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## A REVIEW OF PRESCRIBED BURNING ON STATE AND PRIVATELY OWNED LANDS IN CALIFORNIA

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ABSTRACT

The use of fire as one tool for changing the characteristics of California's wildlands has long been a subject of controversy. Undeniably fire can be an economic and useful tool and can help achieve desirable results, if used in the right place and time and manner. The controversy arises in trying to define what is "right." This paper attempts to summarize the use of fire in California and to review the known ecological effects of fire. A brief notice is given to alternatives to fire.

This paper was prepared originally in September 1975 as a regional input to a national summary of the use of fire in the management of wildlands. The national summary will be a report to the Executive Council of the Society of American Foresters. By agreement the regional summaries were to emphasize the use of fire on state and privately owned lands, with one individual summarizing the use of fire by federal land-management agencies.

The author's intent was to review very broadly the state-of-the-art of using fire in California, not to evaluate the worth of prescribed burning for specific purposes.

## INTRODUCTION

The deliberate and planned use of fire for the purpose of affecting or changing the characteristics of the wildland environment has been a subject of long-standing controversy in California. The controversy does not revolve around whether or not fire should be a tool in managing the wildland environment. Generally, both public and private land managers tend to agree on that point. Differences arise in regard to the questions of how, when, where, under what environmental conditions, and for what specific purposes fire should be used.

Reasons for the differences vary. Mostly, they are rooted in people's attitudes, experiences, and opinions. To some extent they are related to the existence or lack of state and local laws. And, finally, they are based on the need for further research in many aspects of using fire under the environmental conditions of California. The following discussion explores the historical use of fire by man to control the wildland environment in California, the effects of fire on various ecological phenomena, and some problems that require solution. Although some references are made to the use of fire by federal land-management agencies, emphasis is given to the application of fire to state and privately owned lands.

Throughout this discussion the term "use of fire" is employed in the broadest sense of man's intentionally setting fire to the wildland environment for some legal or illegal purpose and regardless of the degree of success in achieving the intended purpose. "Prescribed burning" is used to describe the planned application and confinement of fire to a pre-selected land area to achieve some specific objective or objectives in land management (11). It includes what has been variously termed as controlled burning, light burning, and planned burning (21).

## PHILOSOPHICAL AND HISTORICAL REVIEW OF THE USE OF FIRE IN CALIFORNIA

There is general agreement that lightning has been a major cause of wildland fires in California for many hundreds of years (83, 56). These lightning-caused fires have been a major factor affecting the wildland's ecology (85).

There is less agreement on the role of aboriginal man in shaping California's wildland through the use of fire. Some investigators claim that the Indians used fire throughout much of the State and that this burning had a significant effect on the characteristics of the vegetation (88, 92). Others dispute these claims, saying that the small population of Indians in California used fire for only a few limited purposes and that these fires were seldom extensive in the area they covered (72, 22). Many proponents of light burning (i.e., using low-intensity fire to reduce the volume of flammable vegetation) cite the writings of John Muir to illustrate that fires set by Indians or lightning were responsible for maintaining open, park-like stands of timber in the Sierra-Nevada in which fires would spread slowly and with low intensity, doing little or no damage to the residual stand of trees (15). Others maintain that these observations can be taken out of context from Muir's writings; that the eminent conservationist also described his observations of high-intensity fires which spread into the crowns of trees; that he termed fire "the master-scourge of forests, and especially of sequoia" (23, 61).

While the Indians did in fact use fire before the arrival of European man in California, their activities in this regard apparently were deplored by the early Spanish-Mexican governors because of the damages created to pasture lands. A proclamation was issued in 1793 by Governor Jose' Joaquin deArillaga, for example, which prohibited all kinds of burning in Alta California (30). Many years later General M. G. Vallejo, in drawing up a treaty with Indian tribes north of San Francisco Bay, demanded that the Indians were not to burn the fields in time of drought and were to do all in their power to prevent other tribes from starting fires (30).

