen over the past decade. Herbs require less water and fewer soil nutrients than more traditional farm crop; hence, small acreages of herb farms may become a familiar sight in the forests and woodland lots that are unsuitable for other cash crops.

Once dried properly, herbs can be marketed in several ways. Direct marketing methods include roadside stands, "U-pick" operations (in which the customers pick the herbs themselves), farmers' markets, gift baskets, and mail order. The market for fresh edible greens is a bit more limited. Fresh wild greens are delicate and must be handled carefully and delivered to the consumer in a timely fashion. A cooperative network marketing system may work best for the edible greens, particularly if the cooperative also offered other exotic edibles such as mushrooms, assorted berries, and edible flowers.

Plant identification is crucial for the edible botanicals. Misidentification of a plant could have potentially disastrous results for the edible greens business. A successful business plan for an edible greens business should include some sort of consumer education on the types of edible greens available, the identifying characteristics of the greens, and the potential uses.

Medicinal and Pharmaceutical Uses

A variety of medicinal and pharmaceutical compounds and nutritional supplements utilize forest botanicals in their manufacture. Though some of these products hold no real medicinal properties, they have established long-term markets and continue to represent an economic opportunity. Other forest botanicals do possess specific chemical properties that are of interest to pharmaceutical manufacturers and even though many of the compounds can be synthesized, new plant chemicals are continually being investigated. For example, taxol, from the Pacific yew, has recently proven to be an effective cancer-fighting drug for certain types of cancer and substantiates that there is still much to learn about the chemical compounds found in plants.

Marketing of medicinal plants for herbal and alternative health care is primarily achieved through small regional botanical or herb-buying houses that process and package the plant parts for final processors or retailers. Natural medicinal plant products are retailed largely through health food or natural food stores, although some drug and grocery stores stock a few medicinal plant products, such as herbal teas.

The issue of most importance in the forest botanicals business, especially in marketing medicinals, is to become fully familiar with federal and state regulations regarding health care products. If a product is marketed as a food substance or nutritional supplement, with no claims of medicinal value, the product will not have to undergo the extensive testing required to certify pharmaceutical drugs.

Forest Greenery

By far the most widely sold special forest product in the United States is evergreen boughs for the wreath-making industry. Hundreds of local people cut and collect boughs for sale to wreath companies. The wreath business is no longer limited to a holiday market, with the increasing popularity of manzanita and twig-type wreaths that are sold year-round. A successful greenery, transplant, and floral products business generally requires diversity of products and avoiding overdependence on seasonal products. A company may deal primarily in floral greens, but will use other products to fill in the gap, such as mushrooms or cones.

Weaving and Dyeing

A variety of materials grown in forests and woodlands can be used for weaving and dyeing (*table 2*). Though commercial utilization of these materials is not common, their utilization as part of a rural craft market does show potential (Adrosko 1971).

Harvesting

Table 2—Forest products used in weaving and dyeing

Alder	Hemlock	Manzanita	Ragweed
Alfalfa	Horsetail	Mistletoe	Sumac
Beargrass	Lichens	Oak	Tanoak
California laurel	Lupine	Oak galls	Yarrow
Douglas-fir	Madrone	Oxalis	

Forest botanicals should be harvested only from areas that have not been sprayed or otherwise contaminated. It is necessary to obtain permission from landowners before any harvesting. Collection of all forest products on a commercial scale from public lands requires permits. However, poaching is still a major concern. It has been estimated that the Forest Service is getting paid for only about one fourth of the material that is actually being harvested (Thomas and Schumann 1993). The most frequently poached items are beargrass, salal, and firewood.

A unique relationship can be developed between land managers and special forest products harvesters. When an area is scheduled for timber harvest, loggers can alert wildcrafters to new areas to harvest and the wildcrafters can help clean up a logged area by salvaging plants and plant parts, thus reducing the amount of slash, or "waste," the logging crews must process.

Mushrooms

A variety of mushrooms are available for collection in the forests and woodlands. The major commercial use of the mushroom is for food, particularly in the exotic or specialty food markets. Mushroom use is expanding beyond the culinary arena; some fungi are being investigated for use in the biopulping process, as dyes for textiles, in medical research, and for use in reducing toxic materials in municipal dumps.

Forest Harvested Wild Mushrooms

A commercial market for wild edible mushrooms began developing in the early 1980's, mostly in the Pacific Northwest, and has increased dramatically since then (Denison and Donaghue 1988). Of the many harvested, the most important wild mushroom species are the chanterelles (*Cantharellus cibarius*), morels (*Morchella conica* and *Morchella esculenta*), matsutake (*Armillaria ponderosa* or *Tricholoma matsutake*), boletus (*Boletus edulis*), and hedgehog (*Dentinum repandum*, or sweet tooth) (*table 3*).

Table 3—Forest-harvested and cultivated mushrooms

Cantharellus cibarius	Chanterelle
Lentinula edodes	Shiitake
Morchella conica	Black morel
Morchella esculenta	Yellow morel
Tricholoma matsutake	Matsutake
Amillaria ponderosa	Pine mushroom
Boletus edulus	Boletes
Dentinum repandum	Hedgehog or sweet tooth
Agaricus campestris	Meadow mushroom
Lyophyllum multiceps	Fried chicken mushroom
Caprinus commatus	Shaggy mane

The Forest Service has implemented a fee system for selling wild mushrooms to commercial harvesters. Personal use permits are needed for families or individuals collecting mushrooms in lesser quantities. Some timber companies allow mushroom harvesting on their land free of charge; others have some sort of fee schedule. Washington State adopted a Wild Mushroom Harvesting Act in 1988 that requires an annual license for buying or processing wild mushrooms (Thomas and Schumann 1993). California has no such requirement at this time, but as the industry continues to grow, licensing requirements and regulations are sure to evolve. Many mushroom harvesters have formed small, local networks to address issues, share information, and/or to cooperatively market their goods.

There have been no definitive studies on the effect that frequent harvesting has on the future production of mushrooms. The two factors that appear to have the greatest impact on the mushroom crop are the weather and timber clearcutting. A few years of drought or wild fluctuations in the temperature can inhibit the production of many species of mushrooms for several seasons. The practice of clearcutting timber can leave some areas devoid of mushrooms for up to 15 years (Thomas and Schumann 1993), and it has been proposed that a study be done to assess whether it might make more fiscal sense to devote some forest lands to the production of special forest products that have an annual yield, like mushrooms, rather than to a timber crop that can be harvested only once every 60 years. Licensing, leasing, and collection issues, though currently unresolved, are sure to be topics under increased discussion.

Cultivated Mushrooms

The most popular varieties of cultivated mushrooms are shiitake, chanterelle, oyster, and enoki. The methods of cultivation vary from species to species. The largest body of information is related to cultivation of the increasingly popular and versatile shiitake (*Lentinula elodes*), known for its high nutritional value and the ease with which it is cultivated. Mushroom cultivation is an excellent way to increase the revenue generated by forest lands with little disruption of the existing ecosystem. The wood generated from thinnings, that would otherwise be unmarketable, is perfect for mushroom cultivation. Wood that is used to cultivate shiitake may generate 10 times the revenue of the same wood sold for firewood. Other media such as corncobs and rice can be used to cultivate shiitake, but the best success has been achieved with oak logs (Stamets 1983).

Public Health Concerns

Mycologists throughout the United States have expressed concern over the possibility of a poisonous species of mushroom finding its way into the consumer market. At present, many states have no form of industry inspection or regulation, and pickers are not certified in any way. The ability to recognize a potentially poisonous mushroom is critical for individuals involved in this industry. Harvesters are encouraged to engage in continuing education regarding plant and mushroom identification.

Summary

The continued development of special forest products seems assured. The special forest products discussed above showcase the ingenuity and creativity people have employed to generate products from any available resource. Specialty products that incorporate more than one resource show some significant potential for commercial success. The Hoopa Valley Tribe in northern California has recently completed a feasibility study concerning the production of value-added special forest products, one of which is a gift box containing traditional items locally produced from native plants and resources, such as acorn soup, smoked salmon, and some medicinal herbal remedies. Production of an item such as this lends itself easily to a cooperative marketing strategy; gift and craft faires seem a natural market.

This industry shows no signs of declining and many signs of expanded development. Special forest products enterprises represent business opportunities to areas that are suffering the effects of a depressed timber industry. Many government agencies see the advantage in promoting and fostering these small industries. The route to sustainable economic development for many rural and fiscally disadvantaged communities will include innovative utilization and management of the available resources.

References

Adrosko, Rita J. 1971. **Natural dyes and home dyeing**. New York: Dover Publications, Inc.

Baker, A.J. 1985. **Charcoal industry in the U.S.A**. In: Symposium on forest products research international: achievements and the future. Volume 5. 1985 April 22-26; Pretoria, Republic of South Africa. Madison, WI: Forest Products Laboratory, Forest Service, U.S. Department of Agriculture; 1-15.

Craker, Lyle E.; Simon, James E., ed. 1987. **Herbs, spices, and medicinal plants**, Vol. 2. Phoenix, AZ: Oryx Press.

Denison, William C.; Donaghue, John. 1988. **The wild mushroom harvest in the Pacific Northwest: past, present and future**. Unpublished paper.

Hamilton, Rick; Levi, Mike. 1987. **Alternative sources of income from your timberland**. Forest Farmer. July-August: 17-19.

Miller, Richard Alan. 1988. **Native plants of commercial importance**. Grants Pass, OR: OAK, Inc.

Schumann, David R. 1979. **Composting sewage sludge: a market for forest products residue**. NA-FR-14. Portsmouth, NH: Northeastern Area State and Private Forestry, Forest Service, U.S. Department of Agriculture.

Stamets, Paul; Chilton, J.S. 1983. **The mushroom cultivator**. Olympia, WA: Agarikon Press.

Thomas, Margaret G.; Schumann, David R. 1993. **Income opportunities in special forest products: self help suggestions for rural entrepreneurs**. Agricultural Information Bulletin 666. Washington, DC: Forest Service, U.S. Department of Agriculture.

Mortality and Growth Rates of Seedlings and Saplings of *Quercus agrifolia* and *Quercus engelmannii*: 1990-1995[1]

Dawn M. Lawson[2] **Paul H. Zedler**[3] **Leslie A. Seiger**[3]

Abstract: *This study followed the fate of oaks <10 cm in diameter at breast height (dbh) in nine experimental plots established in 1988 on Camp Pendleton, California. In that year, plots were burned in early season or late season, or left unburned as controls. Each tree was individually marked with a numbered steel tag, and its location along a transect was recorded. This paper reports the changes in this cohort from 1990 to 1995. The data show that there was significant mortality over that period, but that some individuals do "escape" and grow rapidly towards the canopy while many remain stunted. Engelmann oak (*Q. engelmannii*), though less successful in seedling establishment, had higher survival into the larger classes apparently because of a greater ability to survive in gaps. This pattern may explain how the two species coexist.*

This study focused on two oak species in coastal southern California: coast live oak (*Quercus agrifolia*) and Engelmann oak (*Q. engelmannii*), the dominant species in the Engelmann oak phase of southern oak woodland (Griffin 1990). Previous studies have hypothesized that *Q. agrifolia* may be increasing in dominance in Engelmann oak woodlands on Camp Pendleton (Lawson 1993). Understanding patterns of mortality and growth is necessary to manage the remaining woodlands to ensure that mixed stands will be preserved.

Methods

The study site is located on Marine Corps Base Camp Pendleton in San Diego County, California. The elevation is approximately 700 m with an average annual precipitation of 585 mm (Camp Pendleton weather records). The understory consists primarily of grassland with patches of poison oak (*Rhus diversiloba*) and scattered coastal sage scrub species.

The effect of fire on seedlings and saplings of the two species was evaluated using a randomized complete block design with three-fold replication. The treatments, applied in 1988, were early-season burn (July), late-season burn (October), and no burn (control). The blocks ranged from 5 to 10 ha and were divided into plots approximately equal in size. All saplings greater than 49.9 cm in height and less than 10 cm in diameter at breast height (dbh) were measured. Subsamples of seedlings (less than 50 cm in height) were sampled in belt transects. The location of each seedling with respect to tree canopies was recorded on a three-point scale by noting whether a seedling occurred beneath a tree canopy in (1) the outer half, (2) the inner half, or (3) in a gap between canopies. The plots were burned in 1988 and were resampled every 6 weeks the first year after the burn, every 8 weeks during the second year, and once in 1995. We are reporting on growth rates and survivorship, from 1990 to 1995, of the cohort sampled in the 1988 study.

[1] Presented as a poster at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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[3] Professor and postdoctoral fellow, respectively, Biology Department, San Diego State University, San Diego, CA 92182.

Analyses

The response variables analyzed were percent mortality and relative growth rate. Mortality was analyzed as a function of treatment, canopy location, block, and species using chi-square analysis. Logistic regression was used to determine the relationship between mortality and height. Data were categorized by height class, and the relative growth rate of each height class was determined as a function of treatment, canopy location, block, and species using an analysis of variance. Chi-square analysis was used to evaluate the location of recruitment with respect to canopies of mature trees.

Results

Growth

Relative growth rate did not differ significantly between species or among treatments. However, relative growth rate was strongly influenced by height class with the smallest individuals having the highest relative growth rates. Location relative to tree canopies was also an important factor influencing relative growth rate. The growth rates of "outer canopy" and "inner canopy" groups did not differ, but both were significantly lower than growth rates in the gaps ($P = 0.0051$).

Mortality

Of the 1214 individuals that were alive in the transects in 1990, 531 survived until 1995. Mortality was similar for both species, 56 percent for *Q. agrifolia* and 59 percent for *Q. engelmannii*. Survivorship between 1990 and 1995 was not significantly different with respect to prior burning treatment.

As expected, survival was highly size-dependent. Analysis by logistic regression predicted the probability of mortality in the 30-cm to 40-cm height class to be about 50 percent. After the plants reached 1 m in height, the predicted probability of mortality dropped to less than 30 percent and was less than 10 percent for individuals taller than 2 m.

Chi-square analysis showed that mortality varied significantly by canopy location ($P < 0.0001$). Gap mortality was 38 percent whereas mortality under oak canopies was 58 percent to 60 percent. This pattern held for each species, with mortality in the gaps slightly lower for *Q. engelmannii* (33 percent) than for *Q. agrifolia* (40 percent).

Recruitment

Between 1990 and 1995, 1118 new seedlings were established—1025 *Q. agrifolia* and 93 *Q. engelmannii*. This contrasted with the previous 2 years in which no seedlings were established in the transects (Lawson 1993). Seedling establishment was highest in the outer half of the canopy for both species, although this trend was stronger for *Q. agrifolia* than *Q. engelmannii*. *Q. engelmannii* was significantly more likely to establish in the gaps than *Q. agrifolia* ($P < 0.0001$).

Relative Stand Composition

The overall proportion of *Q. engelmannii* dropped from 20 percent in 1990 to 12 percent in 1995. When the data were evaluated by size class, however, a much different picture emerged. This can be shown by the change in the ratio of *Q. engelmannii* (Qe) to *Q. agrifolia* (Qa), which can be measured by drawing a ratio of this ratio for the years 1990 and 1995 and plotting this against size class. If there were no change in the relative proportions of the two species between the two sample years, this ratio of ratios would fall along the line Y = 1. Values below 1 indicate a shift toward *Q. agrifolia*, and values above 1 a shift to *Q. engelmanii* (*fig. 1*). A size trend in the data is clearly apparent (r_s = 0.88; $P < 0.03$). In the smaller size classes, the aggregate population shifted toward greater relative abundance of *Q. agrifolia*, but this tendency reversed with increasing size so that *Q. engelmannii* showed a relative increase in all the size classes above 30 cm (*fig. 1*).

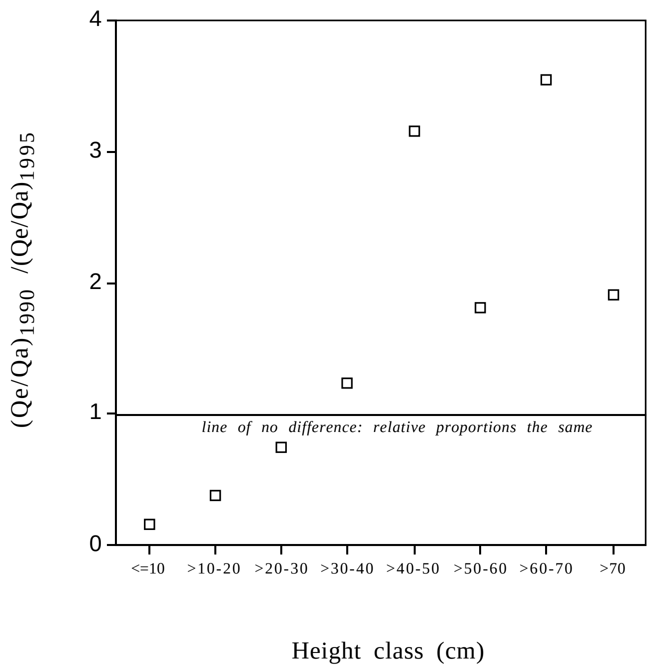

Figure 1—Plot of the ratio for 2 years, 1990 and 1995, of the ratio of *Q. engelmannii* (Qe) to *Q. agrifolia* (Qa) against size class. Points falling on the horizontal line Y = 1 show no change in the ratio of Qe to Qa from 1990 to 1995. Points above this line indicate increased relative abundance of *Q. engelmannii*, and below the line decreased relative abundance of *Q. engelmannii*. The trend in the points shows that the changes in relative abundance over the course of the study were size-dependent.

Discussion

Though the species did not differ with respect to growth rate and *Q. agrifolia* had greater seedling establishment, this did not necessarily give the advantage to *Q. agrifolia*. *Q. engelmannii* may compensate for poorer seedling establishment by greater survival in the gaps. *Q. engelmannii* was significantly more likely to establish in gaps than *Q. agrifolia*. Muick (1991) found that *Q. agrifolia* required shade for seedling survival. Snow (1972) noted that *Q. engelmannii* has the ability to delay shoot emergence in seedlings for a year. He hypothesized that this may allow this species to become established in open dry habitats more easily than *Q. agrifolia*, which his laboratory germination studies suggested may need more protected and moister habitats for initial establishment.

Conclusions

In Engelmann oak woodlands on Camp Pendleton, *Q. engelmannii* is much less abundant than *Q. agrifolia*, with roughly a little less than half the numbers per acre of *Q. agrifolia* (Lawson 1993). However, our data suggest that *Q. engelmannii* is not being displaced by *Q. agrifolia* and may actually be increasing, as evidenced by its increase in relative abundance in the larger size classes between 1990 and 1995. It appears that *Q. agrifolia* has an advantage in overall seedling establishment while *Q. engelmannii* is better able to establish in gaps where mortality is lower and growth rates higher. This pattern may explain how the two species coexist.

Acknowledgments

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References

Griffin, J.R. 1990. **Oak woodland**. In: Barbour, M.G.; Major, J. Terrestrial vegetation of California. New York: Wiley; 383-415.

Lawson, D.M. 1993. **The effects of fire on stand structure of mixed *Quercus agrifolia* and *Q. engelmannii* woodlands**. San Diego, CA: San Diego State University; 122 p. M.S. thesis.

Muick, Pamela C. 1991. **Effects of shade on blue oak and coast live oak regeneration in California annual grasslands**. In: Standiford, Richard B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 21-24.

Snow, G.E. 1972. **Some factors controlling the establishment and distribution of *Quercus agrifolia* Nee and *Q. engelmannii* Greene in certain southern California oak woodlands**. Corvallis: Oregon State University; 111 p. Ph.D. dissertation.

Monitoring Fire Injury in Canyon Live Oak with Electrical Resistance[1]

Marcia G. Narog[2] **Timothy E. Paysen**[2] **Bonni M. Corcoran**[2]
Miguel A. Zavala[3]

Fire-caused tree injury and mortality can generally be recognized by visible signs, but injury from heating can sometimes go undetected. Canyon live oak (*Quercus chrysolepis* Liebm.) mortality may be difficult to predict because tree death may not occur until 8 years after a fire. A shigometer, a specialized ohm meter, was developed to measure electrical resistance (ER) in live and dead wood. Measurement of ER has been used in other forest types, but never in canyon live oak. We present some results of early postfire monitoring of prescribed burning injury on canyon live oak with a shigometer.

An 8-hectare section of closed-canopy canyon live oak forest was divided into three blocks—each containing three different treatment plots: control, thin, and thin/burn. Trees were thinned to about 50 percent of basal area, and slash was left on site. A prescribed understory burn was completed in November 1985. In summer 1987, shigometer measurements were made on a subsample of 15 oaks from each of the nine plots. All trees were measured at four aspects (north, south, east, and west) of the bole and base for a total of eight readings per tree. ER values (in Kohms) were averaged for each treatment. We assumed that ER values greater than 50 Kohms indicated dead or dying tree tissue.