This attitude was not wholly shared by the early American settlers in California who arrived from the eastern United States and elsewhere. Fire was used freely by farmers to clear brush and timber for cultivation of crops (30), by loggers to remove slash from the woods (83, 44), and by stockmen to remove brush and improve feed for their domestic animals (30, 83). There were many owners of timber lands who felt that promiscuous use of light burning was necessary to reduce the hazard and the chance of disastrous conflagrations or simply to "open up the forest" (31).

Opposed to these viewpoints were those people who just as firmly believed that the use of fire must be regulated by the government to protect natural resources as well as life and property (30). Strong arguments were given for not practicing light burning or for not using fire in the burning of slash in the redwoods (31, 44). Still others advocated fire exclusion, particularly in timbered areas (83).

These opposing viewpoints came into focus in the deliberations of California's first Board of Forestry in 1885 and of ensuing Boards (30). Many efforts were made to work with the State's landowners and to control their use of fire so as to accomplish desired goals without unwanted damage to other resources and property. Studies, sponsored by the various Boards of Forestry, were made by the University of California, the U. S. Forest Service, and others to determine the effects of fire on California's wildland environment and to recommend procedures which the Boards should take to regulate the use of fire.

California's first Board of Forestry came to an abrupt legislative end in 1893. Whether the reasons for its demise were political, fiscal, or something else, the first Board at least laid the ground work for future state policies in regard to the use of fire in California's wildlands.

Just 12 years later the Forest Protection Act of 1905 re-established the Board of Forestry and provided the legal cornerstone for the present Division of Forestry. That Act also included a broad scope of laws regulating the use of fire during the "dry season" and provided for enforcement of the laws (30). The first State Forester, E. T. Allen, an Assistant Forester with the U. S. Forest Service, was appointed in July 1905 and declared that his "activity will relate most largely to the matter of prevention of forest fires." Mr. Allen and subsequent State Foresters all wrestled with the conflict of attitudes regarding the use of fire in California's wildlands. Over the years, however, the trend has been toward a state policy of fire exclusion during the dry months, except for those fires ignited under permit obtained from the Division of Forestry. For a variety of reasons response to this policy of regulating the use of fire has varied. During the first 40 years of the Division of Forestry's existence, many illegal fires were set throughout the State for the obvious purpose of removing brush. The Board of Forestry and the Division of Forestry continually worked with the landowners in an attempt to meet common goals of enhancing the productivity of the wildlands. Success was not easily nor consistently attained.

Finally, in 1945, a new series of laws was passed by the State Legislature which, among other things, recognized the State's interest to eliminate "fire hazards and to reduce the risk of uncontrolled fires which result in great annual financial losses to the people of the state, to increase range forage, to return wastelands to production, and to reduce the danger of incendiarism" (Public Resources Code, Section 4771). This purpose was to be achieved by the use of prescribed burning or other practices on privately owned lands under permit from the Division of Forestry. Other Sections of the Public Resources Code authorized the Division of Forestry to provide advisory services and standby fire protection, to conduct field studies and research in range improvement in cooperation with other public and private agencies or landowners, and to report the results of the program for public use (5).

The results of this program for range improvement are described in Section IV, Uses of Fire, in this report.

After all the turmoil and conflict over the past years, what is the status of the use of fire on state and privately owned land in California today? Most prescribed burning is done on privately owned lands for the purpose of range improvement. The extent of this type of burning has decreased in recent years, however, from a high figure of 227,000 acres in 1954 to some 31,000 acres in 1972 and only 19,000 acres in 1973. Many reasons are given for this downward trend: changing patterns of land ownership and land use, increasing environmental values, fear of liability for damages and suppression costs of escaped fires, and restrictions imposed by air pollution control boards (9).

Incendiary fires still persist, constituting about 25% of the fires starting in the some 28 million acres of wildland directly protected by the California Division of Forestry. Most of these fires, however, appear to be malicious vandalism rather than a planned effort to burn brush for the purpose of improving the range, as was the principal reason until 1945.

The use of prescribed burning to reduce the volume of slash on privately owned timber lands is practiced very little in California today, although it is legal to do so under permit. The practice not only is expensive, but also it is frowned upon by at least the larger timberland owners because of severe damages to residual trees and reproduction (27).

There are advocates of light burning in the ponderosa pine type of California today (16, 95). But admonitions to use fire as a management tool in ponderosa pine have not been accepted to any large degree by landowners and land managers principally because of the high initial costs involved, unsatisfactory results in many tests, the uncertainties of potential damages to residual trees, and the expressed need for additional research (27). Past experiences and experiments in the use of light burning still leave unhealed scars on the minds of many timberland owners (85, 31).

The Federal agencies use prescribed burning in California today to meet various management objectives: restoration or maintenance of ecologic communities (54), re-establishment of preferred timber types (2, 49, 53), reclamation of brush fields through establishment of timber plantations (57), conversion of brush to grass for hazard reduction and improvement of wildlife habitat (12, 13, 47), and reduction of slash (58). The National Park Service practices a "let burn" policy in Sequoia-Kings Canyon, Yosemite, and Lassen National Parks (54). This policy permits all lightning-caused fires which start above 8,000' elevation to burn naturally so long as they do not adversely threaten high values, do not threaten to burn beyond the park's boundaries, and so long as there is not the probability of critical fire weather which might cause the fire to escape. The National Park Service also uses prescribed burning to reduce the hazards and to encourage the growth of giant sequoia (54).

Many public and private agencies and individuals continue to be concerned about the condition of California's wildland environment and its many ecologic communities (6, 24, 41, 86). Many people have advocated using the expertise, personnel, and equipment of the California Division of Forestry to conduct prescribed burning on private lands. At the heart of this possibility, however, lie the philosophical concepts of using public money to benefit private landowners, and the assignment of liability should fire conducted by the Division of Forestry escape and create unwanted damages to adjoining property (24). These concepts require further discussion and resolution, probably through legislation.

The primary question is not so much, "Should we use prescribed burning as a tool in land management in California?" but rather, "How do we use prescribed burning safely in California's wildland vegetative types without causing unwanted side effects to environmental values?"

What is the nature and extent of these side effects to wildland values that can be caused both by prescribed fire and wildfire? Considerable research has taken place in California that helps provide many answers to this question.

## ECOLOGICAL EFFECTS OF FIRE IN CALIFORNIA

### General

Considerable research and study have been conducted in California to determine the ecological effects of fire on wildland values (25, 82, 86, 90). As is sometimes the case with any research, the results of research in prescribed burning in California have not always been interpreted the same by all interested parties. Or, different studies made for essentially the same purpose may apparently produce opposing results (15, 85). It is this basic conflict that still needs to be resolved by future research study and discussion before prescribed burning can be used regularly and with some degree of confidence as a tool in land management in California.

Some of the ecological effects of fires have been highly detrimental - to soil, to vegetation, to waterways, to water quality, and to property. These drawbacks to using prescribed burning will be discussed below. Much of the problem, it will be seen, is attributable to the steep and rugged topography that exists in much of California. Very few areas are so flat that they lend themselves readily to the prescribed burning techniques used in the southeastern United States. Even in the Southeast prescribed burning has been said to have no place on steep slopes (59). Steep slopes and broken terrain can cause (1) frequent changes in wind speed and direction, and, hence in fire behavior; (2) considerable differential heating on the stems of vegetation; (3) soil erosion through the movement of dry soil particles following removal of the protective vegetative cover; (4) soil erosion through the removal of the top layer of soil during extensive rainfall; (5) soil removal through sheet erosion or landslides following frequent and prolonged rainfall; (6) deposition of soil, rocks and debris in stream beds, reservoirs and residential areas. These effects are well chronicled and will be presented in more detail below.