Of 135 oak trees measured, only those in the thin/burn treatment had ER values above 50 Kohms (*table 1*). The number of high ER readings per tree varied (*fig. 1*). Of the trees with values under 50 Kohms, mean ER readings for the control, thin, and thin/burn treatments were 21 Kohms, 15 Kohms, and 13 Kohms respectively.

[1] Presented as a poster at the Symposium on Oak Woodlands: Ecology, Management and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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Table 1—Electrical resistance (ER) arranged by treatment, value, and number of observations in a canyon live oak forest, San Bernardino National Forest, California.

Treatment	Number of trees[1]		Number of readings[2]
	ER < 50	ER > 50	ER > 50
		Kohms	
Control	45	0	0
Thin	45	0	0
Thin/burn	19	26	94

[1]45/treatment
[2]Sites/treatment (8/tree)

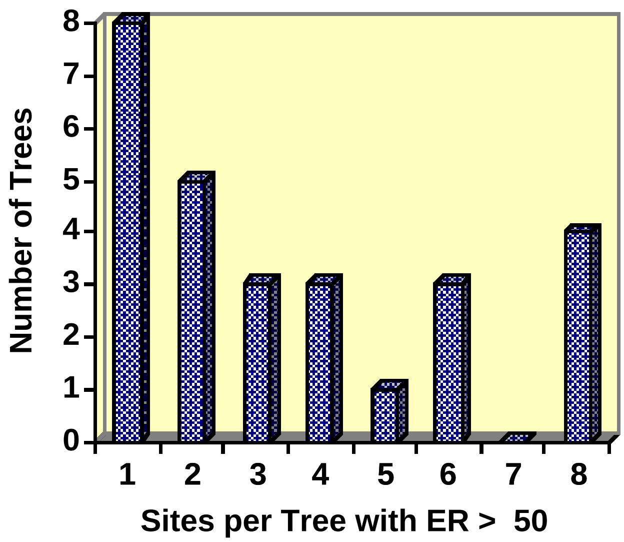

Figure 1—The number of trees which had high electrical resistance-ER (>50 Kohms) values for one to eight sites. Eight sites were measured (four base, four breast height) on each of the 27 canyon live oaks monitored on Skinner Ridge, San Bernardino National Forest, California.

No oaks in the thinned treatment had ER values greater than 50 Kohms. This suggests that thinning alone did not contribute to the high ER values observed on the thin/burn treatment trees. Initial fire injury (e.g., crown scorch or bole charring) was observed on all trees in the prescribed burn plots; yet, tree mortality was difficult to assess. Three years after the fire, evaluation of tree injury, based on visible fire damage, indicated that 69 percent of the trees in the thin/burn treatment had serious injury. Shigometer measurements made one year earlier showed that 58 percent of sample trees in the thin/burn treatment had detectable tissue damage with ER > 50 Kohms. This may or may not indicate that mechanically applied shigometry and visual evaluation techniques are interchangeable. However, the results from canyon live oaks with ER < 50 Kohms indicate that early detection of injury shortly after a burn treatment may be possible; this may not be the case using visual techniques. Measuring ER with a shigometer may improve early detection of injury and mortality in canyon live oak and influence the timing of management action.

Seeds That Fly on Feathered Wings: Acorn Dispersal by Steller's Jays[1]

Marilyn A. Fuchs[2] **Pam G. Krannitz**[3] **Alton S. Harestad**[4]
Fred L. Bunnell[2]

The Garry oak (*Quercus garryana*) is the only native oak in British Columbia. On southern Vancouver Island, Garry oak ecosystems have been severely reduced, fragmented, and degraded. Efforts are currently underway to protect and restore these ecosystems. In this study we investigated oak dispersal and regeneration, to supply information that will help guide conservation efforts.

Steller's jays (*Cyanocitta stelleri*) hoard Garry oak acorns to use as overwinter food. They transport acorns in their throats and bills and hide them singly in the ground at scattered locations. If the jays do not eat all of the hoarded acorns, seedlings may grow at the hoarding locations.

This study addresses the following questions: (1) How deep, and in what habitats, do jays hoard acorns? and (2) How do burial depth and hoarding habitat affect seedling emergence rates? Field work was conducted at two sites at Metchosin, the most southerly portion of Vancouver Island. Methods included: (1) observing hoarding, measuring burial depth of acorns, and assessing habitats used by jays; (2) measuring habitat along transects to estimate habitat availability; and (3) planting acorns at different depths and in different habitats and measuring seedling emergence during the first growing season.

How Deep Do Jays Hoard Acorns?

Virtually all acorns hoarded by jays were buried, but not usually in the soil (*fig. 1*).

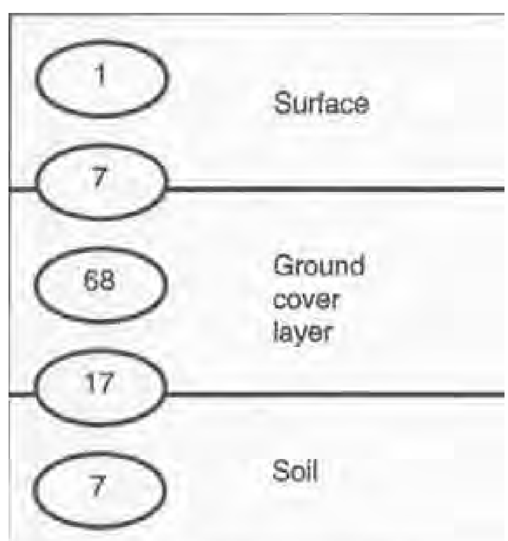

Figure 1—Percentages of hoarded acorns in relation to surface, ground cover layer, and soil (*n* = 151). Ground cover layer refers to leaf litter, moss, and matted grass roots.

[1] Presented as a poster at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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In What Habitats Do Jays Hoard Acorns?

Only a few habitat types were used by the jays in relatively high numbers and in much greater proportion than they were available (HC, CS, and RP). However, only about half of the hoards were placed in these three preferred habitats. The rest were distributed among a wide variety of habitat types (*fig. 2*).

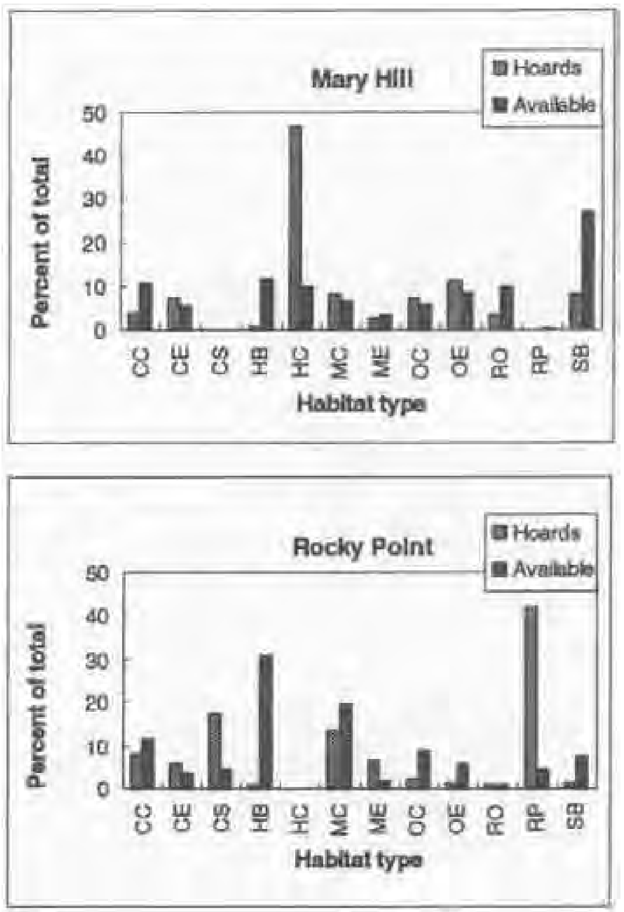

Figure 2—Comparison of use for hoarding and availability of habitat types in two study sites: Mary Hill (hoards n = 177; available n = 356) and Rocky Point (hoards n = 134; available n = 409). CC = conifer canopy; CE = conifer edge; CS = conifer sapling patch within the oak stand; HB = herb; HC = small clump of overlapping canopies of Garry oak, *Arbutus menziesii*, and *Pseudotsuga menziesii*; MC = mixed canopy; ME = mixed canopy edge; OC = oak canopy; OE = oak edge; RP = riparian; SB = shrub.

How Do Burial Depth and Habitat Affect Seedling Emergence Rates?

Effects of burial depth and habitat type were significant at both sites (ANOVA, $P < 0.05$). Acorns planted in the ground cover layer and in the soil fared significantly better than acorns planted on the surface. Acorns in the three habitats used most frequently by the jays had low emergence rates. Acorns in a number of habitats used less frequently by jays had high emergence rates (*fig 3*).

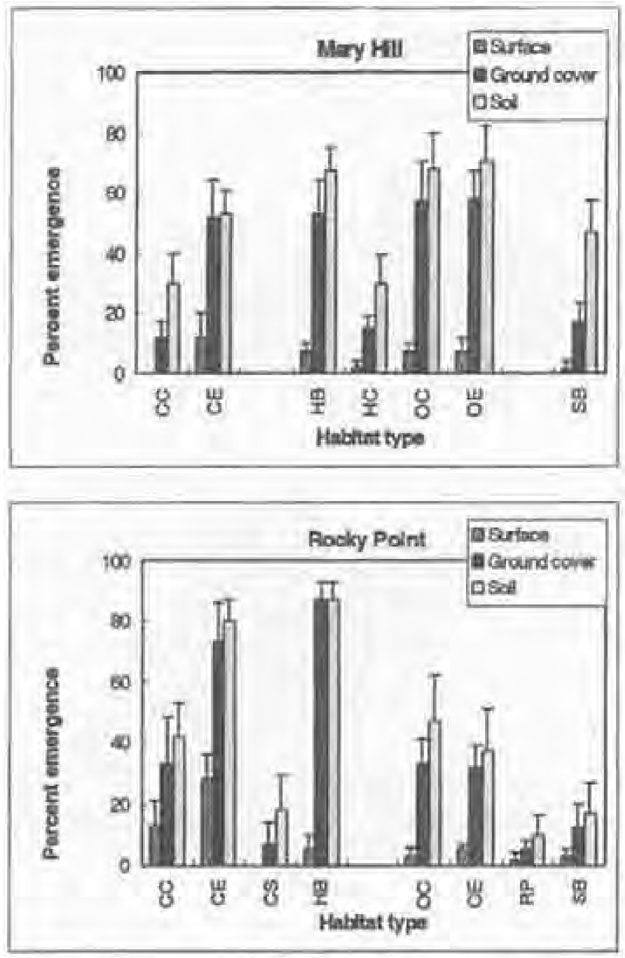

Figure 3—Results of acorn planting experiment at two sites (Rocky Point and Mary Hill). 2,700 acorns planted in a split-plot, completely randomized design; 6 replicates per treatment combination. Vertical bars represent standard errors. CC = conifer canopy; CE = conifer edge; CS = conifer sapling patch within the oak stand; HB = herb; HC = small clump of overlapping canopies of Garry oak, *Arbutus menziesii*, and *Pseudotsuga menziesii*; OC = oak canopy; OE = oak edge; RP = riparian; SB = shrub.

Conclusions

Burial of acorns by jays within the ground cover layer and soil may play a crucial role in Garry oak regeneration. On the other hand, jay habitat preferences may result in poor seedling emergence rates. Variability in use of habitats for hoarding may be essential for dispersal. Observations suggest that some of the variability noted in this study may be the result of spillover from preferred to adjacent habitat patches. Efforts to promote effective acorn dispersal might thus entail management for habitat patchiness, to juxtapose habitats preferred by the jays with habitats that foster oak regeneration.

Competitive Effects of Alfalfa on Survival, Growth, and Water Relations of *Quercus lobata* Seedlings[1]

Jean G. Hubbell[2]

Abstract: *Successful intercropping of native plants with farm crops without weed/crop control, requires knowledge of the native plants' competitive ability. To assess the competitive ability of* Quercus lobata *(valley oak), it was grown in second-year alfalfa fields. Alfalfa was either unmanaged (high competition) or reduced with glyphosate herbicide (low competition). A relatively small decrease (< 50 percent) in survival and growth in spite of a large decrease in light and water in the high competition treatment suggests a reasonable competitive ability of valley oak seedlings. Therefore, for valley oak restoration, competition reduction may be decreased or unnecessary. For this project granivory was the greatest obstacle to successful intercropping.*

Less than 4 percent of California's pre-European riparian forests remain, and remnants are generally small and fragmented (California State Lands Commission 1994, Cepello 1991, Roberts and others 1980, Smith 1980). This and the great ecological significance of riparian forests have generated an interest in riparian forest restoration.

The Sacramento River Project is designed to restore riparian forests, seasonal and permanent wetlands, and native grasslands along 161 km of the Sacramento River from Red Bluff south to Colusa. This project is a joint effort by The Nature Conservancy (TNC), the U.S. Fish and Wildlife Service, California Departments of Fish and Game and Water Resources, U.S. Army Corps of Engineers, and private landowners to create a corridor of lands adjacent to the river vía ownership, easements, and restoration.

Restoration of native plants is costly, due to the efforts required to maintain irrigation and weed control for several years until the plants are established. TNC defrays costs in a variety of ways, one of which is farming at the restoration site, which can reduce costs by approximately half (Griggs and Peterson 1997). Farming the site reduces costs by providing income for restoration and providing irrigation if restoration plants are intercropped with the farm crops. If intercropping can be done without weed / crop control around the native plants, then the restoration costs could be reduced even further. Successful intercropping without weed / crop control during initial restoration efforts requires knowledge of the competitive ability of the native plants. Thus TNC is interested in experimenting with intercropping of native riparian species with farm crops such as alfalfa (*Medicago sativa*) with and without weed / crop control.

A field experiment was designed to assess competitive effects of alfalfa on survival, growth, and water relations of valley oak (*Quercus lobata*) seedlings at Kopta Slough Preserve. The study addressed the general question, what is the competitive ability of valley oak when grown in alfalfa? The specific null hypothesis was: seedling emergence, survival, growth, and water relations are the same for valley oak when grown in alfalfa (high competition) as when grown in reduced alfalfa (low competition).

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[1] Presented as a poster at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996; San Luis Obispo, Calif.

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Methods

The 283-ha Kopta Slough Preserve, managed by TNC, is located on the west bank of the Sacramento River, 10 km east of Corning, in Tehama County, California, USA. The area has a Mediterranean climate, with an average annual precipitation of 54 cm. Soils are mapped as Columbia loam.

Acorns were harvested from the ground in October/November 1992 from three locations within 10 km of the site and stored in a cool place until planting.

Four locations in two second-year alfalfa fields were sown with valley oak acorns in December 1992. Three acorns were planted at each of the 432 planting spots in the two competition levels described below (864 total). Since acorn mass may affect emergence (Tecklin and McCreary 1991), mean acorn mass was estimated before planting, for each group of acorns to be planted in each set of treatment plots for each location.

Acorn predation and seedling mortality from animals, especially small mammals, are common problems for oak restoration/regeneration studies (Adams and others 1987, Adams and others 1991, Adams and Weitkamp 1992, Griffin 1980, McBride and others 1991, McCreary and Tecklin 1993, Plumb and Hannah 1991). Unfortunately, the project was too large to protect seeds at each of the 864 planting spots. However, a buffer zone (~183 m) was left between potentially high rodent populations and experimental locations. Acorns also were sown approximately 5 to 10 cm into the soil, as this can reduce acorn predation (Davis and others 1991, Tietje and others 1991). Although each seedling had a milk carton placed around it, milk cartons protected seedlings from herbicide applications more than herbivores.

Two levels of competition were established in March 1993: high (alfalfa) and low (reduced-alfalfa). In the high competition treatment, the alfalfa crop was not managed, such that it would grow over the valley oak seedlings. The low competition treatment entailed minimizing alfalfa and weeds by application of glyphosate herbicide in a meter-wide strip, three times during the growing season.

Measurements described below were taken during the 1993 growing season. Competitive ability of valley oak seedlings was assessed by percent emergence as of June, and by monthly survival and growth measurements made from April through September. Bimonthly midday photosynthetic photon flux density (PPFD) measurements, taken at valley oak seedling tops from July through September, described the light regime in each competition level. Bimonthly July-through-September stomatal resistance and soil moisture, as well as September stem predawn water potential, were used to study water relations. Emergence and survival data were analyzed using χ^2 tests. All other response variables were analyzed with least squares regression ANOVA.

Results

Valley oak seedling emergence did not differ significantly between alfalfa and reduced-alfalfa (4 percent versus 13 percent, respectively; $P = 0.823$). A negative relationship was found between percent emergence and acorn mass ($r^2 = 0.575$), with the heaviest acorns having the lowest emergence (0.3 percent) and the lightest acorns having the highest (11 percent) emergence.

June census of emerged seedlings was used as the baseline for percent survival. Seedlings grown in low competition had statistically greater survival (100 percent) than seedlings in high competition (58 percent) for July, August, and September ($P < 0.0001$). Patterns of growth, expressed as heights, also were significantly different between competition levels (*fig. 1*). Survival and growth were reduced 42 and 46 percent respectively, for seedlings grown in alfalfa.

Throughout the season, midday PPFD at seedling tops was decreased an average of 13-fold for alfalfa-grown seedlings (*fig. 2*). September predawn water potential was less negative in the low competition than in the high competition (-0.447 MPa vs. -0.875 MPa; $P < 0.0001$). Stomatal resistance and soil moisture also differed significantly (*figs. 3* and *4*). Thus, water availability was decreased as indicated by lowered percent soil moisture, increased stomatal resistance, and lowered predawn water potential for valley oak seedlings in alfalfa, despite irrigation.

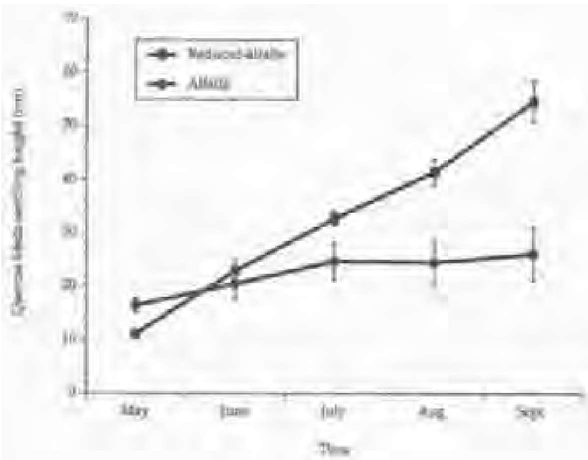

Figure 1—Mean heights of valley oak seedlings for high (alfalfa) and low (reduced-alfalfa) competition levels with standard error bars (n = 6, n = 10, respectively). Growth (as height) was significantly lower in alfalfa than in reduced-alfalfa (P=0.027).

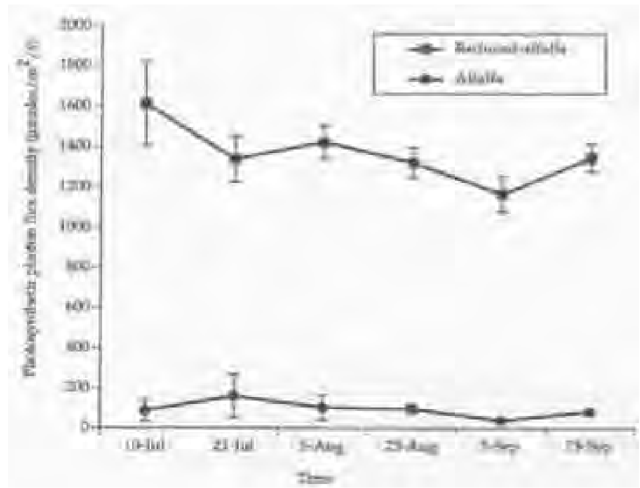

Figure 2—Mean midday photo-synthetic photon flux density (PPFD) (µmol/m²/s) of valley oak seedlings in each competition level with standard error bars. PPFD was significantly lower in the alfalfa than in the reduced-alfalfa ($P < 0.0001$). Sample size differed between treatments and among months as follows: reduced-alfalfa n = 5 for 10-July and n = 10 for other times; and, in chronological order, alfalfa n = 3, 6, 6, 5, 6, 5.