The conditions under which vegetation ignites and burns in California are prescribed largely by the state's complex geography. The state has large areas of steep mountainous terrain; the Great Central Velley forms the only major area of flat land in the state. To the east of the Valley lie the Cascade and Sierra-Nevada ranges, rising to more than 14,000'; to the west are the lower mountains of the Coast Ranges which continue into southern California. The mountains are slashed by deep canyons with vertical sides which often rise 2,000' or more to the ridges. Such rough topography channels air flow, creating extremely erratic winds on lee slopes and in canyons. Fires starting in the bottom of a canyon may rush quickly to the ridge and become large before initial attack forces can arrive at the scene - simply because of topography.

California's Mediterranean climate (cool, moist winters followed by long, dry summers) is the delight of tourists but the bane of wildland firefighters. Total winter precipitation (snow and rain) is greatest in the northern part of the state and in the high mountains where timber grows. Rainfall decreases sharply with a drop in elevation from the mountains to the lower foothills and valleys; it also generally decreases latitudinally from northern to southern California. The lesser rainfall supports a growth of brush in the interior foothill areas of northern California and throughout most of southern California. The dry summer is accompanied by relatively high air temperatures and low humidities away from the immediate coastline. The long rainless periods, heat, and dry air combine to draw the moisture out of the large accumulations of dead fuel and place living vegetation under increased moisture stress. Occurrence of dry north or east winds in combination with a winter drought can mean a 12-month wildland fire season in California.

The highly varied conditions of topography and weather in California combine to provide a mosaic of vegetation that is also highly varied in its characteristics. Only 14% of California's land area is occupied by cities or by agricultural crops. Another 25% is in desert or in barren mountain areas high above timberline. The remainder, some 61%, is mountains and hills covered by timber, woodland, brush or grass. All this wildland vegetation reaches some degree of flammability during the dry summer and, under the right weather conditions, during the winter months. Adding to the complexity of the wildland fire problem are the many subdivisions, individual homes, and recreational developments located in the hills and mountains.

Because of these complex environmental conditions in the wildlands of California, land managers are extremely careful in their use of fire to change that environment. Considerable research has been conducted, for example, to find ways of burning fuels at safer times of the year, principally during the winter or early spring months. Some of these tactics include crushing brush with heavy equipment and burning the dried fuel while surrounding vegetation is still moist and green (11, 18, 19, 42, 45, 99); dessicating standing brush (28, 96); coating slash piles with bituminous emulsions and burning after snow has fallen (80); using various petroleum gels or explosives to ignite slash or brush during wet weather and fuel conditions (39, 77, 78); or simply burning brush in small strips while it is still dormant in the early spring. (Although this technique removes the brush, it generally leaves many brush stubs which discourage use of the area by larger wildlife) (13, 35). Except for the latter technique, these methods are all somewhat expensive. Since the purpose of burning is generally achieved without damage to wildland values beyond the intended bounds, however, the initial costs may be well justified.

## Vegetation

### Major Vegetative Types in California

What are the areas of the major vegetative types in California? One of the most comprehensive inventories made in the state shows the following distribution (97):

| Vegetation Type | Million Acres and Percent* |
|---|---|
| Timber Forest | 18 |
| Other Coniferous Forest | 6 |
| Woodland (hardwoods) | 10 |
| Chaparral | 10 |
| Sage Brush | 7 |
| Grass | 10 |
| Desert | 24 |
| Cultivated, urban & industrial | 14 |
| Barren | 1 |
| Total | 100 |

*The same figure expresses both millions of acres and percent because the total land area of California is approximately one hundred million acres.