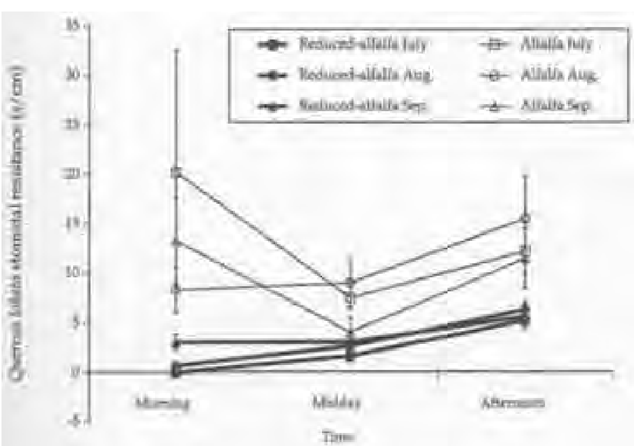

Figure 3—Mean stomatal resistance (s/cm) of valley oak seedlings in each competition level during the day with standard error bars. Stomatal resistance was significantly higher in the alfalfa than in the reduced-alfalfa ($P < 0.0001$). Sample size differed between treatments, among months and times of day as follows: in chronological order, reduced-alfalfa n = 5, 15, 15 for July, n = 15, 20, 20 for August, n = 20 all times for September; in chronological order, alfalfa n = 3, 9, 6 for July, n = 8, 10, 10 for August, n = 10, 8, 10 for September. Bimonthly measurements were averaged for each month.

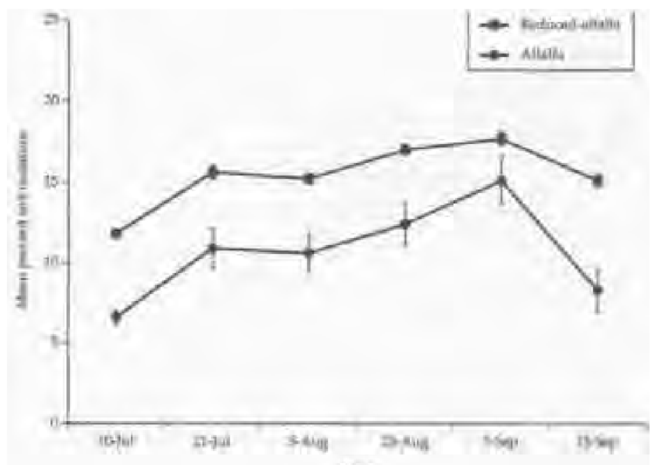

Figure 4—Mean percent soil moisture of valley oak seedlings in each competition level with standard error bars. Percent soil moisture was significantly lower in the alfalfa than in the reduced-alfalfa ($P < 0.0001$). Sample size differed between treatments and among months as follows: reduced-alfalfa n = 5 for 10-July and n = 10 other times, and alfalfa n = 3 for 10-July and n = 5 other times.

Implications for Valley Oak Restoration

Reduction of valley oak seedling survival and growth by less than 50 percent when grown with 13 times less light and reduced water availability in the alfalfa treatment reflects the ability of the valley oak seedlings to persist in suboptimal environments. This suggests a reasonable competitive ability for valley oaks in alfalfa. Griffin (1980) noted the persistence of valley oak seedlings in dense grass cover after three years in his Carmel Valley studies. Similar results also were found for valley oak plantings in grass cover after one and two years at Llano Seco Ranch south of Chico, California (J. G. Hubbell and F.T. Griggs, unpublished data[3]). Valley oak seedling tolerance for reduced water availability is in part due to deep tap roots initiated during fall acorn germination, as well as other morphological and physiological features typical of plants adapted to an arid climate.

[3]Unpublished data on file, The Nature Conservancy, Hamilton City, CA

Low overall percent emergence was probably due to granivores such as California ground squirrels (*Spermophilus beecheyi*), pocket gophers (*Thomomys bottae*), mule deer (*Odocoileus hemionus*), etc., since acorn shells were found at most planting spots in March 1993. However, no quantitative analysis was done. A negative relationship was found between acorn mass and percent emergence, with the lightest acorns having greater percent emergence than the heaviest. This relationship may further implicate granivory if animals preferentially selected large acorns, as might be suggested by optimal foraging theory. Despite efforts to reduce seed predation, so few seedlings emerged at the two locations closest to the buffer zone, that they were dropped from the study. Thus granivory confounded any assessment of competitive ability of valley oak in terms of emergence.

Seed predation in this study further supports the importance of considering granivores at restoration sites. Even if seedling transplants are utilized, they are subject to mortality from the same small mammals that are responsible for most seed predation (Adams and Weitkamp 1992, Tecklin and McCreary 1993). Thus an estimate of granivore/herbivore populations would be helpful. If granivore/herbivore populations are known to be high, then appropriate proven measures can be taken, such as above and below ground screening, tree shelters, etc., for small-scale projects. At present I am unaware of any large-scale measure that has been quantified, and is both economical and ecologically appropriate. Poisoning has long been used by farmers but is in disfavor for obvious ecological reasons. Flooding and raptor posts appear to be the most promising possibilities for lowland projects (Griggs and Peterson 1997). This is an area that needs further research.

The need to reduce light and water competition for valley oak seedlings depends on the goals of the restoration project. For projects requiring high survival, competition reduction (i.e., crop/weed control) or sowing more acorns than needed, will be necessary. For projects where lower survival and growth are acceptable, competition reduction could be minimized or eliminated (e.g., projects done by volunteers, where resources may be limited). However, as Adams and Weitkamp (1992) point out, competition may be irrelevant unless seed/seedling predators are controlled.

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References

Adams, T.E.; Jr., Sands, P.B.; Weitkamp, W.H.; McDougald, N.K. 1991. **Blue and valley oak seedling establishment on California's hardwood rangelands**. In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 41-47.

Adams, T.E. Jr., ; Sands, P.B.; Weitkamp, W.H.; McDougald, N.K.; Bartolome, J. 1987. **Enemies of white oak regeneration in California**. In: Plumb, T.R.; Pillsbury, N.H., technical coordinators. Proceedings of the symposium on multiple-use management of California's hardwood resources; 1986 November 12-14; California Polytechnic State University, San Luis Obispo, CA. Gen. Tech. Rep. PSW-100. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 459-462.

Adams, T.E., Jr., Weitkamp, W.H. 1992. **Gophers love oak to death**. California Agriculture 46(5): 27-29.

California State Lands Commission. 1994. **California's rivers: a public trust report**. 2d ed. Sacramento: California State Lands Commission; 334 p.

Cepello, S.A. 1991. **Riparian vegetation distribution along the middle Sacramento River in relation to flood frequency**. Chico: California State University; 41 p. M.S. thesis.

Davis, F.W.; Borchert, M.; Harvey, L.E.; Michaelsen, J.C. 1991. **Factors affecting seedling survivorship of blue oak (*Quercus douglasii* H. & A.) in central California**. In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 81-86.

Griffin, J.R. 1980. **Animal damage to valley oak acorns and seedlings, Carmel Valley, California**. In: Plumb, T.R., technical coordinator. Proceedings of the symposium on the ecology, management, and utilization of California oaks; 1979 June 26-28; Claremont, CA. Gen. Tech. Rep. PSW-44. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 242-245.

Griggs, F.T.; Peterson, D.R. 1997. **Evaluation of techniques and costs for valley oak riparian forest restoration on the Sacramento River**. [these proceedings].

McBride, J.R.; Norberg, E.; Cheng, S.; Mossadegh, A. 1991. **Seedling establishment of coast live oak in relation to seed caching by jays**. In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 143-148.

McCreary, D.D.; Tecklin, J. 1993. **Tree shelters accelerate valley oak restoration on grazed rangelands (California)**. Restoration & Management Notes 11(2): 152-153.

Plumb, T.R.; Hannah, B. 1991. **Artificial regeneration of blue and coast live oaks in the central coast**. In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 74-80.

Roberts, W.; Howe, J.; Major, J. 1980. **A survey of riparian forest flora and fauna in California**. In: Sands, A., ed. Riparian forests in California: their ecology and conservation. Berkeley: Agricultural Sciences Publications, University of California; 3-19.

Smith, F. 1980. **A short review of the status of riparian forests in California**. In: Sands, A., ed. Riparian forests in California: their ecology and conservation. Berkeley: Agricultural Sciences Publications, University of California; 1-2.

Tecklin, J.; McCreary, D.D. 1991. **Acorn size as a factor in early seedling growth of blue oaks**. In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 48-53.

Tecklin, J.; McCreary, D.D. 1993. **Dense vegetation may encourage vole damage in young oak plantings (California)**. Restoration & Management Notes 11(2): 153.

Tietje, W.D.; Nives, S.L.; Honig, J.A.; Weitkamp, W.H. 1991. **Effect of acorn planting depth on depredation, emergence, and survival of valley and blue oak**. In: Standiford, R.B., technical coordinator. Proceedings of the symposium on oak woodlands and hardwood rangeland management; 1990 October 31-November 2; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 14-20.

The Effects of Native Soils on Engelmann Oak Seedling Growth[1]

Thomas A. Scott[2] **Nanette L. Pratini**[2]

Abstract: *We present 6 years of data from a study of restoration techniques for the Engelmann oak (*Quercus engelmannii*), a southern California endemic. Acorns and 1-year-old seedlings treated with native soil collected from a stand of native oaks were more vigorous than comparison trees in all measured variables: survival, tree height, trunk diameter, leaf volume, number of new leaves in spring, and number of trees producing acorns. These differences were apparent after the first year and have continued well into their sixth year. Results of root excavations in the second year were equivocal, with no significant differences in mycorrhizal infection rates or root length between treatments.*

The Engelmann oak (*Quercus engelmannii*) is endemic to Orange, Riverside, and San Diego Counties in southern California (Scott 1990). In 1988 we initiated a study of the effects of several commonly used restoration techniques on Engelmann oaks at South Coast Research and Extension Center (SCREC). The most successful of these was the addition, at the time of planting, of soil collected from under mature Engelmann oaks. These soils (hereafter referred to as native soils) may confer benefits owing to the presence of mycorrhizae, other beneficial soil microorganisms, or plant nutrients.

We have monitored growth and vigor of these trees from 1989 to present. The conditions at SCREC are not natural (we used weed control and irrigation); we wanted to test the potential growth rate enhancement that could be achieved if oaks were planted into a disturbed site and given a certain amount of post-planting care.

Methods

Study Site

SCREC is a University of California field station located in southern Orange County, at the approximate northern boundary of the species' natural range. Annual precipitation is slightly lower at SCREC than in most of the Engelmann oaks' range, but temperature and evapotranspiration rates are similar. The field was grown in barley from 1984 to 1988 in an effort to remove agricultural residues. The soil is classified as San Emigdio, a fine sandy loam. Soil depth is 60-120 inches, pH is moderately alkaline (7.8 - 8.4), and the soil is slightly calcareous. The field was sprayed with glyphosate approximately 4 weeks before seedling emergence in early 1989; subsequent weed control was through mechanical means (mulching, hand-trimming when necessary, and disking between rows). Seedling irrigation was based on CIMIS (California Irrigation Management Information System) estimates of weekly evapotranspiration rates (Scott 1991).

Seed Stock

All acorns were collected from a single Engelmann oak, located at Camp Pendleton Marine Base, San Diego County. It occurred in a relatively isolated stand with only four trees upwind as potential pollen sources. Acorns less than

[1] Presented as a poster at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996; San Luis Obispo, Calif.

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0.176 ounces and greater than 0.243 ounces were discarded; all others were germinated with peat and vermiculite until planting (approximately 2 weeks).

Acorns for the trees planted as seedlings were collected in the fall of 1987. They were planted into 4-in. by 12-in., 1-gal containers and grown in a greenhouse until November 1988.

Treatments

Native soil was collected from an Engelmann oak woodland at the Santa Rosa Plateau in western Riverside County. After removing leaf litter and debris, soil was taken to a depth of 7.8 inches, transported to SCREC (2 h) and used in planting.

In November 1988, acorns and seedlings were planted in four rows spaced 19.7 feet apart at SCREC. Acorn planting sites (n = 80) were placed 9.8 feet apart along the rows. Seedling planting sites (n = 40) were placed 19.7 feet apart along the same rows. Acorn treatment pairs consisted of quadruplets of equal radicle length, planted two per site. Fifty-six quadruplets were planted at 112 emitters along four irrigation lines. Seedling treatment pairs consisted of treated and nontreated seedlings matched by height.

Acorn treatment sites were excavated to a depth of 3.9 inches and backfilled with 1.1 pint of either field soil or native soil. Planting sites for the container trees were backfilled with either 1.1 lb of native soil amendment or field soil around the root and soil mass (approximately 7.7 lb). Twenty-eight seedling pairs were planted along the same four irrigation lines.

Measurements

Tree measurements were taken on a monthly basis for the first 4 years of the study and on an annual basis thereafter. Trunk diameters were measured at 3.2 inches above ground. As some trees had multiple main stems, total basal area of the combined stems was used for treatment comparisons. Leaf density in July 1994 was visually rated on a scale of 1-10, where 1 = sparse leaves and 10 = many leaves. The proportion of new leaves was visually estimated in March 1995 and assigned a score of 1 (no new leaves), 2 (new leaves on <30 percent of the branches), or 3 (new leaves present on 30 percent or more of the branches). The number of acorns produced on a tree (in October 1994) was ranked on a scale from 0 (no acorns) to 3 (most branches with several acorns each). All measurements and rankings were done by the second author. If more than one seedling emerged from an acorn planting site, both were left in place but only the largest (at 1 year of age) was monitored. Roots of the trees planted as seedlings were examined for the presence and extent of mycorrhizal fungi infection in July and August 1991 (2.5 years post-planting). Approximately 27 pints of soil were excavated from the north side of each tree at a distance of 3.9 inches from the trunk. Root material was sifted from the soil, refrigerated in water-filled vials, and examined within 1 day of collection. Total length of root fragments in the sample and the proportion of mycorrhizal-infected root tips were measured for each tree.

Results

Emergence rates of the acorns planted with and without native soil amendment were similar (85/112 and 80/112, respectively), but by January 1995, significantly more treated trees than untreated trees were still alive (*table 1*) (t-test, $P < 0.005$) (paired t-tests could not be performed because of the low number of pairs with both trees still alive in 1995). Survivorship was also significantly higher in the trees planted as seedlings with native soil than in the comparison trees (t-test, $P < 0.05$).

Table 1—Summary of differences between acorn and seedling trees planted with field soil and with native soil for the measured characteristics[1]

Soil treatment	Acorn trees			Seedling trees		
	Field soil (n = 19)	Native soil (n = 35)	Significance[2]	Field soil (n = 19)	Native soil (∑= 26)	Significance[2]
Emergence (*pct*)	71	76	n.s.			
Survival (*pct*)	46	88	***	63	90	*
Mean height (*feet*)	16.1	21.3	***	19.2	23.8	***
Mean basal area (*feet*^{2})	4.9	10.2	***	7.9	12.7	**
Mean leaf density rating (scale 1-10)	6.3	7.6	***	7.1	7.9	n.s.
Mean new leaf rating (scale 1-3)	2.5	2.9	**	2.9	2.9	n.s.
Trees producing acorns (*pct*)	32	57	n.s	58	65	n.s
Mean acorn crop rating (scale 0-3)	0.4	1.2	n.s.	1.1	1.4	n.s

[1]Measurments and significance tests are described in the text.
[2]*** = $P < 0.005$, ** = $P < 0.01$, * = $P < 0.05$, n.s. = $P \geq 0.05$

Mean tree height in January 1995 was significantly greater in the treated trees than in the comparison trees (t-test, $P < 0.005$). This was true for both the acorn-planted trees and the seedling-planted trees (hereafter referred to as acorn trees and seedling trees, respectively). Mean trunk basal area (in 1994) was also significantly greater in treated acorn trees (t-test, $P < 0.005$) and seedling trees ($P < 0.001$) than in comparison trees (*table 1*).

Treated acorn trees had higher mean scores for new leaf production (chi-square, df = 1, $P < 0.001$) and higher leaf density ratings (chi-square, df = 3, $P < 0.005$) than comparison trees. New leaf ratings and leaf density ratings for the seedling trees were slightly higher than in comparison trees, but not significantly so ($P > 0.05$).

Although a higher proportion of treated trees produced acorns in 1994 than comparison trees, the differences were not significant (chi-square, df = 1, $P > 0.05$). Acorn crop ratings were also nonsignificantly higher in soil-amended acorn and seedling trees than in nontreated trees (chi-square, df = 3, $P > 0.05$).

For the excavated root samples of treated (n = 27) and comparison (n = 23) seedling trees, neither mean total root length (378.5 and 363.7 feet, respectively) nor mycorrhizal infection rates (26 percent and 21 percent, respectively) could be differentiated between the treated and comparison trees planted as seedlings (paired t-test: df= 36, $P > 0.05$).

Discussion

Even after six growing seasons, the trees planted with native soil amendment were more vigorous than comparison trees in every variable measured. The treatment seemed to be most effective when used with acorns. Further research and analysis will, we hope, determine the most efficient techniques for long-term monitoring of tree vigor in this species.

Although we can define the benefit of using native soils to augment tree growth, we cannot precisely define the cause. Three possible explanations are:

(1) mycorrhizal infection rates were higher at treated sites the first year or two after planting but have decreased to background levels or spread to neighboring nontreated sites; (2) the benefit resulted from other biological factors in the native soils such as nitrogen-fixing bacteria, nematodes, or mites; or (3) the early benefits resulted from physical or chemical properties of the native soils, such as nutrients, pH, or soil structure. These are, of course, not mutually exclusive, and the result may have been a combination of factors. Planting sites were completely interspersed, and the trees with the highest growth rates were randomly distributed across the field; therefore it seems that field or systematic effects are unlikely. The lack of a sterilized comparison treatment does not allow us to rule out benefits resulting from physical or chemical differences between treatments. Additionally, we have observed significant, although less dramatic, differences in growth rates of Engelmann oaks grown in sterilized and unsterilized native soils collected from the same area (unpub. data[3]). The possible effects of other biological factors also cannot be ruled out, but would not be expected to cause by themselves the differences in growth that we observed. The first explanation is also difficult to rule out, that mycorrhizae from the native soil conferred a growth advantage during the first 2 years.

[3] Unpublished data on file, Dept. of Earth Sciences, University of Calif., Riverside.

References

Scott, Thomas. 1991. **The effectiveness of radicle trimming, auger planting, mycorrhizal inoculation, and irrigation on Engelmann oaks.** In: McCreary, Douglas, ed. Selected techniques for restocking hardwood rangelands in California with native oaks. Report submitted to the California Department of Forestry and Fire Protection; 106-128.

Scott, Thomas A. 1990. **Conserving California's rarest white oak: the Engelmann oak.** Fremontia 18(3): 26-29.

Conservation Reserve Program (CRP) Oak Regeneration Study[1]

William H. Weitkamp[2] Sally L. Yoshida[3] William D. Tietje[4]

The federal Conservation Reserve Program (CRP) was begun in 1985 to conserve and improve natural resources by taking highly erodible cropland out of grazing and crop production for at least 10 years. In California, San Luis Obispo County and southern Monterey County lead in CRP participation, with more than 100,000 acres of privately owned land entered in the program. Much of this land is blue oak (*Quercus douglasii*) or valley oak (*Q. lobata*) rangelands. During autumn 1995, we conducted a pilot study to acquire information for setting up a research project on the effects of the CRP on oak regeneration (*figs. 1* and *2*).

Study Objectives

Pilot Study

- Test study methods for site selection, field sampling, and data analysis.

Follow-up Study

- Assess oak regeneration on CRP versus non-CRP oak rangelands.
- Provide initial assessment of effect of CRP on the sustainability of oak rangelands.

Study Sites

CRP and non-CRP sites for the pilot study were established on ranches in northern San Luis Obispo and southern Monterey Counties (*fig. 3*). Criteria for selection were that the ranch was in the oak (*Quercus* spp.) woodland vegetation type and that it had been in the CRP for at least 5 years.

Methods

The Farm Service Agency (FSA), formerly the Agricultural Stabilization and Conservation Service (ASCS), administers the CRP. We identified eight ranches from aerial photos obtained at the FSA Office in San Luis Obispo County (*fig. 4*). On three of the ranches, a CRP site was compared with a nearby non-CRP site that was similar in tree cover and topography but was grazed by cattle.

At each ranch, we explored the use of two techniques to detect the level of oak regeneration: (1) Strip Transects, 25 m long and 6 m wide, established in the four cardinal directions at randomly selected mature oak trees within the CRP and non-CRP sites, and (2) Timed Searches of the CRP and non-CRP sites. Oak species and height were recorded for all seedling and sapling trees encountered along the transects or during the timed searches.

Results and Discussion

Pilot Study

The number of seedlings found per 120 minutes in the timed searches varied from 0 to 299 for three non-CRP fields and from 0 to 150 for nine CRP fields (*fig. 5*). The study areas in general had a low percentage of tree cover (see *fig. 4*), and the trees

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Figure 1—Non-Conservation Reserve Program (non-CRP) land, which has been grazed by livestock, served as a control for the study.

Figure 2—Conservation Reserve Program (CRP) land–no farming or livestock grazing has occurred on this land since being entered into the Program.

were located mainly in riparian areas, along fences, and on steep hillsides. Most seedlings were found within 15 meters of the drip lines of mature oak trees.