Volume of Fuels

What is the potential volume of fuel in California's wildland vegetative types that can be treated by prescribed burning? Among the many studies that have been made are the following figures:

| Fuel Type | Tons of Vegetation Per Acre |
|---|---|
| Grass & Litter, So. Calif. (4) | 1.05 - 3.40 |
| Coastal Sage, So. Calif. (4) | 12.42 - 17.09 |
| Chamise, So. Calif. (4) | 7.31 - 32.54 |
| Heavy Chaparral (Principally scrub oak and Toyon), So. Calif. (4) | 27.19 - 46.84 |
| So. Calif. Chaparral (47) | 35.0 |
| Mature Timber, mostly ponderosa pine (materials 4" and less in diameter)(62) | 88.4 - 104.5 |
| Ponderosa Pine Timber, medium reproduction, and brush (materials 4" and less in diameter) (62) | 59.5 - 88.7 |
| Second-growth Ponderosa Pine, medium poles (material 4" and less in diameter ) (62) | 65.2 - 84.7 |
| Slash and litter from clear-cut, young-growth ponderosa pine (89) | 53 - 89 |
| Slash and litter from clear-cut, young-growth ponderosa pine and Douglas fir (89) | 83 - 110 |
| Slash and brush from clear-cut, virgin mixed conifer (79) | 39 - 43 |

## Effects of Fire on Vegetation

Several plant communities in California provide evidence that they depend on fire as an integral part of their environment or that they have adapted to the frequent occurrence of fire (15, 82, 84). There is little argument that chaparral, knobcone pine and lodgepole pine are among the plant communities in which fire plays a major environmental role (21, 60, 86). There is general agreement that perpetuation of the giant sequoia depends on an environment that has been opened by fire (49, 53). There is less agreement that the mixed conifer forests of the Sierra-Nevada compose a "fire type" vegetation (15, 21).

Plant communities which depend ecologically on the frequent disturbing influence of fire are generally characterized as follows (22):

- . . There is a reduction in the number of species making up the plant community
- . . One plant species or a very few species tend to dominate the community
- . . The member plants have adapted physiologically or morphologically to prevent the destruction of the species by fire.

These characteristics are exemplified by the chaparral community (48). Although the plant species making up the chaparral community vary from location to location because of subtle differences in environmental conditions, most of them are sprouters. It is this physiological change that enables chaparral to rejuvenate itself very rapidly following a fire. One study was made of a 40-year old stand of chaparral in southern California that had been burned by a wildfire in July. By December sprouting had occurred as follows (65):

| Plant Specie | Percent of Plants Sprouting |
|---|---|
| Chamise | 56 |
| Scrub oak | 70 |
| Toyon | 71 |
| Laurel sumac | 100 |
| Sugar pine | 97 |
| Canyon live oak | 66 |

Low soil moisture can sometimes delay sprouting of some species such as scrub oak for as much as two years (66).

Immediately following a fire, only the larger stems of the chaparral plants generally remain unburned. Within a short time, depending on conditions of the soil and precipitation, sprouting begins in most of the plant species. For the next 15-20 years the plants grow vigorously (59). During that time they are especially valuable as browse for deer and provide cover for many other vertebrates (98). They are also relatively fire resistant (64). Gradually, however, the living parts of the plant die, litter accumulates on the surface of the ground, and the stand again becomes highly flammable (51). The stand slowly fills in and, at around 40 years of age, becomes so dense and decadent that it no longer provides a viable environment for deer. Therefore, to provide a continuing habitat for deer and other wildlife and to prevent the buildup of excess dead fuels which can lead to highly destructive conflagrations, the claim is made that chaparral is to be managed so that it remains in the younger age classes (48, 98). Prescribed burning is one of the tools, and perhaps the most practical tool, available to the land manager to accomplish this task (51, 64).

Without the characteristics of adaptation to fire, plant communities can be damaged or destroyed by fire or may change in composition. In illustration of the latter point, the advent of Europeans into California brought an increase in fire incidence to the foothills surrounding the Sacramento and San Joaquin Valleys. The frequent use of fire, together with other disturbing influences brought on by man's activity, has resulted in continuous stands of brush occupying areas formerly held by grasses and herbs in the woodland community. For the same reason, chaparral has extended into adjacent woodland and grassland communities and into areas that were once relatively open within the chaparral community itself (20).

As has been noted, the use of prescribed burning in the forest is a controversial subject in California. Even those foresters who advocate using fire to help manage second-growth ponderosa pine state that it must be used with care, in selected places and times, and to meet specified goals of land management (15, 16). Without proper care the use of prescribed burning can have the same damaging effects as wildfire: killing the younger trees and even some older ones; injury to the main stems or the crowns of older trees, making them more susceptible to attack by disease and insects and lowering their quality for harvesting later for wood products; and slowing the growth of the residual stand (46, 83). Even the forests of virgin redwood can be irreparably damaged by repeated fires, causing loss of merchantable wood, slowing of growth, production of heart rot, change in stand composition, and destruction of young-growth (44).

Following the occurrence of a high intensity wildfire or prescribed burn in timber, it is highly desirable to salvage as rapidly as possible those trees which have obviously been killed or give strong evidence of not surviving; without such rapid salvage the stand will quickly attract insects which are likely to destory or damage the surviving trees (93). Studies have shown the differential susceptibility of forest trees to damage by fire. The following conditions seem to prevail (93):

(1) The later the fire occurs in the season, the better the tree is prepared to withstand damage from the fire;

(2) Young, fast-growing trees on good sites have a better chance for survival than old, overmature veterans on poor sites;

(3) The amount of kill to buds, twigs and cambium are just as important as the amount of green foliage remaining;

(4) The killing of cambium that extends up the trunk for more than a few feet contributes more to reducing the chance for survival than injury close to the ground;

(5) The thinner and denser bark of sugar pine has a poorer insulating capacity than the bark of associated conifers, making sugar pine more susceptible to damage by fire.

Other studies have indicated that deterioration of fire-killed trees varies by species (Douglas fir deteriorates least rapidly, followed in order by sugar pine, ponderosa and Jeffrey pine, and white fir); by site (wet sites favor activity by diseases and insects); by growth rate during the life of the tree (wide rings favor more rapid deterioration); and by age (younger trees deteriorate more rapidly than older trees, under the same conditions) (55).

Although considerable more research has been devoted to the ecological effects of fire on plants, studies have also been made in California of fire's effects on animals.

## Animals

Although many individual animals can be killed by prescribed burning or wildfires (82), their habitat generally is improved by periodic burning (35). As has already been noted, the burning of overaged chaparral increases the amount and availability of food for those animals that have adapted to the chaparral environment (60). Succulent sprouts and seedlings of the shrubs and seeds of the annual plants benefit mammals and many species of birds which in turn provide food for predators (98). Even the giant condor of the Sierra Madre in south coastal California seems to be benefited by periodic burning of its chaparral environment (34). Excluding fire from chaparral results in dense, over-grown stands of decadent chaparral which become "biological deserts" in the sense that they support little wildlife (82).

Fire may temporarily drive out some animals, such as deer, and discourage the continued occupancy by other animals, such as rabbits, but mice and other small rodents seem to survive fire *in situ* in remarkably good fashion (98). Fresh litters of mice and large numbers of adult mice found in the centers of large burns within a day or two following a fire give evidence of that mammal's ability to "ride it through" in underground burrows (82). This ability of burrowing rodents to survive wildland fires *in situ* is apparently related to the earth's insulating effect. While temperatures rise in the burrows as fire sweeps over the area, the heat rarely exceeds $130^{\circ}$ - $150^{\circ}$ F. at 3" below the surface and much lower temperatures are found at greater depths (36). Birds can usually escape the flames, although they may lose their eggs and young in the nests.

When a fire occurs in chaparral, the temporary change in habitat from brush to grass results in a shift in specie composition in both birds and most small animals. But total population densities remain as high, or higher, than before the fire (98).