Because of the great variation in seedling counts and the small number of non-CRP fields, no statistically valid comparison of oak regeneration could be made between CRP and non-CRP fields. However, the number of seedlings found per unit of time (120 minutes) during the timed searches was positively and significantly ($P \leq 0.10$) correlated with the number of seedlings found per unit of area during the transect searches. Spearman's rank correlation coefficient between timed and transect searches was 0.6276 ($P = 0.0704$) as computed across management regimes on nine fields.

Follow-up Studies

Aerial photos will be used to select approximately 10 pairs of CRP and non-CRP fields. Because the pilot study indicated that timed searches were more efficient than area-constrained (transect) searches, timed searches will be used to count oak seedlings. The results will be used as baseline data to compare with future surveys and to assess the effects of eliminating farming and livestock grazing on oak regeneration.

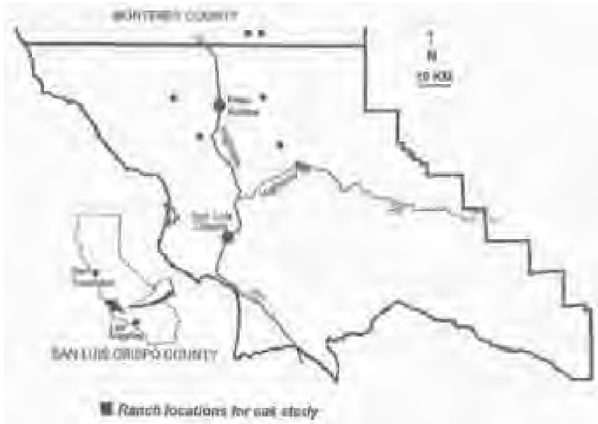

Figure 3—San Luis Obispo and southern Monterey Counties showing the locations of the eight ranches selected for study sites.

Figure 4—Aerial photos from the Farm Service Agency (FSA) in San Luis Obispo County were used to locate study sites and delineate Conservation Reserve Program (CRP) and non-CRP areas.

Figure 5—Non-Conservation Reserve Program blue oak woodland showing oak regeneration on area with planned grazing by cattle.

Acknowledgments

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Quercus wislizenii Growth Rings[1]

Scott D. White[2]

Introduction

Growth rings are often used to determine ages of trees and shrubs, but interpretation necessitates (1) stem cores or cross-sections and (2) verification that rings are produced annually. Collecting cores from dense-wooded shrubs and hardwood trees is difficult and unreliable, because growth rings are rarely centered at the geometric centers of the stems. Cross-sections provide reliable data, but necessitate destructive sampling and may be inappropriate in many study areas. If reliable, stem diameter would provide a faster and less destructive technique to determine age, though it would not be as accurate as ring counts. This report describes *Quercus wislizenii* (interior live oak) growth rings in the San Bernardino Mountains (San Bernardino Co., California) and provides a linear regression of ring number vs. stem diameter as a means of estimating stem age. I anticipate that a clearer understanding of ring deposition will help generate a model of *Q. wislizenii* forest stand development and stem dynamics. Keeley (1992, 1993) has verified the annual nature of growth rings in several chaparral shrubs and used growth rings to analyze stem recruitment and shrub demography in long-unburned chaparral. He did not publish data for *Quercus wislizenii*, but his 1992 paper provided a regression equation to estimate stem ages from their diameters with constant values for 22 species, including *Q. wislizenii* at Mt. Tamalpais (Marin Co.). My results are compared with Keeley's regression line.

Methods

Four cross-sections were collected from living *Quercus wislizenii* stems and two adjacent *Prunus ilicifolia* stems. *P. ilicifolia* was selected for comparison because (1) it was growing within the same stand, (2) Keeley (1993) has established the annual nature of its growth rings, and (3) its rings were readily recognized and compared with rainfall data. Seventeen additional cross-sections were collected from dead *Q. wislizenii* stems on a fuelbreak site where much of the vegetation had been cleared and removed. Stem sections were prepared by sanding with 180-grit sandpaper on bench-mounted and/or hand-held disk sanders. Growth rings of the living *Q. wislizenii* and *P. ilicifolia* stem cross- sections were counted using a binocular dissecting microscope and correlated as closely as possible to annual rainfall data (San Bernardino County Flood Control District). After a correspondence between rainfall and ring width was established for recent decades, additional rings were counted without reference to rainfall data. Most *Q. wislizenii* stems are roughly elliptical in cross-section. Stem diameters were estimated by averaging the widest and narrowest distances across the cross-sections.

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Results and Discussion

Keeley (1993) concluded, "there is good evidence that for many shrubs growth rings give a close approximation of age," but cautioned against "assigning specific years to most rings." I find that *Quercus wislizenii* growth rings fit his synopsis closely.

Cross-sections taken from living *Prunus ilicifolia* stems clearly showed a series of closely spaced rings corresponding to the 1984-1990 drought years and a series of wide and narrow rings corresponding to high and low rainfall years in 1969-1972. *Quercus wislizenii* rings are much more uniform, but very narrow rings correspond well to years of exceedingly low rainfall in 1989 and 1972. Studying the appearance of rings dated to known rainfall years in cross-sections collected from living plants facilitated interpretation of cross-sections from dead plants in which the outermost ring could not be dated to a known year. Annual rings were generally distinguished from "waves" by the appearance of a few regularly spaced wide vessel elements in each one (see Keeley's [1993] description of *Q. dumosa* rings). Visible *Q. wislizenii* growth rings do not always correspond precisely to calendar years. Several of the cross-sections examined had discernible rings merging in a 'Y' pattern into either a single ring or a pair of rings so closely spaced that they could not be resolved under the microscope. The dead stems, particularly older ones, were often discolored and thus more difficult to interpret and a few closely spaced rings may have been overlooked. Even with these difficulties, rings reflecting rainfall patterns of the early 1970's correspond within a year or two to their count dates.

Linear regression of stem diameter against ring count is shown in *figure 1*. *Quercus wislizenii* stem diameters in the San Bernardino Mountains are larger than those at Mt. Tamalpais (Keeley 1992), perhaps because of lower latitude and a (presumably) longer growing season.

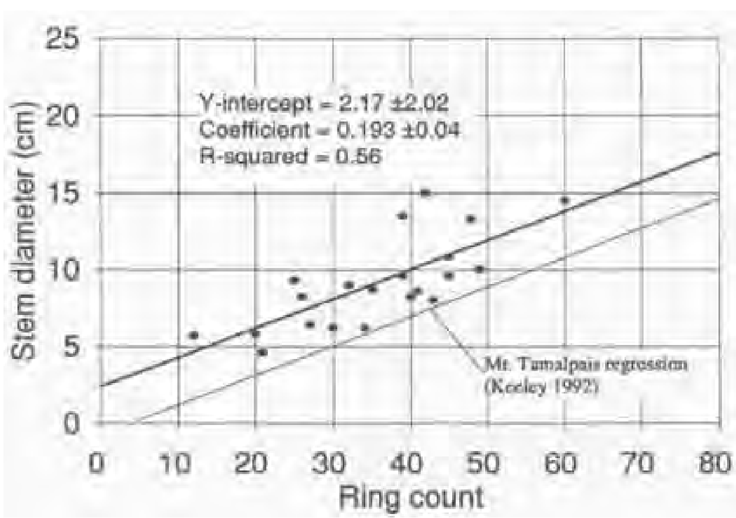

Figure 1—Regression of stem diameter vs. ring count for *Quercus wislizenii* in the San Bernardino Mts. (heavy line) and Mt. Tamalpais, California.

Ring widths were not measured or compared statistically, but ring width tended to be much more consistent from year to year within a single *Quercus wislizenii* stem than within a single *Prunus ilicifolia* stem or within single stems in Keeley's (1993) data. This may reflect deep rooting by *Q. wislizenii,* perhaps enabling constant growth rates even in years of relatively low rainfall. Wide variation in average ring width among stems was evident and is reflected by the regression line's wide standard errors (*fig. 1*). This pattern indicates that some stems grow much more vigorously than others, regardless of rainfall or other factors causing rapid or slow growth in any particular year. This variation may reflect differential light availability, insect attack, interaction with adjacent vegetation, or resource allocation to other products (e.g., acorns) among stems or among individual plants.

Quercus wislizenii forest stands in the San Bernardino Mountains have been defined on the basis of stem structure (White and Sawyer 1994). In each of these stands, at least 5 percent of the sampled stems were $\geq$15 cm in diameter, and in most of these stands, at least 5 percent of sampled stems were $\geq$20 cm in diameter. If these large stems follow the regression equation, then the oldest living stems in forest stands have expected ages of 75 to 100 years and minimum ages of 45 to 70 years. Since *Q. wislizenii* clones continually recruit new stems, stem ages cannot be taken to represent stand ages. If these forests replace dead canopy stems with new recruits, as seems likely, then the forests themselves may be much older.

I plan to refine the analysis presented here by increasing the sample size (particularly among larger stems), verifying the annual ring pattern against additional species with known annual growth rings, and comparing variation in ring widths among years, substrates, and geographic locations. I particularly hope that a larger sample size will reduce the regression line's standard errors and enable more precise determination of stem age based on diameter. A time-based model of stem recruitment and turnover in *Q. wislizenii* shrubland and forest canopies will be developed by applying the regression to existing stem diameter data.

References

Keeley, J.E. 1992. **Recruitment of seedlings and vegetative sprouts in unburned chaparral**. Ecology 73: 1194-1208.

Keeley, J.E. 1993. **Utility of growth rings in the age determination of chaparral shrubs**. Madroño 40: 1-14.

White, S.D.; Sawyer, J.O., Jr. 1994. **Dynamics of *Quercus wislizenii* forest and shrubland in the San Bernardino Mountains, California**. Madroño 41: 302-315.

Pruning Oak Resprouts to Enhance Growth

Sheila J. Barry[1] Ronald S. Knight[2] Douglas D. McCreary[3]

Introduction

Firewood harvest on California's hardwood rangelands has increased since the mid-1970's with the expanding markets for firewood. There has been considerable concern about the amount of oak regeneration occurring in harvested areas and whether these stands can be sustained. However, one rancher in Tehama County (California) observed that oaks on his property sprout vigorously and grow rapidly after harvests. He has witnessed the same trees harvested twice during his lifetime and anticipates harvesting them again in the near future. Many other ranchers have also commented on significant regrowth of their oak woodlands after harvest. Their testimony was supported by a recent study measuring stump resprouting from oak trees harvested in Shasta and Tehama Counties. More than 54 percent of harvested trees on 20 different range sites resprouted (Standiford, 1996).

Unfortunately, oak resprouts initially seem to take on the form of a "bush." Numerous sprouts grow from a single stump. Over time, only two or three dominant sprouts seem to persist, and the regrowth takes on the form of a multi-stemmed tree.

In 1987, a study was initiated to investigate whether pruning 2 year-old oak stump regrowth to two dominant sprouts would enhance regrowth. It was thought that enhancing regrowth could result in a viable oak tree sooner and a shorter harvest interval.

Materials and Methods

A blue oak (*Quercus douglasii*) range site, west of Red Bluff, was selected for this study because of its history of successful stump sprouting and rapid growth of resprouts. Before the harvest in fall 1985, the site had 100 percent canopy cover with 300 trees/ha. Approximately 7 cords per ha were harvested.

Two years after the harvest, regrowth on 10 stumps was pruned. Two dominant sprouts were left unpruned on each stump. The 10 pruned stumps were paired with 10 nonpruned stumps with similar regrowth. Two dominant sprouts were identified from among the regrowth on each unpruned stump. Stumps were paired on the basis of location and similarity of size. Paired stumps were within 3 m of one another. From February 1987 to September 1990, the regrowth from the pruned stumps was controlled (pruned) so that only the two dominant sprouts persisted. After September 1990, further new sprouting ceased.

Basal diameter and height of the two dominant sprouts from both pruned and nonpruned stumps were measured immediately after the pruning in February 1987 and repeated in the early fall of 1987 to 1990, 1993, and 1995. Basal diameter of the stump was measured 10 cm above the ground line. In 1987-1990, dominant sprouts were straightened out to measure height. Height was measured as the distance from the ground to the tip. In 1993 and 1995, sprouts had grown too tall to straighten, and heights were measured to the top of the sprouts using a measuring stick.

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Means and standard deviations for basal diameter and height of sprouts from pruned versus unpruned stumps were calculated for each measurement date. Significant differences between means were determined using two-sample *t*-tests (Nintze 1995). Means from data with normal distribution were compared using the Equal-Variance Test. Means from data not normally distributed were compared using the Mann-Whitney *U* test. All means exhibited equal variance. Differences reported as significant were at the $P < 0.05$ level.

Results and Discussion

There were no significant differences between either the diameter or height of dominant oak sprouts on pruned versus unpruned stumps at time of pruning (*tables 1, 2*). However, after the first growing season, the dominant oak sprouts on pruned stumps had significantly larger diameters than those on unpruned stumps (2.88 cm versus 2.50 cm, respectively). Significant differences in height of dominant oak sprouts from pruned versus unpruned stumps were not achieved until after the second growing season (295.8 cm versus 271.5 cm, respectively). Although the relative difference in height and diameter of sprouts from pruned versus unpruned stumps has been maintained for the past 8 years, these differences in general have not increased very much. For example, in July 1995, dominant sprouts of pruned trees had a significantly larger basal diameter (9.8 cm vs 8.4 cm) and were significantly taller (465 cm vs. 440 cm) than sprouts of

Table 1—Diameter of oak sprouts from pruned vs. unpruned (control) stumps

	Mean		Standard deviation		*t*-Test	
Date	**Control**	**Prune**	**Control**	**Prune**	**Prob.**	**Test**
	cm		*cm*			
Feb-87	1.58	1.68	0.31	0.35	0.34	Equal-Variance *t*-test
Aug-87	2.50	2.88*	0.58	0.62	0.04	Mann-Whitney *U*
Aug-88	3.08	3.57*	0.61	0.77	0.03	Equal-Variance *t*-test
Aug-89	3.75	4.41*	0.83	0.87	0.01	Mann-Whitney *U*
Sep-90	4.32	5.10*	1.00	0.91	0.01	Equal-Variance *t*-test
Aug-93	6.42	7.41	1.78	1.42	0.10	Mann-Whitney *U*
Jul-95	8.40	9.75*	2.34	2.00	0.02	Mann-Whitney *U*

*Means are significantly different, $P \leq 0.05$

Table 2—*Height of oak sprouts from pruned vs. unpruned (control) stumps*

	Mean		Standard deviation		*t*-Test	
Date	**Control**	**Prune**	**Control**	**Prune**	**Prob.**	**Test**
	cm		*cm*			
Feb-87	199.9	206.6	35.5	33.9	0.55	Equal-Variance *t*-test
Aug-87	232.4	254.0	35.2	34.3	0.08	Mann-Whitney *U*
Aug-88	271.5	295.8*	41.8	46.5	0.05	Mann-Whitney *U*
Aug-89	287.1	322.8*	48.9	51.9	0.01	Mann-Whitney *U*
Sep-90	293.0	331.0*	59.1	54.4	0.01	Mann-Whitney *U*
Aug-93	372.2	403.2	59.9	70.0	0.14	Equal-Variance *t*-test
Jul-95	439.0	462.5	74.3	69.3	0.30	Mann-Whitney *U*

*Means are significantly different, $P \leq 0.05$

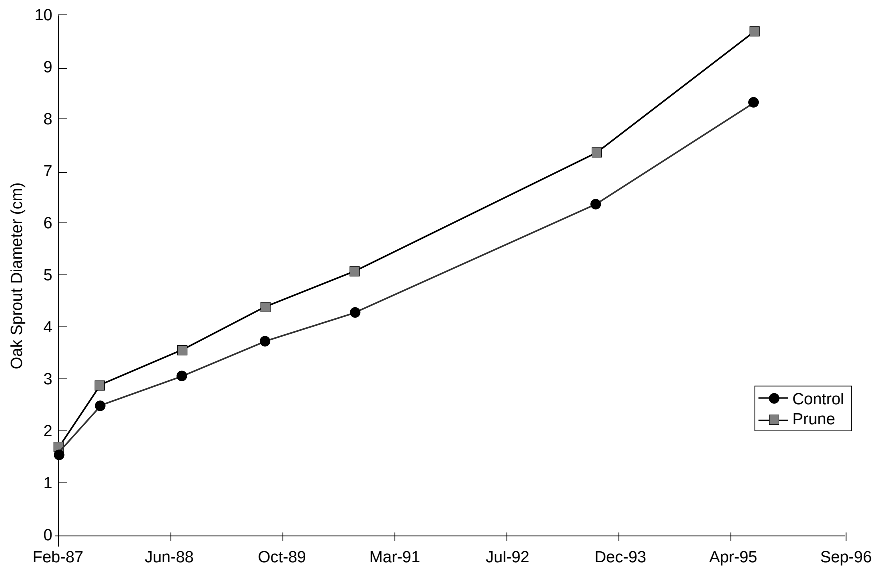

Figure 1—Diameter of oak sprouts from pruned vs. unpruned (control) stumps.

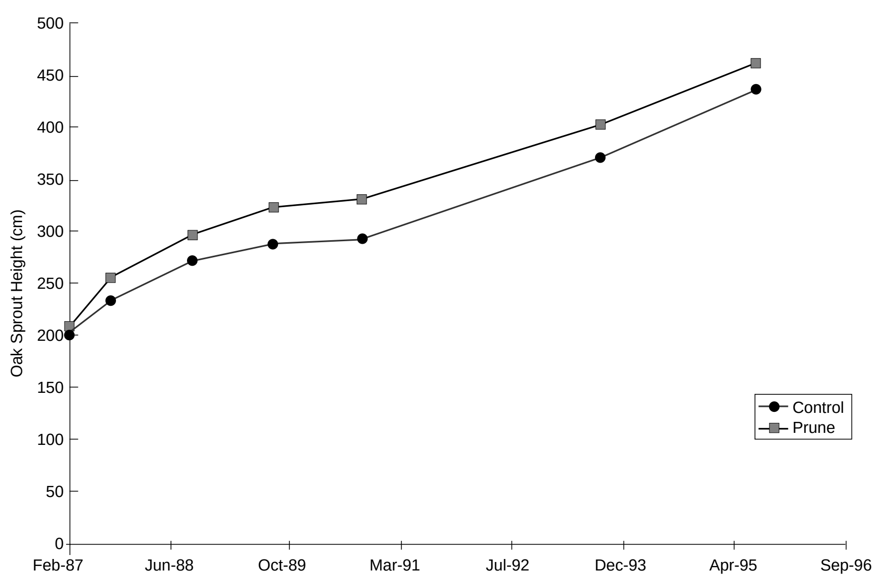

Figure 2—Height of oak sprouts from pruned vs. unpruned (control) stumps.

unpruned trees. *Figures 1* and *2* illustrate the diameter and height growth rate, respectively, of sprouts from pruned vs. unpruned stumps.

The initial hypothesis of this study was that pruning the regrowth of harvested oaks so that only two dominant sprouts persisted would improve the growth rate of the dominant sprouts and develop into a viable oak tree more quickly. After the first season of growth following the pruning, we observed that the sprouts from pruned stumps had larger diameters than those from unpruned stumps. After two growing seasons, similar observations were made in regard to height. Since these initial increases, however, the growth between the pruned and unpruned groups has been very similar. When considering differences in growth rates of sprouts from pruned versus unpruned stumps over an 8-year period, it seems that the additional growth achieved by pruning is relatively small and not worth the effort expended.

References

Nintze, Jerry. 1995. **NCSS 6.0 user's guide.** Kaysville, UT: Number Cruncher Statistical System.

Standiford, Rick B.; McCreary, Douglas; Gaertner, Sheila; Forero, Larry. 1996. **Sustainability of firewood harvesting on hardwood rangelands.** California Agriculture. 50(2): 7-12.

Assessment of a Prescribed Burning Project: 1987–1995[1]

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Abstract: *A multiple objective vegetation management program was initiated in 1986 to improve livestock management and provide an anchor for a community fuelbreak system. Burn preparation activities and the prescribed burn greatly reduced woody vegetation canopy cover in areas where the initial canopy cover was dense. Primary reductions were from removal of the shrub component and interior live oak (*Quercus wislizenii*). Blue oak (*Quercus douglasii*) and valley oak (*Quercus lobata*) were largely unaffected, partially because of their occurrence in areas of less dense vegetation and lower canopy cover than those where interior live oak was found.*

A multiple objective vegetation management program was initiated in 1986 to improve livestock management and provide an anchor for a community fuelbreak system through manipulation of woody vegetation on the Ellis Ranch near North Fork, California. A 600-acre burn was conducted in 1987 through the California Department of Forestry's Vegetation Management Program with the goal of reducing the canopy cover of woody plants and the fuel volume. Accomplishment of these goals would increase accessibility to the land for the livestock producer, resulting in increased efficiency and effectiveness in livestock management, and provide an area for fire suppression activities to be successful in stopping a wildfire before it reached the community.

Study Area

The Ellis Ranch is located two miles southwest of North Fork on Road 200, Madera County, California. The ranch ranges from 2,500 to 3,250 feet in elevation and receives an average of 32 inches of precipitation annually. Three soil series are present on the ranch: Ahwahnee (*Mollic Haploxeralf*); Auberry (*Ultic Haploxeralf*); and Holland (*Ultic Haploxeralf*). The vegetation is mixed chaparral and oak with an understory of annual herbaceous plants. Dominant woody species include blue oak (*Quercus douglasii*), interior live oak (*Quercus wislizenii*), valley oak (*Quercus lobata*), foothill pine (*Pinus sabiniana*), wedgeleaf ceanothus (*Ceanothus cuneatus*), mariposa manzanita (*Arctostaphylos mariposa*), western mountain mahogany (*Cercocarpus betuloides*), western redbud (*Cercis occidentalis*), and California coffeeberry (*Rhamnus californica*).

Methods

In 1986 a Vegetation Management Program project was entered into by Walter Ellis and the California Department of Forestry. In summer 1987 approximately 600 acres of the Ellis Ranch, and neighboring ranches, were burned. Pre-burn preparation was conducted, consisting of crushing brush and interior live oak using a D-4 bulldozer, felling of selected foothill pine, and selective cutting of interior live oak for firewood.

Six 0.20-acre plots were established in 1986. These reflect each of the different canopy cover–slope class designations present in the project area, as described by Passof and others (1985). The classes present during the period of this study were:

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Class designation	*Slope*	*Canopy cover*	*Predominant tree species*
	pct	*pct*	
C	<30	26 - 40	Blue oak, valley oak
E	<30	41 - 60	Blue oak, valley oak
GG	<30	>60	Interior live oak
HH	>30	>60	Interior live oak

Each plot was sampled in 1986 before the burn preparation work had begun, in July 1987 after completion of burn preparation, in October 1987 following the August burn, in November 1988 and 1989, and again in November 1995. Each tree more than 4 inches d.b.h. was measured and heights estimated with a clinometer. Hardwood tree volume was determined using equations developed by Pillsbury and Kirkley (1984). Canopy cover was measured through the use of the line intercept method (Canfield 1941) on ten 92.5-foot transects randomly located in each plot beginning along the northeast boundary of the plot. Analysis of variance was conducted for the canopy cover measurements to determine whether a significant change had occurred among the sampling dates (Little and Hills 1978). All seedlings within each plot were counted.

Results and Discussion

Plot 1

At the beginning of the project, the site description for this plot was "HH", i.e., the area had greater than 30 percent slope and more than 60 percent canopy cover of predominately interior live oak. At the final sampling date the site was still classified as "HH" although much of the canopy cover was composed of yerba santa (*Eriodictyon californicum*), rather than predominately interior live oak.

The total canopy in 1986 was dominated by interior live oak with a fairly large blue oak component. Small amounts of other species were present, including foothill pine, mariposa manzanita, western mountain mahogany, California coffeeberry, and wedgeleaf ceanothus (*table 1*). Total canopy cover and interior live oak canopy cover were significantly reduced by pre-burn preparation. The selective crushing of interior live oak was also evident from the resulting piles which occupied 39 percent of the area upon completion of the preparation work.

Table 1—Canopy cover of woody vegetation in Plot 1.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	Post-burn 1988	Post-burn 1989	Post-burn 1995
	pct					
Interior live oak	69a[1]	31b	6c	10c	13c	34b
Blue oak	15a	15a	3b	1b	10a	2b
Mariposa manzanita	3	1	0	0	0	0
Western mountain mahogany	3	2	0	0	0	0
Foothill pine	2	1	0	1	0	0
California coffeeberry	2	0	0	0	0	0
Wedgeleaf ceanothus	0	1	0	1	0	5
Yerba santa	0	0	0	3	7	26
Total canopy cover	94a	51b	10d	14cd	30c	66b

[1]Values in a row followed by a different letter were significantly different, $P > .05$

Burning also significantly reduced the total canopy cover. Both blue oak and interior live oak were significantly reduced as trees were killed, but left standing. In addition, the small shrub component was eliminated. Blue oak canopy in 1989 had returned to a level similar to that at the beginning of the study because of stump sprouting from the trees removed. By 1995 the blue oak canopy was significantly reduced because of mortality of the sprouts. Interior live oak canopy has increased to 34 percent from a low of 6 percent (*table 1*). These sprouts are increasing in size and are anticipated to recover to previous canopy cover levels.

Before preparation activities there were 40 interior live oak stems in the plot containing 1.21 cords of wood. Only seven were left following the burn preparation work, reducing the volume (*table 2*). All seven of these stems survived the burn but were subsequently removed by wood cutters in 1989. In contrast, all five blue oak trees in the plot were left untreated during the preparation work and remained standing following the burn. Blue oak wood volume was 2.57 cords at all sampling dates through 1988 (*table 2*). All blue oaks were removed by wood cutters during fall 1989.

Table 2—Volume of wood in Plot 1.

Tree species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	1988	1989	1995
	cords					
Interior live oak	1.21	0.72	0.72	0.72	0.00	0.00
Blue oak	2.57	2.57	2.57	2.57	0.00	0.00

Plot 2

The site designation for Plot 2 was "C" at both the beginning and end of the project, i.e., slope under 30 percent and canopy of 26 to 40 percent, predominately blue oak. Total canopy cover in 1986 was 33 percent (*table 3*) , composed largely of blue oak and interior live oak. No preparation work was conducted in Plot 2 and thus the canopy cover was similar in the second sampling. After the burn, the canopy cover was virtually identical to the cover in the initial sampling, with the exception of the removal of poison oak. No significant changes in canopy cover occurred in this plot during the period of the study.

Table 3—Canopy cover of woody vegetation in Plot 2.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	1988	1989	1995
	pct					
Interior live oak	10	5	6	1	2	3
Blue oak	23	23	24	29	22	23
Wedgeleaf ceanothus	0	2	1	3	2	0
Poison oak	0	2	0	0	0	0
Mountain mahogany	0	0	0	0	1	0
Total canopy cover	33	32	31	32	28	26

All trees present in 1986 were unchanged following the burn. The tree stand consisted of four interior live oaks and five blue oaks. Total wood volume has not significantly changed over the 9 years (*table 4*).

Table 4—Volume of wood in Plot 2.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	Post-burn 1988	Post-burn 1989	Post-burn 1995
	cords					
Interior live oak	0.15	0.15	0.15	0.15	0.15	0.15
Blue oak	2.56	2.56	2.56	2.56	2.56	1.83

Plot 3

Plot 3 was classified as an "E" site at the beginning of the study, with less than 30 percent slope and between 41 and 60 percent canopy cover, predominately blue oak. Blue oak composed the vast majority of the canopy cover in 1986, with small amounts of interior live oak, mariposa manzanita, wedgeleaf ceanothus, and foothill pine (*table 5*). Burn preparation work left the blue oak and removed most of the other four species. Burning significantly reduced the total canopy cover to 35 percent with all shrub species being removed. By the end of the project the site was classified as "C" as the total canopy cover had been reduced to 29 percent.

Table 5—*Canopy cover of woody vegetation in Plot 3.*

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	Post-burn 1988	Post-burn 1989	Post-burn 1995
	pct					
Interior live oak	5	0	0	0	0	0
Blue oak	37	40	35	35	28	35
Mariposa manzanita	4	0	0	0	0	1
Wedgeleaf ceanothus	1	0	0	0	0	0
Foothill pine	0	0	0	0	0	1
Total canopy cover	47a[1]	40ab	35b	35b	29b	37b

[1]Values in a row followed by a different letter were significantly different, $P > 0.05$

All trees within the plot were left standing, a volume of 0.80 cords of blue oak (*table 6*). The interior live oak reflected in the canopy cover were trees rooted outside the plot whose canopy partially covered the plot area. These were not included in the wood volume determination. In addition, the lone digger pine was left standing.

Table 6—Volume of wood in Plot 3.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	Post-burn 1988	Post-burn 1989	Post-burn 1995
	cords					
Blue oak	0.80	0.80	0.80	0.80	0.80	0.82

Plot 4

Plot 4 typifies the situation where the slope was gentle (<30 percent) and canopy cover was dense (>60 percent), classified as "GG." At the beginning of the project, the canopy cover was 100 percent, primarily interior live oak (80 percent), with foothill pine, California bay (*Umbellularia californicum*), western redbud, and California coffeeberry comprising the remainder (*table 7*). The majority of shrubs were mature plants, in mostly unavailable form. Burn preparation work reduced the canopy cover to 86 percent, with the reduction largely due to removal of interior live oak. The western redbud canopy increased significantly because of a unique situation in which the plants were shifted off vertical to an approximate 45-degree angle by the bulldozer, yet remained rooted and growing. The prescribed burn eliminated both the interior live oak and all of the shrub component, with only the foothill pine remaining to make up all of the 11 percent canopy cover.

Table 7—Canopy cover of woody vegetation in Plot 4.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	Post-burn 1988	Post-burn 1989	Post-burn 1995
			pct			
Interior live oak	80a[1]	39b	0d	30b	15c	26b
Western redbud	2c	18a	0c	6bc	14ab	15a
California coffeeberry	1	0	0	0	0	0
Foothill pine	15a	18a	11a	9a	0b	0b
California bay	7ab	11a	0c	2bc	0c	9a
Wedgeleaf ceanothus	0c	0c	0c	0c	6b	43a
Yerba santa	0	0	0	1	2	0
Total canopy cover	100a	86b	11d	48c	39c	93a

[1]Values in a row followed by a different letter are significantly different, $P > 0.05$

In 1989, 2 years following the burn, the canopy cover had increased to 39 percent, a mixture of interior live oak (15 percent), western redbud (14 percent), wedgeleaf ceanothus (6 percent), and yerba santa (2 percent). The age class of the community had changed dramatically from the beginning of the project, with interior live oak present only as sprouts, and the shrubs as all young plants and all available to browsing animals. Almost all shrubs exhibited little evidence of browsing. An exceptionally large number of seedlings were present for yerba santa (187) where no plants had been detected before this sampling.

In 1995, 8 years after the burn, total canopy cover was similar to the pre-project situation (93 percent). The makeup of the canopy was changed, with interior live oak comprising 26 percent, wedgeleaf ceanothus 43 percent, western redbud 15 percent and California bay 9 percent. This area has shifted from a tree-dominated canopy to a largely shrub-dominated canopy. The plants present are primarily mature plants with the exception of western redbud, which has an even mix of young and mature plants. The large number of seedlings of yerba santa present in 1989 did not persist to the 1995 sampling.

There have been no interior live oak trees recruited into the stand from seedlings, although 88 seedlings were present in the pre-project sampling, 22 in the post-preparation sampling, and two in 1989. The volume of wood in Plot 4 (determined for trees more than 4 inches d.b.h.) was reduced significantly, from 2.14 cords in the pre-project sampling, to 1.3 cords following preparation work, and 0 cords following the burn which removed all interior live oaks greater than 4 inches d.b.h. (*table 8*).

The site was still classified as "GG" at the end of the study, as the total canopy cover was returned to 93 percent from a low of 11 percent after the 1987 burn.

Table 8—Volume of wood (in cords) in Plot 4.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	Post-burn 1988	Post-burn 1989	Post-burn 1995
	cords					
Interior live oak	2.14	1.30	0.00	0.00	0.00	0.00

Plot 5

Plot 5 is an example of an area with less than 30 percent slope and canopy cover dominated by large trees (valley oak), classified as "E" at both the beginning and end of the study. Total canopy cover at the beginning of the project was 58 percent, primarily valley oak (45 percent) and interior live oak (11 percent), with a small shrub component of California wild rose (*Rosa californica*) (2 percent) (*table 9*). The canopy cover has changed little over all phases of the project and through the 8 years after the burn. The valley oak, interior live oak, and wild rose components have not changed. A small increase in total canopy cover has occurred because of the establishment of blue oak and western redbud, both contributing 1 percent canopy cover in 1995. Despite the presence of valley oak and interior live oak seedlings on three sampling dates, none was successful in establishing.

Table 9—Canopy cover of woody vegetation in Plot 5.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	Post-burn 1988	Post-burn 1989	Post-burn 1995
	pct					
Interior live oak	11	10	10	9	11	10
Blue oak	0	1	1	1	1	2
Valley oak	45	46	44	43	47	45
Western redbud	0	2	0	1	1	2
California wild rose	2	3	0	4	3	5
Total canopy cover	58	62	55	58	63	64

The plant community in Plot 5 has been largely unchanged and is typical of areas in which the canopy was either sparse or dominated by a few large, well-spaced oaks. The only fluctuation was elimination of seedlings (63 wild rose, 3 poison oak) by the burn. Seedlings of shrub species were not found at any sampling dates after the burn. The volume of wood present in Plot 5 did not change over the 8-year period, but was a steady 2.3 cords throughout (*table 10*).

Table 10—Volume of wood in Plot 5.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	1988	1989	1995
	cords					
Valley oak	2.30	2.30	2.30	2.30	2.30	2.30

Plot 6

Plot 6 was designated as a "C" site at all sampling dates. It had a slope less than 30 percent and canopy cover of 26-40 percent dominated by valley oak. No preparation work was conducted in Plot 6, and canopy cover remained constant over the entire project period (*table 11*). No trees were removed, and the volume for the large (30+ inch d.b.h., 75 feet tall) valley oak was 5.14 cords at all sampling dates (*table 12*). No shrubs were present at any time.

Table 11—Canopy cover of woody vegetation in Plot 6.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	1988	1989	1995
	pct					
Blue oak	0	1	1	0	2	2
Valley oak	32	30	31	31	29	33
Foothill pine	1	2	2	3	5	4
Total canopy cover	33	33	34	34	36	39

Table 12—Volume of wood in Plot 6.

Species	Pre-project 1986	Post-preparation 1987	Post-burn 1987	1988	1989	1995
	cords					
Valley oak	5.14	5.14	5.14	5.14	5.14	5.14

Summary

Areas dominated by interior live oak were those most affected by the project. On sites where deciduous oaks (blue or valley oak) were dominant, there was a lesser effect, primarily because of the larger spacing between trees. Pre-burn preparation work, where conducted, greatly impacted the vegetation. In general, total overstory canopy cover was reduced by the preparation activities where initial canopy cover was >60 percent, largely due to removal of interior live oak and selected shrubs by crushing and firewood cutting. Total wood volume was reduced by these same means. These activities also changed the species composition as interior live oaks were felled and crushed while blue oaks and valley oaks were avoided. The age and form class of the shrub component was shifted from predominately mature or decadent and largely unavailable before the project, to seedling or young plants and mostly available following the preparation work. Shrub numbers and canopy cover were decreased. The disturbance of the preparation activities stimulated tree seedling establishment.

The burn had little effect on total canopy cover overall, consuming piles created during the preparation work and opening up the area. Burning did not greatly affect species composition, though some shrubs were eliminated and all seedlings were destroyed. Fuelwood volume was not affected. Seedling numbers were greatly affected by the project. In general, blue oak, interior live oak, and valley oak seedling numbers decreased. The most dramatic changes were increases in yerba santa and wedgeleaf ceanothus. In one half of the plots these species were non-existent in the initial inventory, whereas 2 years after the burn, large numbers of seedlings were present and some had already grown to be classified as young plants. In these areas these species now make up about one half of the total canopy cover.

Eight years following the burn the total canopy of the burn area is similar to the pre-project inventory in many areas. Those which had an initially large canopy cover (>60 percent) had a significant reduction after the burn (with the exception of the valley oak dominated area), but the canopy cover has increased to near pre-project levels. The composition of the community has changed, with the shrub component replacing a large amount of the canopy formerly occupied by trees. In the areas which had an initial canopy cover of about 40 percent or less, there has been little change in total canopy or the makeup of the canopy over the 8-year period.

References

Canfield, R.H. 1941. **Application of the line interception method in sampling range vegetation.** Journal of Forestry 39: 388-394.

Little, Thomas M.; Hills, F. Jackson. 1978. **Agricultural experimentation**. New York: Wiley and Sons; 350 p.

Passof, P.C.; Clawson, W.J.; Fitzhugh, E.L. 1985. **Preliminary guidelines for managing California's hardwood rangelands.** Publication 21413. Berkeley, CA: Division of Agriculture and Natural Resources, University of California; 92 p.

Pillsbury, N.H.; Kirkley, M.L. 1984. **Equations for total wood, and saw-log volume for thirteen California hardwoods.** Research Note PNW-414. Portland, OR: Pacific Northwest Forest and Range Experiment Station, U.S. Department of Agriculture; Forest Service; 52 p.

Acorn Collection, Storage, Sorting, and Planting for the Establishment of Native Oaks Without Supplemental Irrigation[1]

Ronald W. Motz[2]

Advantages of Direct Seeding and Importance of the Taproot

Although the most common method of planting oaks is from containerized seedlings, direct seeding of acorns into the landscape produces clearly superior trees. The root system develops naturally without the twisting, girdling, or spiraling that often occurs in traditional containerized seedlings. Most important, the taproot grows at its natural rate without any premature termination or damage. The taproot is able to penetrate deeply to the water source while also providing a firm anchor to the seedling and food storage to help ensure survival. The taproot grows from the end (apical meristem), and once it is exposed to air or damaged, as is inevitable in traditional containers, it *never regenerates* (although multiple replacement roots usually form at the point of injury.) A seedling without a taproot will have less chance of survival without supplemental irrigation since it will never develop the root system nature intends for it to successfully adapt to the planting site.

Direct seeding of acorns is often discouraged because growers expect poor germination rates and a high loss of planted acorns to rodents. These problems are eliminated with careful selection and storage of acorns and the use of newly available low-cost tree shelters to protect the seed and growing seedling in the ground. The seed-handling method described below has been shown in numerous settings to produce germination rates >95 percent. When used with the appropriate tree shelters, a high rate of healthy vigorous saplings with strong natural root systems will result. While other planting strategies may be effective in some circumstances, results will be less predictable, and more follow-up and maintenance may be required.

Collection of Acorns

Yearly weather patterns and geography affect when acorns are ripe for harvest. Acorns are ready when the caps are removed easily without damage to the acorns. Usually when acorns start dropping to the ground, most of the acorns remaining on the tree are ripe. Acorns may be picked directly from the tree when they are ripe. The freshest seeds are collected this way. Seeds may also be gathered from the ground. Choose the acorns that are green or dark brown. Light brown color usually indicates that the acorns have been on the ground longer and are more likely to have become dehydrated. Select the largest acorns, and avoid those with obvious cracks, holes, or damage from rodents or worms, and those that feel unusually light or hollow.

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Collect acorns as close to the proposed planting site as possible, preferably within 25 miles, and within 500 feet of the planting site's elevation. Maintain a broad genetic base by choosing individual trees sufficiently separated to avoid collection from closely related individuals (Lippitt 1991). Keep a record of the specific trees or groves from which the acorns were collected. Note the date and exact location and species of the trees. These notes, perhaps supplemented with photos made in the field, can help locate the trees in future years. Avoid purchasing seeds when the specific collection site is not known.

The harvest time can vary, plus or minus 1 to 4 weeks, from year to year, based on yearly weather changes. Oak trees in the wild can have unpredictable reproduction patterns, with some trees producing an acorn crop only once every 3 to 5 years and others producing only a handful of acorns. However, trees in parks or trees that have received supplemental watering can produce a crop each year. These trees often produce the largest acorns, with the most predictable crop.

Controlled studies have shown that larger acorns produce bigger seedlings faster (Tecklin and McCreary 1991). A larger seed has more cotyledon to feed the radicle and rapidly growing root system. The seed is still supporting root growth long after the root has started to branch. Plants increase on the basis of their present size because of the geometric rate of cell division, and therefore a larger seed produces more cells faster. Larger acorns produce better seedlings both in the nursery setting and with direct seeding into the landscape, but using the largest available acorns is especially crucial in wildland planting where growing conditions will be less controlled. The early advantage of more stored food for the emerging seedling may be critical to early seedling survival.

Storage of Acorns

Direct seeding from the tree into the landscape is the best planting method. But where this is not practical, because the planting site is remote from the source of acorns, or there is insufficient ground moisture to ensure successful germination at the time of harvesting, storage of the acorns is necessary. The primary goal of storage is to reduce the metabolic activity (i.e., keep the seed dormant) and maintain the health and vigor of the acorn until planting time. Proper storage technique is essential to *maintain metabolic inactivity*. It is preferable to keep the radicle from emerging, even inside the shell, until the acorn is planted in the soil. If the radicle emerges during storage, the roots will continue to twist as the acorn is repositioned in storage and in planting. The acorn is perishable, and the other goals of storage are to prevent the acorns from drying out, becoming moldy, or freezing. Some oak species require a cold wet storage period (stratifying) to simulate winter conditions and allow germination.

Do not wash or soak acorns before storage, as the water and room temperature will start the germination process. Freshly harvested acorns should be stored at 33-41 °F as soon as possible. A home refrigerator is adequate; however, the temperature will vary greatly within each appliance. Use a thermometer to check for the coldest spot. *The temperature should not reach freezing*. For larger quantities, commercial cold storage facilities are preferred, since the temperature will be maintained continuously within 1-2 degrees of the ideal. Longer storage of 3 to 4 months can be successfully achieved this way, but temperature closer to 33 °F is important for long-term storage.

The easiest way to store acorns is in 1-gallon zip-lock-type plastic bags. Fill them only *half full* with acorns. Add a handful of dry peat moss. Peat moss is slightly acidic, which inhibits bacterial growth, and it absorbs excess moisture given off by the acorns, which helps prevent mold growth. *Do not seal the bags*.

Leave them completely open, and lay them on their sides to allow air circulation so the acorns do not become moldy.

Planting of the acorns should be scheduled once the ground has been saturated with substantial rain. Acorns will thus be stored for 1 to 2 months at most.

Once the radicle has emerged, the acorn is already past the optimum opportunity for successful planting, since the tap root, which grows from the end (apical meristem), may be damaged when exposed to air. If the acorn is to be planted at this point, the radicle must be kept moist and the acorn planted as soon as possible. However, if the tip of the radicle is discolored or damaged, the acorn should be discarded.

Sorting

Seeds should be sorted after an initial storage period and immediately before planting. Seeds can be sorted for size by eye or mechanically, by weight or by screen.

No more than a few days before scheduled planting, remove the desired quantity from cold storage and place them in a plastic bucket filled with cold water. Soak the acorns for a few hours. The unhealthy seeds will float, and the solid seeds will sink to the bottom. Discard the "floaters." Drain the remaining healthy acorns, and dry them on newspaper about 1 hour at room temperature before replacing them in the bags. Place a handful of new peat moss in the bag with them, and store as described above, but this time for no more than a few days.

If the available crop of healthy acorns is inadequate, an alternative soaking method may rehydrate some "floaters," that would otherwise be considered inferior. After the soaking and separation described above, re-soak the "floaters", changing the water every 12 hours. Retrieve the acorns that sink, and continue soaking the remaining "floaters" until no more acorns sink. Drain and store any salvaged acorns as described above. Sometimes even seeds with obvious damage from insects or rodents can be salvaged, but it is important that the apex of the acorn (i.e., the end opposite from the cap) not be damaged.

Preparation for Planting

Remove from storage only enough acorns for a day's planting. Maintain the acorns at a cold temperature at all possible times. Keep the acorns cool while transporting them to the planting site, for example, by using an ice chest. *Never leave the acorns unrefrigerated for more than a few hours*. Any acorns that are not planted that day should be refrigerated again until the next planting time.

Planting: Direct Seeding into the Landscape

Once autumn rain has fallen and the ground moisture is sufficient, *time is of the essence*. Sowing the acorns as early as possible is *extremely* important (McCreary 1990). The taproot must penetrate to levels where moisture will be present the following summer. Plant only 1 acorn per hole, no more than 1 inch deep with 1 inch of soil covering the seed above ground level. Planting acorns too deep in soil with poor drainage may result in the newly emerged radicle being flooded or deprived of oxygen and may make it difficult for the shoot to grow through the soil. The use of a low-cost tree shelter is recommended, for protection and enhanced growth.

If the first winter's rainfall totals have been below normal, partial top-pruning of the seedlings may be beneficial (McCreary and Tecklin 1993). This should be done before summer approaches to decrease transpiration of moisture through the leaves and conserve the limited available ground moisture. Where feasible because the extent of the planting is limited and the site is accessible, supplemental watering will accelerate growth. However, if acorns are stored properly and the above procedures are followed, establishment of trees from acorns is extremely successful even without supplemental watering.

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References

Lippitt, L. 1991. **Producing containerized seedlings**. Paper presented at Intermountain Nurserymen's Association meeting, August 1991.

McCreary, D. 1990. **Acorn sowing date affects field performance**. USDA Tree Planters Notes 41-2: 6-9.

McCreary, D.; Tecklin, J. 1993. **Top pruning improves field performance of blue oak seedlings**. USDA Tree Planters Notes 44-2: 73-77.

Tecklin, Jerry; McCreary, Douglas D. 1991. **Acorn size as a factor in early seedling growth of blue oak.** In: Standiford, Richard, B. Proceedings of the symposium on oak woodlands and hardwood rangeland management; October 31 - November 2, 1990; Davis, CA. Gen. Tech. Rep. PSW-126. Berkeley, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 48-53.

The Diet of California Spotted Owls in Riparian Deciduous and Oak Habitats of the Southern Sierra Nevada[1]

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Abstract: *From 1988 through 1992 we studied diets of California spotted owls (*Strix occidentalis occidentalis*) in low-elevation riparian deciduous and oak habitats in the southern Sierra Nevada. Spotted owl pellets were collected at roost sites between 300 and 685 m elevation in the Sierra and Sequoia National Forests and were examined for remnant bones, feathers, and insect exoskeletons. Remains of 664 individual prey were found. Mammals comprised 70.0 percent of prey frequency and 96.5 percent of prey biomass. The remainder consisted of birds (4.8 percent of prey frequency and 3.4 percent of prey biomass) and insects (25.2 percent of prey frequency and 0.1 percent of the prey biomass). Woodrats (*Neotoma *spp.) were the primary prey, accounting for 79.5 percent of the biomass. Pocket gophers (*Thomomys *spp.), the only other prey representing more than 5 percent of the biomass, comprised 11.0 percent of the biomass. A larger proportion of pocket gophers, voles, and insects and a smaller proportion of woodrats, mice, and birds were taken in the breeding period than in the nonbreeding period.*

Diet studies of the California spotted owl in the Sierra Nevada of California have focused on mixed-conifer habitats (Laymon 1988, Marshall 1942, Thrailkill and Bias 1989, Verner and others 1992). Preliminary results from our study were the first reported diets from all seasons for California spotted owls in riparian deciduous and oak habitats of the Sierra Nevada (Verner and others 1992). This paper describes diets of California spotted owls in low-elevation riparian deciduous and oak habitats of the southern Sierra Nevada and summarizes diets in breeding and nonbreeding periods.

Study Area

The study area of approximately 90 km^2 was located on the Sierra and Sequoia National Forests in Fresno County, California, 34 km east of Fresno. The dominant vegetative types were digger pine-oak, blue oak savannah, and low-elevation riparian deciduous habitats (Verner and Boss 1980). Spotted owls were usually located in riparian deciduous or oak habitats between 300 and 685 m elevation.

Methods

Pellets were collected at spotted owl nest and roost locations from February 1988 through October 1992. Pellets were grouped by period of deposition: breeding period included pellets egested from March 1 through August 31, and nonbreeding period included pellets egested during the remainder of the year. Pellets collected at the same site on the same day or within several days were combined into one sample (Forsman and others 1984). Pellets were dissected and components identified using a magnifying lamp and a dissecting microscope. Skeletal remains, feathers, and pieces of exoskeletons were used to identify prey items. A Carnegie Museum of Natural History specimen collection and other

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references and keys (Borror and DeLong 1964, Burt and Grossenheider 1976, Dunning 1984, Forsman and others 1984, Ingles 1990, Jameson and Peeters 1988, Robbins and others 1983, Swan and Papp 1972) were used to identify prey and estimate mean weights. The number of individual mammals and birds per sample was obtained from the largest number of skulls or identical bone structures for each prey taxon. The number of insects was obtained from either the largest number of paired mandibles or the largest number of legs divided by six. Biomass was calculated by multiplying observed frequency of each taxon by its estimated mean weight. Prey frequency and biomass were summarized for breeding and nonbreeding periods.

Results

We collected and analyzed 520 pellets. Sampling intensity varied between sites, seasons, and years. At each of four sites, 76-184 pellets were collected. The remaining seven sites accounted for 31 or fewer pellets each. At five sites sampling was limited to either the breeding or the nonbreeding period. Almost half (239) of the pellets were collected in the breeding period of 1989 and the nonbreeding period of late 1989 and early 1990.

We identified 664 prey items. Identification to species of all prey items was not possible because remains were incomplete. At least 20 species (nine mammals, six birds, and five insects) were present (*table 1*). Mammals comprised 70.0 percent of all prey and 96.5 percent of the biomass. Large prey (greater than 100 g) represented 48.5 percent of the prey and 91.8 percent of the biomass. Woodrats contributed the most biomass to owl diets, followed by pocket gophers (*table 2*). Mice (mostly *Peromyscus* spp.), birds, voles (*Microtus* spp.), moles (*Scapanus latimanus*), insects, and shrews (*Sorex* spp.) accounted for the remainder of the biomass. Other owl species (western screech owl, *Otus kennicotti*; northern saw-whet owl, *Aegolius acadicus*; and unidentified owls) and western scrub-jays (*Aphelocoma californica*) were the most numerous birds identified (*table 1*). Insects comprised 25.2 percent of the prey but accounted for only 0.1 percent of the biomass (*table 2*).

The percent frequency and percent biomass of woodrats, mice, and birds decreased and those of pocket gophers and voles increased in spotted owl diets from the nonbreeding period to the breeding period (*table 3*). The difference in percent biomass between periods was greatest for pocket gophers, followed by woodrats. Insects exhibited the largest percent frequency change between periods, increasing in the breeding period, but percent biomass remained less than 0.2 percent for each period.

Discussion

Large prey dominated the diet of California spotted owls in this study. Combining pellets for analysis, as done here, provides a conservative estimate of the proportion of large prey (Marti 1987); thus, large prey numbers may have been underestimated. Although a variety of prey were taken, woodrats (79.5 percent of the biomass) and pocket gophers (11.0 percent of the biomass) were the primary prey. These values agreed with the observations of Verner and others (1992) that California spotted owls generally rely on one to four prey species groups for at least 85 percent of the diet biomass, and in the Sierra Nevadan foothills and throughout southern California the diets are composed of 79 to 97 percent woodrats by biomass. Maximizing the desired prey species for spotted owls in the oak woodlands may require different management techniques than used in the mixed-conifer forests. In conifer habitats, the primary prey

Table 1—Number, percent, mean weight, and cumulative percent biomass of 664 prey items identified in 520 California spotted owl pellets.

Categories Common name	Taxon	Number	Percent of total (664)	Mean weight	Cumulative percent biomass
				g	
Woodrats					
Bushy-tailed woodrat	*Neotoma cinerea*	1	0.2	327.5	0.4
Dusky-footed woodrat	*Neotoma fuscipes*	221	33.3	271.0	69.4
Woodrat	*Neotoma* spp.	31	4.7	271.0	9.7
Gophers					
Botta's pocket gopher	*Thomomys bottae*	22	3.3	155.5	4.0
Pocket gopher	*Thomomys* spp.	39	5.9	155.5	7.0
Mice					
Mouse	*Peromyscus* spp.	110	16.6	29.5	3.8
Calif. pocket mouse	*Perognathus californicus*	2	0.3	18.5	< 0.1
Pocket mouse	*Perognathus* spp.	1	0.2	18.5	< 0.1
Jumping mouse	*Zapus* spp.	1	0.2	22.5	< 0.1
Voles					
California vole	*Microtus californicus*	2	0.3	53.5	0.1
Vole spp.	*Microtus* spp.	22	3.3	53.5	1.4
Moles					
Broad-footed mole	*Scapanus latimanus*	2	0.3	56.0	0.1
Shrews					
Shrew spp.	*Sorex* spp.	2	0.3	7.5	< 0.1
Other Mammals					
Unknown mammal	Class Mammalia	2	0.3	157.4	0.4
Unknown small mammal	Class Mammalia	7	1.1	20.0	0.2
Birds					
Spotted towhee	*Pipilo maculatus*	1	0.2	40.5	0.1
Warbler	Family Emberizidae	1	0.2	9.2	< 0.1
Western scrub-jay	*Aphelocoma californica*	9	1.4	86.4	0.9
Woodpecker	Family Picidae	1	0.2	66.2	0.1
Northern saw-whet owl	*Aegolius acadicus*	1	0.2	82.8	0.1
Western screech owl	*Otus kennicotti*	3	0.5	150.0	0.5
Unknown owl	Family Strigidae	3	0.5	127.6	0.4
Unknown avian	Class Aves	13	2.0	86.1	1.2
Insects					
Grasshoppers	Order Orthoptera	2	0.3	1.0	< 0.1
Crickets	Family Gryllacrididae	1	0.2	1.0	< 0.1
Jerusalem cricket	*Steropelmatus* spp.	28	4.2	1.0	< 0.1
Beetles	Order Coleoptera	2	0.3	2.0	< 0.1
Scarab beetles	Family Scarabaeidae				
	Plecoma tularencus	11	1.7	1.0	< 0.1
Long-horned beetle	Family Cerambycidae	1	0.2	2.0	< 0.1
Long-horned beetle	*Ergates* spp.	3	0.5	2.0	< 0.1
Long-horned beetle	*Prionus* spp.	11	1.7	2.0	< 0.1
	Order Hymenoptera				
Ants	Family Formicidae	100	15.1	0.05	< 0.1
Unknown insect	Class Insecta	8	1.2	1.0	< 0.1

Table 2—Summary of spotted owl diets by prey categories for all seasons.

	Individual prey items		Biomass	
	Number	Percent	Total	Percent
			g	
Woodrats	253	38.1	68,619.5	79.5
Gophers	61	9.2	9,485.5	11.0
Mice	114	17.2	3,323	3.9
Voles	24	3.6	1,284	1.5
Moles	2	0.3	112	0.1
Shrews	2	0.3	15	< 0.1
Other	9	1.4	454.8	0.5
Birds	32	4.8	2,928.4	3.4
Insects	167	25.2	89	0.1
Total	664	100.1	86,311.2	100.0

Table 3—Percent frequency and percent biomass of prey in California spotted owl pellets.

	Nonbreeding period[1]		Breeding period[2]	
	Percent of individuals	Percent biomass	Percent of individuals	Percent biomass
Woodrats	45.9	81.9	27.3	74.3
Gophers	7.3	7.3	11.9	18.5
Mice	24.1	4.7	7.6	2.2
Voles	2.6	0.9	5.0	2.7
Moles	0.5	0.2	0.0	0.0
Shrews	0.3	< 0.1	0.4	< 0.1
Other	1.6	0.7	1.1	0.2
Birds	6.7	4.2	2.2	1.8
Insects	11.1	0.1	44.6	0.1

[1] $n = 386$
[2] $n = 278$

species is the northern flying squirrel (*Glaucomys sabrinus*) (Verner and others 1992) or a combination of woodrats and northern flying squirrels (Laymon 1988, Thrailkill and Bias 1989) in the central Sierra Nevada. In low-elevation riparian deciduous and oak habitats of the Sierra Nevada, management for spotted owls should include managing for woodrat populations (Verner and others 1992).

Diets of spotted owls vary by season. Forsman and others (1984) reported an increase in the proportion of pocket gophers, western red-backed voles (*Clethrionomys occidentalis*), and insects in the breeding period diet of the northern spotted owl (*S. o. caurina*). Ganey (1992) generally found an increase in insects in the breeding period diets of the Mexican spotted owl (*S. o. lucida*). We also found an increase in the proportion of gophers, voles, and insects during the breeding period. However, Forsman and others (1984) found an increase in the proportion of small birds and shrews during the breeding period, whereas we found a decrease in birds during this period and only one shrew present in the pellets of each period. Our results indicating an increase in the proportion of insects in pellets collected in the breeding period may be misleading. One pellet contained approximately 100 small ants (Formicidae), the only ants found in this study. More than 90 percent of the change in percent frequency of insects between periods was due to the ants from this pellet. Although Forsman and others (1984) also reported ants in spotted owl pellets, it is possible that the ants found in this study were on a cached prey item when it was consumed, and thus may not represent prey items but rather an incidental part of the diet.

It is unknown whether the differences in percentages of prey groups found in the spotted owl diet reflect selection of certain species or merely differences in prey abundance or availability. Several factors may have affected the estimation of the breeding and nonbreeding period diets. Laymon (1988) found that significant pair-to-pair differences in diets were not exceptional in spotted owls in the central Sierra Nevada in similar habitat and concluded that pooling is rarely justified. Differences in diets of breeding and nonbreeding spotted owl pairs have been documented (Barrows 1987, Thrailkill and Bias 1989). Annual differences in the diet of spotted owl pairs have been observed (Forsman and others 1984, Laymon 1988). We pooled data from all sites and years to estimate prey numbers for each period. Thus the comparison of the diets between periods should be viewed with caution. Further studies are required to examine the interplay of site, period, and annual variation in the low-elevation riparian deciduous and oak habitats of the Sierra Nevada.

References

Barrows, Cameron W. 1987. **Diet shifts in breeding and nonbreeding spotted owls**. Journal of Raptor Research 21: 95-97.

Borror, Donald J.; DeLong, Dwight M. 1964. **An introduction to the study of insects**. New York: Holt, Rinehart and Winston; 819 p.

Burt, William H.; Grossenheider, Richard P. 1976. **A field guide to the mammals**. Boston, MA: Houghton Mifflin Company; 289 p.

Dunning, John B., Jr. 1984. **Body weights of 686 species of North American birds**. Western Bird Banding Association, Monograph No. 1; 38 p.

Forsman, Eric D.; Meslow, E. Charles; Wight, Howard M. 1984. **Distribution and biology of the spotted owl in Oregon**. Wildlife Monographs 87; 64 p.

Ganey, Joseph L. 1992. **Food habits of Mexican spotted owls in Arizona**. Wilson Bulletin 104: 321-326.

Ingles, Lloyd G. 1990. **Mammals of the Pacific states.** Stanford, CA: Stanford Univ. Press; 506 p.

Jameson, E.W., Jr.; Peeters, Hans J. 1988. **California mammals.** Berkeley, CA: Univ. of California Press; 403 p.

Laymon, Stephen A. 1988. **The ecology of the spotted owl in the central Sierra Nevada, California.** Berkeley: Univ. of California; 285 p. Ph.D. dissertation.

Marshall, Joe T. 1942. **Food habits of the spotted owl.** Condor 44: 66-67.

Marti, Carl D. 1987. **Raptor food habits studies.** In: Pendelton, Beth A. Giron; Millsap, Brian A.; Cline, K.W.; Bird, D.M., eds. Raptor management techniques manual. Washington, DC: National Wildlife Federation; 67-80.

Robbins, Chandler S.; Bruun, Bertel; Zim, Herbert S. 1983. **Birds of North America.** New York: Golden Press; 360 p.

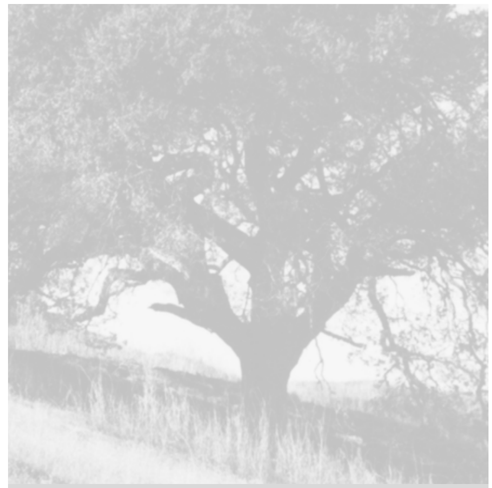
Swan, Lester A.; Papp, Charles S. 1972. **The common insects of North America.** New York: Harper and Row; 750 p.

Thrailkill, James; Bias, Michael A. 1989. **Diets of breeding and nonbreeding California spotted owls.** Journal of Raptor Research 23: 39-41.

Verner, Jared; Boss, Allan S., technical coordinators. 1980**. California wildlife and their habitats: western Sierra Nevada.** Gen. Tech. Rep. PSW-37. Berkeley, CA: Pacific Southwest Forest and Range Experiment Station, Forest Service, U.S. Department of Agriculture; 439 p.

Verner, Jared; Gutiérrez, R.J.; Gould, Gordon I., Jr. 1992. **The California spotted owl: general biology and ecological relations.** In: Verner, Jared; McKelvey, Kevin S.; Noon, Barry R.; Gutiérrez, R.J.; Gould, Gordon I., Jr.; Beck, Thomas W., technical coordinators. The California spotted owl: a technical assessment of its current status. Gen. Tech. Rep. PSW-GTR-133. Albany, CA: Pacific Southwest Research Station, Forest Service, U.S. Department of Agriculture; 55-77.

POSTER ABSTRACTS



Overview—A Bird's-Eye View of the Poster Abstracts

John M. Bryant, Technical Chair

Thirty-one posters were displayed during the symposium. These covered a wide range of topics in highly creative and informative ways. Fifteen of these are presented here as extended summary papers, 11 are presented as brief abstracts. Topics are:

Poster Abstracts

Moon Stumpff—A presentation of Native American history and philosophy in relation to methods for reconstructing the ecological past.

Berman and Bledsoe—Studies suggest that forest soil used as inoculum can increase mycorrhizal infection of the roots of valley oak seedlings.

Bledsoe and Millikin—Reports on oak root activity during the summer.

Fong, Bayer, and Schwan—Reports accelerated growth rates of coast live oak and valley oak with tree shelter vs. no shelter.

Matzner, Rice, and Richards—Found no differences in the water relations between blue oaks in regeneration and nonregeneration areas.

Montalvo, Conrad, Conkle, and Hodgskiss—Describes genetic structure, importance of cloning, and the link between the oaks' reproductive ecology and extent of genetic diversity to ensure long-term viability.

Work—Discusses seed source, reduction of annual vegetation, periods of young plant rest, and good seed soil for oak regeneration.

Connor and Joyce—A model plan for management of the hardwood rangeland at the University of California's Sierra Foothill Research and Extension Center.

Narwarth, Quinn, Roberts, and Bihari—Describes a research and restoration program for the California walnut in the Puente and San Jose Hills of eastern Los Angeles County.

Lian—Presents Pacific Gas and Electric Company's vegetation management program.

Lomas, Pillsbury, and Larson—Describes programs of various agencies and organizations to promote protection and conservation of oaks and oak woodlands throughout California.

Kruger and Thompson—A cross-sectional survey of the attitudes, beliefs, and behavior of oak woodland landowners.

Oak Woodlands and Prescribed Burning—An American Indian Perspective

Linda Moon Stumpff[1]

This poster provided historic and archeological evidence of Chumash management in oak woodlands. It presented cultural and scientific methods for reconstructing the ecological past. Cultural ecology, cultural materials, and the significance of oaks in Indian culture today were shown:

- Prescribed burning and basketry materials
- Oaks and culture
- Interpreting oak woodlands

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Effect of Forest Soil Inoculum on Mycorrhizal Root Development and Growth of Valley Oak Seedlings

Jennifer Berman[1] **Caroline Bledsoe**[1]

Ectomycorrhizae are an almost ubiquitous occurrence on trees and are known to improve the growth and nutrition of many species of tree seedlings. Little is known about the importance of ectomycorrhizal infection to the establishment, survival, and growth of California oaks. In this study a field experiment and a greenhouse experiment were carried out to assess the effects of mycorrhizal infection on valley oak (*Quercus lobata* Née) seedling growth. This information could be a valuable aid in efforts to reintroduce valley oaks to disturbed riparian areas.

In the field experiment, valley oak acorns were planted in a cleared agricultural field, where no fungal inoculum was expected to be present. Soil collected from a mature riparian valley oak forest containing abundant potential fungal inoculum was put in acorn-planting holes. Two additional treatments, one using the local agricultural field soil and one using pasteurized forest soil, were set up as controls. Six months later there were no significant differences in survival and stem height among the treatments. When seedlings were harvested 10 months later, mycorrhizal roots were found on all the treatments, though with significantly greater infection in the unpasteurized forest soil treatment than in the agricultural soil and the pasteurized forest soil treatments. Preliminary analysis shows no significant differences in root biomass among the treatments.

In a greenhouse experiment, acorns were planted in riparian forest soil, agricultural field soil, and pasteurized forest and agricultural field soils. After 6 months there were no significant differences in stem height between treatments. After 1 year mycorrhizal infection in the seedlings in the unpasteurized forest soil treatment was greater than the infection in the agricultural and pasteurized soil treatments.

These studies suggest that forest soil used as inoculum can increase percent mycorrhizal infection on valley oak seedling roots. The effect of mycorrhizal infection on growth should be evaluated in a longer-term study.

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Soil Water Potentials Provide Evidence of Hydraulic Lift and Oak Root Activity in a California Blue Oak Woodland

Caroline S. Bledsoe[1] **Catherine S. Millikin**[1]

Blue oaks (*Quercus douglasii*) and annual grasses coexist in an environment that appears to be unfavorable toward growth during hot dry summers. To see how the dry summer affects root activity, soil water potential was measured with thermocouple psychrometers at four depths (25, 50, 75, and 100 cm). Values remained relatively high (>-0.3 MPa) until late May, when soil water potential began to drop. Lowest water potentials occurred in early October, reaching mean values of -5.7, -4.7, -3.6, and -4.3 MPa for 25, 50, 75, and 100 cm, respectively.

Because root uptake decreases soil water potential below 25 cm (evaporation is minimal) and grasses senesce by June, the decreases in soil water potential suggest that oak root activity continues throughout the summer. Plots of hourly soil water potential show patterns characteristic of hydraulic lift (water transport from deep root transpiration and nocturnal water release from shallower roots). After sunrise, soil water potential decreased rapidly, presumably because of root transpiration, and, after sunset, soil water potential gradually increased, presumably because roots release water. These patterns occurred between late May and October, when soils were drier, and were observed throughout the soil profile.

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Effects of Tree Shelters on Growth Rates of Directly Seeded California Oaks

Herb Fong[1] **Robin Bayer**[2] **Joan Schwan**[2]

In 1984, Stanford University assessed ways to re-establish populations of native oaks (*Quercus agrifolia, Q. douglasii, Q. lobata*) on rural land near central campus. Consultants designed a regeneration strategy, and a local ecology organization implemented a planting and maintenance program. Techniques have been repeatedly adjusted in response to livestock grazing, drought, wildfire, and rodent predation. Since 1991 we have used tree shelters to accelerate growth and protect against predators. *Q. agrifolia* and *Q. lobata* seeded in sheltered sites have shown median growth of two and one-half to three times that of controls seeded in sites without tree shelters.

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Comparisons of Water Stress and Stomatal Conductance in Different Size Classes of *Quercus douglasii* from Different Sites

Steven L. Matzner[1] Kevin J. Rice[2] James H. Richards[1]

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Patterns of water stress and its effect on stomatal conductance were determined for different size classes of blue oak (*Quercus douglasii*), a species that is not regenerating throughout much of its range. Predawn xylem water potentials ψ_{pre} and stomatal conductance (g_s) were measured using a pressure chamber and a steady-state porometer. Measurements were made on seedlings, saplings, and adults at three sites that differed in annual precipitation and temperature extremes. Comparisons were also made between adults and seedlings from areas exhibiting regeneration (saplings present) and nonregeneration areas (only adults and seedlings present). Average ψ_{pre} values for adults, saplings, and seedlings, respectively, were -2.1, -2.9, and -3.8 MPa in 1993 and -2.7, -3.8, and -4.8 MPa in 1994. Regeneration and nonregeneration areas did not differ in ψ_{pre}. Diurnal measurements of g_s indicate highest rates in the morning for all size classes with g_s declining after midday. Seedlings had high g_s rates early in the season but declined to only 60 percent for adults by mid-season. Average g_s values for adults and saplings were not different. Comparison of regeneration and nonregeneration areas did not reveal differences in g_s. Although differences between size classes, sites, and years were discovered, there was no evidence that blue oaks in regeneration and nonregeneration areas differ in their water relations.

Population Structure and Clonal Variation in *Quercus chrysolepis* Liebm.

Arlee M. Montalvo[1] Susan G. Conard[1] M. Thompson Conkle[2] Paul Hodgskiss[2]

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Mature stands of canyon live oak (*Quercus chrysolepis*) are maintained for fire management, habitat for wildlife, recreation, and fuelwood. Basal sprouting is the primary means of reproduction following fire or cutting, and stands frequently include groups of visibly connected trees in a clustered distribution indicative of cloning. Information about genetic structure, importance of cloning, and the link between the oak's reproductive ecology and extent of genetic diversity is important in developing land management policies that will maintain the long-term viability of populations. We determined the extent to which clusters of trees are clonal and defined the spatial pattern and diversity of genotypes for populations in the San Bernardino Mountains in southern California. All sites were within an elevational zone of 1350-1700 m. We mapped more than 100 trees at each of five sites and

genotyped each tree for genetically controlled enzyme variants (allozymes) at seven polymorphic loci (loci with > one allele). We identified clones using the allozyme genotypes and detected an average of 34.4 ± 7.3 (s.d.) clones and 33.4 ± 7.2 genotypes per site. The findings that clustered trees belong to single clones and that most clones consist of few trees were confirmed by the very high spatial autocorrelation of genotypes within 4 m. However, clone size increased significantly with the number of heterozygous loci present in a clone, suggesting that the long-term integration of selection over time favors highly heterozygous clones. Clonal diversity was high relative to reports for most other clonal species; an average of 97 percent of clones had distinct genotypes. Population genetic analyses of 319 clones from six sites revealed high genetic diversity within sites (mean $H_S = 0.443$). Only 1.8 percent of the total genetic diversity was explained by variation among sites (mean $G_{ST} = 0.018$), and we found essentially no substructure among plots within the two sites examined at that level. This indicates that genotypes are essentially randomly distributed within the sample space. Moreover, inbreeding coefficients within sites were generally small and positive, suggesting that little inbreeding occurs. Resulting estimates of gene flow within and among sites were high. These patterns are consistent with studies of other tree species that are highly outcrossing and wind pollinated, such as red oak, Ponderosa pine, and quaking aspen. Despite this, spatial autocorrelation analysis of clones indicated that clones within 4 m of each other tend to be related, possibly because of limited seed dispersal. We recommend that when populations are sampled for genetic structure or gene conservation, collections from single populations should be separated by at least 10 m to minimize duplicate sampling of clones or inclusion of close relatives. We also suggest that elevational zone and microhabitat be carefully matched when transplanting seeds and trees to other locations. This is consistent with seed transfer zone guidelines for coniferous trees. Future studies will examine if there is population structure at the level of different elevational bands or mountain ranges.

Practical Methods of Regenerating Oaks on a Cattle Ranch

George R. Work[1]

The cattle ranch is located 15 miles NE of San Miguel, in southern Monterey County, California. Elevation is 1,000-2,200 feet. There are rolling hills and 12-14 inches of rainfall per year.

On our ranch the regeneration of oaks and other native perennial species require four basic things:

- Seed source, preferably from a parent plant on site,
- Reduction of annual vegetation during its growing period (mechanical or chemical most commonly used),
- Periods of rest if defoliation or damage to the young plant occurs ,
- With small seeded perennials it is necessary to provide a good seed soil contact if a duff layer is present. This does not seem to be a problem with the oaks.

The bulk of the oak woodland operators will have to have a financial

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incentive to motivate them and to pay for the costs of any changes that might be needed to regenerate our oak woodlands.

Our experience has shown that, here in California, most all of our native perennials, including the oak, respond and regenerate when the same management principles are applied. This is fortunate because it allows the cattleman to produce more grass to feed his animals while producing perennial grasses and oaks for long-term stability and production.

The seed sources for our regeneration of the oak are usually present in existing trees. It is important to assure a healthy population of scrub jays as they are the planting crew in this regeneration project. Accessible water plays an important role in having jays present. Often water systems are not designed with birds or other wildlife in mind. Existing water troughs can be made more accessible with cement ramps in and out of the troughs. If available, rocks piled inside and outside the trough serve the same purpose. These ramps allow the bird to reach the water regardless of the water level. Another help is using a 0.25- inch coupler nut with a hole drilled through it to make a float ball adjuster so the water level on the trough can be set very close to the edge but still not run over it. Water really belongs on the ground so it is accessible to all the critters in the oak woodlands.

The suppression of the annual vegetation during its growing period, in our area, is done by the rooting of the feral pig. The pig is also a revenue generator. It is harvested through a guided hunting program.

Allowing heavy cattle grazing when the plants are small and the soil is very wet also suppresses the annuals but it is more difficult to achieve.

The necessary periods of rest needed by the oak can be easily accomplished with planned grazing moves. If cattle are given other things to eat, they tend to avoid the seedling oaks and, to a degree, the young saplings until they begin to mature a bit. These periods of rest accomplished with planned grazing will also produce more annual and perennial forage. This will allow the rancher to stay in business and keep the land in trees and grasses.

A Model Nonpoint Source Management Plan For Hardwood Rangeland

J. M. Connor[1] **Melissa Joyce**[1]

The State Water Resources Control Board has adopted and is beginning to implement the California Rangeland Water Quality Management Plan (CRWQMP). This plan was initiated by the state's livestock grazing industry as a proactive means for addressing federal Clean Water Act water quality requirements for California's rangelands. We developed a plan for management of the hardwood rangeland at the University of California Sierra Foothill Research and Extension Center. Its objectives are to guide resource use at the Center and to serve as a practical example for managers of grazing land as they write their own plans as suggested by the CRWQMP. Our planning process is outlined as follows:

- Resource inventory or description. The resources—soils, vegetation types, watersheds, grazing areas, facilities, wildlife, and livestock—

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and their management were discussed.

- Statement of the goals for resource management and water quality. Production, landscape, and research and education goals were described.
- Assessment of current conditions. How is current management affecting the resource? Are there any impairments to beneficial uses in local water bodies? Potential nonpoint sources of sediments, nutrients, and pathogens, including those located upstream from the subject property, were noted.
- Implementation of current management practices that are maintaining and improving water quality and any management changes that are necessary to meet the goals. The nonpoint pollution sources that each management measure addresses were discussed.
- Monitoring to determine whether the management practices are achieving the stated goals. The plan describes the monitoring methods that will be used.

Restoration of California Walnut Woodlands at the Urban-Wildland Interface in Southern California

Steve Narwath[1] Ronald D. Quinn[2] James Roberts[1] Gabor Bihari[1]

The California walnut (*Juglans californica*) has a very limited range, occurring naturally only in scattered locations between Ventura and San Diego counties. Within that range the most extensive stands are found on north facing slopes in the Puente and San Jose Hills of eastern Los Angeles County. In recent decades much of the walnut woodlands and forests in these hills has been lost to urbanization, and there is no explicit protection of remaining stands. The present landscape includes edges between naturally occurring walnut woodlands and urban, range, and agricultural land uses.

In response to these losses California State Polytechnic University, Pomona, in cooperation with the Los Angeles County Sanitation District, has undertaken a research and restoration program that includes mapping existing walnut stands on and around the campus, monitoring of natural reproduction and growth, and restoration. Since 1990, seeds, and saplings germinated in containers, have been planted on the slopes of a landfill and around the newly established Center for Regenerative Studies. There is some evidence that young trees are more easily established from seeds than from 2-year-old saplings outplanted from containers.

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Pacific Gas and Electric Company's Vegetation Management Program

Heidi E. Lian[1]

Urban forestry interface issues influence Pacific Gas and Electric Company every day in its Vegetation Management Program. As more people move into rural areas, where there are more trees there is a greater need for public understanding of vegetation management.

Vegetation Management at PG&E strives to improve safety and reliability of our electric distribution system in compliance with all applicable laws by running an efficient, responsive, and environmentally sensitive vegetation management program. The program is managed by a centralized team with a director, 10 area arborists, six staff members, quality auditors, administrative support, contracted tree pruning companies, and contracted utility forestry consultants.

In 1995 and 1996, PG&E attained the status of a Tree Line USA Utility. PG&E is one of 17 utilities nationwide with this designation. The National Arbor Day Foundation presents this award to utilities whose employees and contractors are trained each year in natural directional tree pruning and tunneling and trenching near trees. The award also requires the company to educate customers about the relationship of trees to utilities and celebrate Arbor Day.

Partnerships are significant in helping to educate every aspect of the communities we serve about line clearance, proper pruning, and planting the right tree in the right place. PG&E works with local governments, environmental groups, schools, homeowners, and other interested parties. By doing this we combine our resources with others to resolve common issues of sustaining a healthy environment, reducing fire potential, increasing public safety, and decreasing maintenance costs.

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Conserve Oak Woodlands

M. Christine Lomas[1] **Norman H. Pillsbury**[1] **Amy Larson**[2]

Oaks (*Quercus* spp.) face a variety of damaging agents such as: fungi, insects, wildlife and humans. Oak woodlands are important for the variety of food they produce (acorns, leaves, bark and resident insects) and the shelter they can provide for wildlife. In recent years, the rise in population and the movement of urban to rural areas have caused a demand for housing and space. This surge in development is causing the eradication of our oak woodlands. Extensive networks of subdivisions, roads, pipelines and transmission lines create a fragmented mosaic of micro-oak habitats that, once isolated, become extinct. Construction sites are not only fragmenting the natural oak woodlands, but causing devastating effects on the natural regeneration of oak seedlings. Agricultural practices are also subject to scrutiny for their field placement and cattle grazing rotations. In fact, grazing now occurs on about 50 percent of

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California's estimated 8 million acres of woodland. The habitat and environment after cattle grazing are so significantly altered that they do not allow for natural oak regeneration.

In hopes of conserving our oak woodlands an effort is being made by several local groups and professional organizations. These include more than 100 municipalities and 38 counties that have established oak tree preservation guidelines and ordinances. Oak reserves have been established by the Bureau of Land Management, the Nature Conservancy, the State of California, the USDA Forest Service, the University of California, and park and water agencies. Organizations such as the California Oak Foundation, established in 1988, promote the statewide protection of oaks and encourage conservation of our oak heritage. The California Oak Foundation's strategy emphasizes the following steps: preservation, habitat restoration, wildland management, urban forestry, and education. With the advancement of communication, the ease in transferring information has permitted various agencies to produce publications, videos, and workshops to provide information to citizens, landowners, and policy makers on how to conserve oaks and oak woodlands.

The Effect of Sociological Factors, Attitudes, and Beliefs on Private Oak Woodland Management[1]

Barbara S. Kruger[2] **Richard P. Thompson**[3]

The results of an area weighted cross-sectional survey of landowners attitudes and behaviors are presented. The goal of the study is to first create a descriptive profile of San Luis Obispo County landowner based on socioeconomic characteristics, land use objectives, physical attributes of the property, and their belief that there is an oak resource problem. Secondly, a relationship between this profile and the likelihood that the landowner would manage oaks is established. Finally, the impact of an economic incentive on oak management likelihood is examined.

To collect the data a questionnaire was mailed to 180 landowners. Seventy individuals returned the questionnaire resulting in a response rate of 39 percent. These landowners were randomly selected using an acreage-based sampling system.

The profile of landowners is assembled using descriptive analysis. The relationship between the landowner profile and the likelihood of oak management is established using multiple regression. Finally, the impact of the incentive on oak management likelihood is calculated using descriptive analysis and multivariate analysis.

[1]Abstract of a poster paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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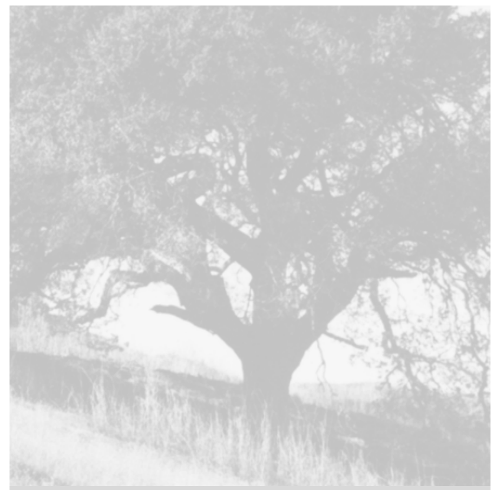
SYMPOSIUM WRAP-UP



The New California[1]

Daniel R. Walters[2]

I want to congratulate Norm Pillsbury and the other organizers of this conference for arranging to have this controversy over the water pipeline erupt just as this conference was going on. This conference has been in the planning stages for a couple of years, and to have that all just kind of reach a climax right in the middle of this conference I think takes real talent. I have never seen a conference that was on the front page of the local newspaper before now, so I mean—wow, what a gift for publicity. Norm has a whole new career awaiting him. I know, it's all just a coincidence, but people in my business never believe they are coincidences. We always suspect there are hidden hands at work, but I think this controversy over the water pipeline is probably a good starting point for what I want to talk to you about today, which is to put the technical issues and environmental issues you have been discussing in some kind of larger context. I thought of several ways of doing that, but I decided that maybe one way would be to conduct a little question-and-answer session since this is kind of what I do for a living, but I'm going to question only myself and provide the answers, which will be very convenient.

We started out with this business of the water pipe, this 4-foot wide pipeline, going to come through the campus of Cal Poly as part of this project to bring water from the State aqueduct, the California Aqueduct near Kettleman City, through the valleys, over the mountains, and down into the Vandenberg Air Force Base/Santa Maria area. We know that this pipeline is coming through; we know that it threatens a very valuable stand of oak trees; now, how is it that this controversy came to pass? I think many times we look at these things; we think of them as just, well, there's this thing, there's this confrontation, and we've gotta do something about it. We rarely think about, you know, why do these things come to pass? What is going on to produce these kinds of conflicts? We are really talking about value conflicts, conflict between, in this case, delivering water and the preservation of a stand oak growth, oak trees.

Well, let's go back. Let's just conduct this little question-and-answer session, this little dialogue. Why is the Department of Water Resources building that pipeline? Because it has water users on the other end of the pipeline. Oh, why do they need the water? They need the water because the area in question, like so many areas of California, really like most of California, does not really generate enough water locally to support the population of the area. Why is that true? It's because the population of California is growing. Why is the population growing and why is it growing there? Well, that's the complicated answer. I just started from the top and went down; now I'm going to start from the bottom and go up, just like the water line is being built from both ends, and we'll meet in the middle. What's happening in California? We are producing these value conflicts because California is experiencing change on a massive scale. Now, one thing about California is always true; it's always changing. That's the one constant about this state. Our society changes; our economy changes; our culture changes; sometimes even our politics change, although not as much as other times. But, the rate of that change is sometimes more and sometimes less. We find ourselves in California during this period in the latter decades of the 20th century, in a particularly volatile, accelerated state of change that is occurring on several levels simultaneously. There are a multitude of specific trends that are identifiable in

[1]This was an invited, plenary paper presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, 19-22 March 1996, San Luis Obispo, California. None of the plenary papers at this symposium was subjected to technical peer review; they were the views of the presenters, in behalf of the organizations they represented.

[2] Journalist and political columnist, *The Sacramento Bee*, Sacramento, California.

California, but I think there are three big ones. Almost everything else is a subset of the three big trends that are happening, and they themselves are somewhat intertwined with one another.

The first of those trends is that the economy of this State is undergoing a massive structural change. In its first century, it was an agrarian state for the most part with a resource-based economy. Its economy depended on extracting materials out of the soil to one degree or another, whether it was oil or agricultural products or timber or whatever. That changed very dramatically with the onset of World War II. It had started to change already, but World War II accelerated that and made the change complete from a resource-based economy into an industrial economy, an economy that took raw materials and made things out of them, first for the emergency of war; then secondly, for civilian markets after the war. There was a great period of very rapid, massive industrialization in California beginning roughly in 1941 and going on for about a generation until roughly the mid-1960's when it came to a plateau stage. And during that period, hundreds of industrial plants were developed for making automobiles and airplanes, building ships, refining oil, and processing food products. Anything that you could imagine in terms of industrial products was built in California, both to serve the markets here and elsewhere; and as I said, that kind of plateaued out in the 1960's for a variety of reasons having to do with the development of the global economy, and ever since then, California has been de-industrializing. The most recent recession that we have experienced in this decade was really, if you think of it in global terms, a normal cyclical recession overlaid by the down-sizing of the last great industrial sector of California, the Aerospace Industry. It was the combination of a cyclical recession and a very dramatic multibillion dollar cutback in Pentagon spending. We were, after all, the arsenal of the Cold War.

It was a combination of those things that produced such a severe recession during the first part of this decade, but it was a continuum of this de-industrialization or an economic conversion process that California has been undergoing for perhaps 20 to 30 years; and that is the conversion from an industrial economy to a post-industrial economy rooted in trade, services, entertainment, and communications. I could cite a lot of data but there are a couple of salient facts. As Aerospace spending and military spending decreased in California down to below the $50-billion-a-year mark from a high of $65 billion, health care has emerged as California's largest single industry. You probably had not thought of that, but health care is now a $100-billion-a-year industry in California. It is twice as big as military spending, Aerospace, and that sort of thing. So that's one indication of the shift to a service-based economy and there are many others. There has been an 85 percent decline in the number of Californians working in tire factories over the past couple of decades as, one by one, every tire factory in California, save one, has been shut down. One tire factory in southern California is now a shopping center. Another one up by Salinas is some kind of an office industrial park, but there is only one tire factory left operating in California near Hanford. More cars, more tires—but fewer and fewer of those tires are being built in California. But California has had a 100 percent increase in the number of people working in hotels during that same period. So it illustrates again the shift from an industrial to a service or post-industrial economy. In 1980, there were 3.4 million Californians working in the traditional occupations in California—manufacturing and utilities, and so forth. In 1995, there were still 3.4 million Californians working in those areas. In other words, all the growth in employment in California in the past 15 years (even despite the recession, about a 35 percent growth in employment) has been in the new, emerging economy, this post-industrial economy. That actually understates the conversion because even within manufacturing, there has been a shift from heavier, basic manufacturing into high-tech forms of manufacturing. The motion picture industry has tripled its employment in the past 15 years. To illustrate the conversion even further, the motion picture industry now employs more people than Aerospace in southern California.

So, the first big thing is a massive and economic conversion to a post-industrial economy. The second big thing that is happening in California is population growth. Population growth has always occurred in California. But the rate of growth has gone up and down. We have been, in recent years, in the period of another great surge of population, driven primarily by foreign immigration that began in California in massive numbers in the late 1970's. Foreign immigration, followed by a baby boom that began in the 1980's, mostly among new immigrant groups, resulted in a tremendous level of population growth in 1980: 6 million new Californians in the 1980's by birth or immigration from a 24 million population to a 30 million population in 10 years. That is a very high rate of population growth. It puts us among the leaders of all the states on a base that is larger. That 6 million new Californians alone was a quarter of all the population growth that occurred in the United States during that period, and to put it in even more dramatic terms, that growth alone in the 1980's, all by itself, would have been the 13th most populous state in the United States, more populous than Virginia or Massachusetts. Now in the 1990's, that slowed down a bit, mostly because of the economy, because we started spurting to get an outflow of population to other states instead of a new inflow. But the two major factors of population growth in the 1980's remain just as strong in the 1990's, i.e., 300,000 foreign immigrants a year and babies. A tremendous, continual baby boom. About 600,000 babies are born in California every year, and only about 200,000 people die. So that alone produces nearly 400,000 new Californians every year. We have the second highest birthrate of any state in the United States, second only to Utah, where it is a matter of religious conviction. We also have the highest rate of teenage pregnancy of any state in the United States. Utah has the lowest rate of teenage pregnancy of any state in the United States. So we have this incredible baby boom going on; we have a continuing high flow of foreign immigration. Those two factors alone, even factoring in deaths, accounts for 700,000 new Californians every year. Now during the early part of this decade, some outflows to other states actually reached more than 200,000 a year at one point. That has now evened out or leveled off as the economy has improved, and the expectation is that we will start getting a net flow into California in the latter part of the 1990's. Our population growth will probably not reach 6 million in the 1990's as it did in the 1980's, but it will be at least 5 million, more likely 5.5 million. And the Census Bureau estimates that, on average, California can expect to add 6 million to its population every decade well into the 21st century. So we were 24 million, and now we're 32, and we're going to be 35 or 36 by the end of this decade, and then we're going to be 42, and then we're going to be 48; then we're going to be 54, and then we're going to be 60, and so on.

One of the issues that should face California is: Do we want this population growth, and if we don't want it, what can we do about it? It's not a simple matter at all.

The third major thing that is happening in California is cultural change, and it is implied by the second, high birthrate among recent immigrant groups which produces cultural change on a massive scale. In 1970, three-fourths of Californians were non-Latino whites or what I'll call Anglos, although some people don't like that word—it's a nice, little short word. Three-fourths of Californians were Anglos in 1970. I just checked with the State demographers a couple of days ago—as of today, it's 53 percent. It was 57 percent in the 1990 census; it is 53 percent today and will fall below 50 percent some time later in this decade, next year, perhaps, or the year after. At the same time, the Latino population has grown to about 30 percent; the Asian population to well over 10 percent; the black population remains right about 7 percent. That's the most gross terms of ethnic or cultural change, and within that are hundreds of specific nationalities and languages and cultural backgrounds. There are 110 languages spoken in Los Angeles schools today. And everything you need to know about California is contained in this one observation, that in the middle of Los Angeles there is a kosher burrito stand. Actually, there may be more than one kosher burrito stand, but the one I'm familiar with is operated by a gentleman from Korea. As Dorothy once said to Toto: "We're not in Kansas anymore." This is as about as far removed from Kansas as you are likely to find. Seriously, this is the most complex society in the history of humankind, on the face of this earth and history of humankind. No other time do people come together and try to live in some sort of reasonable harmony, without killing each other, and the jury's still out as to whether we're going to succeed in that endeavor.

Those are the Three Big Things. You put those together—population growth, economic change, and cultural change— and it produces myriad specific issues and trend lines. For example, and this starts getting into the specific reason of why that water needed to go to Santa Maria or why it's wanted in Santa Maria, at least, and therefore why the issue of the threat to the oaks that exist on the Cal Poly Campus. One of the impacts of having a post-industrial economy is that jobs are portable. They no longer need to be on seaports, on railheads, and industrial areas. Jobs can be developed or moved any place in the new economy, and they are being developed and moved any place in the new economy. Just put that satellite dish on the roof, and you're in business. Until recently, I was a member of the Blue Cross Health Care Plan, and I would get these little things from Blue Cross all the time, that said, well, you know, you can do this, then you pay this bill; you know, just a little paper work. Those notices were generated in Grass Valley, northeast of Sacramento up in the Sierra Nevada foothills. Because it was just as easy for Blue Cross to have its claims processing center in Grass Valley as it would be to have it in San Francisco, and probably cheaper, and probably cheaper for their employees; probably easier lifestyles. One of the salient facts about California in the 1990's and beyond is the dispersal of the economy throughout the outlying urban fringes and sometimes beyond. That has also pulled people out to those urban fringes and beyond. The great story of California is the shift of population from the coastal metropolitan areas into formerly rural areas, mostly but not exclusively in the interior valleys; certainly along the Central Coast is not an interior valley. Areas that once considered themselves rural now are becoming population and job centers with the underlying engine of inexorable population growth driving them. Actually, it is a two-pronged process, as near as I can figure. Immigration, foreign immigration, and the birth phenomena are primarily a central city or metropolitan phenomena, but there is an offsetting flight, a white flight for the most part, if you will, out of the metropolitan areas into these new growth centers. These "edge cities," as some people call them, or "Exurbia" as others have termed them. I'll give you a couple of examples, and if you look at the pattern of growth in California, if you take a map that shows where the high growth areas are, county by county in the state, you see a certain pattern, both in jobs and in population. For example, while the state as a whole was growing by 25 percent in the 1980's, Riverside County was growing three times as fast. That's 76 percent population growth in 10 years, and over the past 15 years, it has grown 107 percent in population. At the same time, it grew 134 percent in jobs. So, there is clearly a shift of employment and people from the metropolitan coastal cities into these formerly rural valleys because jobs are portable. That produces in itself myriad sub-issues—transportation, education, how do you cope with school children, how do you cope with the commute patterns? We have doubled the vehicle miles of personal vehicle travel in California in the past 20 years. We have added 7 percent to the highway lane miles in the past 20 years. If you wondered why you are in traffic jams, now and then, that is why. We add anywhere from 300 to 500 vehicles to our roads and streets and highways every 24 hours, including all those that crashed, burned, or were demolished in Los Angeles the night before. In other words, a net increase. We Californians buy a million new cars every year, a million new cars. That itself is a $20-billion-a-year industry, just buying new cars. Education—we need to be building one school every 24 hours in California to keep pace with growth in enrollment, one 20-classroom school every 24 hours, 365 days a year, ad infinitum, as far as you can envision into the future. Merely coping with the baby boom of the '80s, there's a school boom in the '90s, and there will be a college boom of the late '90s, all into the 21st century; "Tidal Wave II," college people are talking about. Just coping with enrollment growth in the schools costs the taxpayers of California a half a billion dollars more every year. That's just the growth; that's not any kind of cost of living raise, that's mainly as growth.

So with population growth and economic change come political issues and changing development patterns—all these sorts of things—which create conflicts of values. The political system is supposed to be the means by which those conflicts of social values are resolved and consensus is identified and achieved, but the conflicts become more deep-seated with every passing year because society itself becomes more complex, and consensus is more elusive within the social complexity, and the political system finds itself somewhat paralyzed, becoming incapable of dealing with these massive changes that are going on. This is the unfortunate tendency of the political system, and I don't mean just the legislature and just the governor—the whole apparatus—the legislature, the governor, the county boards of supervisors, state agencies like the Department of Water Resources. It is interesting to note in this particular case, for example, what we have here are two state agencies fighting each other, so there is not even a consensus within the bosom of government so to speak. But the whole apparatus of political policy making finds itself paralyzed by the immensity of the change going on in California and the disconnection between that change and the politics as practiced on a day-to-day basis. Let me give you a couple of examples of how that works. I have mentioned that the cultural or ethnic makeup of California is changing very rapidly with the Anglo population scarcely over 50 percent and falling below 50 percent within a year, another year, 2 or 3. But of the people who will vote next Tuesday, well more than 80 percent will be non-Latino white or Anglo. So in ethnic terms alone there's a great disconnect between the voters and the population as a whole, and the gap is widening because the population is changing at a very rapid rate, and the voting block is not changing. It is not growing appreciably nor is it changing at anywhere near the rate of the population as a whole, so the disconnect, the characteristic gap, is increasing.

So even if you had a consensus of social values, it is not necessarily true that it would translate into a consensus of political values or political consensus over here, and ethnicity is only one of the disconnects. Voters in California are markedly older, whiter, and more affluent than the population as a whole. The median age of California voters is 50 and going up. And it is going up because the Anglo population is aging rapidly. The non-Anglo population of California is a young population—lots of babies, lots of young immigrants—with a median age in the lower 20's. The overall median age of California is about 31. The non-Anglo population is about 10 years younger than that. The Anglo population is almost 10 years older than that, has a median age in the upper 30's and going up, and the age curve will accelerate because the baby boomers are getting older. My brother turned 50 a couple of weeks ago. My brother-in-law turned 50 a couple of weeks ago. My wife is going to turn 50 this year. I'm going to another 50th birthday party tonight, and Bill Clinton has a 50th birthday some time this year. The baby boomers are getting old! That first generation of baby boomers, born in

1946, is turning 50 this year, and as the baby boom generation, age 30 to 50, gets older, the aging curve accelerates dramatically. And one impact of that is that the proportion of voters with children in the public schools has declined to about 20 percent. Only 20 percent of actual voters have children in public schools. So there is this disconnect between the social reality, a society that is changing and growing very dramatically, and the political reality, which is the electorate is neither growing nor changing very rapidly, and politicians are getting caught in this paradoxical dilemma. You deal with the needs, the wants, and the desires of the general population or you follow the dictates of an electorate that is not represented in that population, and we all have seen the results of that, whether we recognize it or not. We have seen spending on the schools. K-12 schools decline in relative terms from above the national average to 20 percent below the national average. We have seen that the population of the prison system increased seven-fold from 20,000 in 1980 to more than 140,000 today and will hit 150,000 before the year is out and will double again to 300,000 in 10 more years. Why? Twenty percent of the voters have children in public schools, but as we get older we become more fearful of crime and we demand ever harsher, and albeit—although we don't want to admit it—more expensive approaches to crime. We now spend four times as much on crime control in California—cops, prisons, parole agents, prosecutors, criminal courts, and so forth ($15 billion)—as we spend on higher education. We spend half as much on crime as we spend on K-12 education, and the gap is narrowing very quickly. Why? Because that is what the voters want. We have these conflicts of values that come to the political realm for resolution, and the politicians are basically paralyzed. They do not know what to deal with. They know that all this stuff is going on over here, they are not that stupid. There are some who are not quite so sure. But they look at that, and they say, "yeah, we gotta do something about that; we gotta do something about that. You know, we can't just—we gotta just think about things like land use controls, and population issues, and some of these more deep-seated issues, but in the meanwhile, I got an election comin' up here pretty soon and I better deal with the reality that those voters are out there, and they want me to do certain things. They want low taxes; they want a lot of money spent on crime control. And if I want to be reelected, I'll deal with that." And there's the disconnect between the social reality and the political reality.

And you say "What does all of this have to do with acorns and oak trees?" Well, it has a lot to do with it. Because the trends that I have outlined to you are not going away. The shifts of population into these interior areas where your oak trees are in such prominence continues. The highest and fastest growing areas of California in terms of populations are the areas in the Sierra Nevada foothills, in the hills surrounding the San Francisco Bay Area, and areas along the Central Coast—those are the areas that are growing in population. Those are the desirable areas to live in, and those are the areas people can live in now in great numbers because the economy is changing, and when they move into these areas they need amenities, or they want amenities at least. They want roads; they want schools; they want housing; they want shopping centers; they want water. And the guiding principle of the political apparatus to the extent there is any guiding principle of the political apparatus is basically to serve those demands. Politicians have this kind of view of themselves, you know, that they're the leaders, and we in the media, unfortunately, kind of reinforce that. We use the term political leaders, assembly leaders, senate leaders, and all this stuff. They are the people at the head of the parade, they think. The truth is they are not. The truth is that they are the people at the end of the parade. Social or economic drivers are creating issues that are left to the politicians to resolve. They are truly the people with the scoop shovels and the brooms at the end of the parade. They don't like to think of themselves that way, of course. But in reacting to the population shifts, to the economic changes, under the best of circumstances, that's what they are. They are the people at the end of the parade. They are reacting; they are not getting ahead of the herd. Now the question is, of course, do we want them to get to the head of the herd, do we want them to be leaders, do we want to change any of these trends, and if we do want to change it, is it possible to change it? Is it possible to slow down the economy?

Yes, they say, well, the economy has been slow. Yes, it has been slow, but I want to tell you, the engine is starting to pick up, and the new economy is taking hold, and there are some dramatic things, and California is probably going to be hopping in the next 5 to 10 years. We exist at this place where North America and Latin America and the Pacific Rim all intersect with one another. We are at the crossroads of much of the world. That and the other factors we have going for us in California will produce the conditions for tremendous economic boom, and we are kind of casting off the old economy and embracing the new economy, and there's going to be a lot of things happening. Do we want that to happen? Do we want our population to continue to grow by 6 million people per decade? And if we don't, what can we do about it? Can we stop people from having babies? Can we stop people from coming here? How far are we willing to go toward an authoritarian state, to enforce some vision of a population growth. People in politics do not want to deal with those kind of fundamental issues. They will deal with the symptoms and stuff at the end of the parade, you know, whether we should put the water line here or put the water line there. But they are very reluctant to deal with these kind of more fundamental issues. Do we want to stop population growth? Do we want to slow population growth? Do you want to direct economic change? Do we want to try to redirect development back into the cities and prevent it from sprawling out into these interior valleys? Because every time you raise the issue that they are trying to deal with one of these trends, then that raises all sorts of instant political conflicts that politicians would rather not deal with. For example, you will hear environmentalists talk all the time about the environmental impact of this or that on the natural environment, on water quality, and on air quality, on land, on open space, and so forth. You rarely hear environmentalists talk about population control because if they started dealing with control of population growth, it puts them in conflict with other otherwise sympathetic groups on kind of the left end of the political spectrum. So, that's putting them in conflict with advocates for Latinos, for example, if you start talking about immigration controls and things like that or more aggressive birth control policies—all sorts of doors are opened and cans of worms are opened, that people would rather not talk about.

So do we want to do something about these trends? Do we? Or do we want to just deal with the instant impacts down the line when the bulldozers are standing there ready to tear up the trees at that moment, or do we want to go back to the roots of the things and start talking about why are so many people settling in the Santa Maria area? What are the economic and social and land use policies that create that condition, which then creates this condition? I guess that is where I have to leave it, with that question. That is the final question of this dialogue and is the one that I don't really have the answer to: do we really want to change these powerful trends that are coursing through California? Do we and our politicians—do we want our politicians to deal with this? Or will we be content simply to mitigate and deal with these issues at the other end of the pipeline when they come out as instant social and political conflicts? Maybe that's where I'm going to leave it. Think about the trees; think about the conditions that create the threats to the ancient oaks of California in the first place; think about whether you really want to do something about that. Thank you very much, folks.

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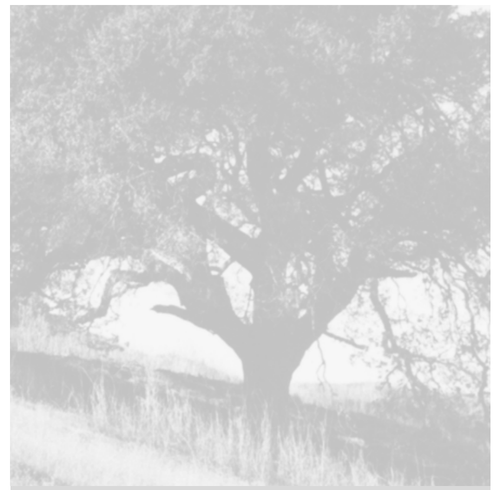

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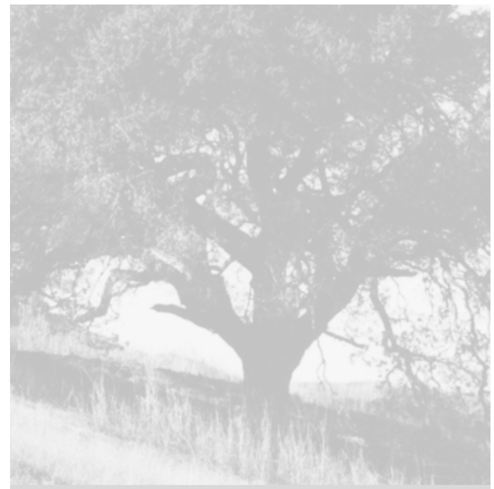

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