How a prescribed burn is planned and conducted in chaparral is important if one of the primary purposes is to improve wildlife habitat by converting the area to grass. Deer, for example, benefit from the grass forage and from browse supplied by brush regrowth (13). But they also require brush for cover. The ideal situation for deer, therefore, is a maximum of "edge" between brush and grass and maximum openings of about 200 yards wide (35). This same "edge" benefits a number of other small animals and birds who rely on the combination of grass and brush to provide both food and cover (12). Leaving islands of brush within the cleared, grassy area, is even more beneficial to wildlife.

## Air

Smoke from burning vegetation has always been a part of the wildland environment. Its effects on forest ecosystems, however, are only beginning to be studied to any great extent in California (36).

Today in California, the use of fire for any agricultural or other land management purpose is closely regulated by the State Air Resources Board. During the past several years the Air Resources Board has worked with most of the public and private land managers or owners to develop regulations pertaining to the use of prescribed burning. These regulations are intended primarily to keep large accumulations of wood smoke or smoke from other cellulosic materials away from large populated areas. These regulations are made more stringent and are enforced by local Air Pollution Control Boards. In cooperation with the National Weather Service, the Air Resources Board daily announces whether or not prescribed burning can occur in different air basins of the State.

Soil

Effects of fire on the chemical, physical and biological properties of wildland soils can be both good and bad. These effects are well documented in a large number of papers prepared in relation to California soils (38).

The burning of organic matter at the soil's surface releases substantial quantities of plant nutrients (91). Principal among these are nitrogen, phosphorous, calcium and magnesium (36). Before the fire, these nutrients are tied up in the living and dead plant material. In the combustion process these nutrients are freed as part of the ash or, to some extent, are volatized into the atmosphere. That portion which is contained in the ash becomes available for rapid plant growth following the fire. One study made in two California forest soil types showed that prescribed fire released nitrogen in both instances. Phosphorous was released in considerable amounts in burning conducted on one soil type (Holland soil type) but not on the second type (Salminas soil type), a soil which fixes phosphorous (91).

Temperatures of some 1400° F. can be produced by fires in heavy fuels. Temperatures in this range can alter the mineral soil near the surface, such as causing irreversible changes in the water of hydration in clays (36). The destruction of organic matter at the surface removes an important aggregating agent, partially responsible for good soil structure. Some of the large pores, which improve water transportation and aeration of the soil, are also lost (36).

Repeated burns on a ranch in the north coastal area of California resulted in sparse vegetation, limited soil humus, and heavy packing of the soil. Such hardening of the soil promoted surface run-off and soil erosion (82). Similarly, burning in the woodland-chaparral type of the Sierra-Nevada foothills destroyed the litter cover and reduced organic matter at the soil's surface and activities of sub-soil earthworms and insects. The result was a 94% reduction in the infiltration capacity of the soil (82).

Studies at the San Dimas Experimental Forest in southern California have shown that brush fires can cause a decrease in water infiltration by producing a water-repellent layer just below and parallel to the soil surface (37). The layer is caused by the composition of the brush and organic litter and the consequent release of vaporized, hydrophobic substances. These substances move downward and coat soil particles a few inches below the surface. The thickness and depth of the water-repellent layer depends on the intensity of the fire, the nature and quantity of the organic matter burned, and certain soil factors (36). When rainfall occurs following the fire, the water penetrates the top, wettable layer and then encounters the non-wettable layer. When a thin layer of soil above the water-repellent layer becomes saturated, the water flows laterally and runs off, taking the upper layer of soil with it. This soil becomes an important source of debris from burned areas. The results are removal of the most fertile layer of soil, deep erosion in rills and gullies, and deposition of soil and accompanying debris in stream beds and downstream reservoirs.

Mass movement of soil by creep or landslides may be the dominant form of erosion on many mountainous slopes in California following a wildland fire (71). Following a large wildfire that swept through the San Dimas Experimental Forest in southern California in 1960, the U. S. Forest Service designed several experiments relating to watershed management. In one study about 350 acres formerly occupied by chaparral were converted to grass for a variety of purposes. Soil erosion on this converted area was compared to a control watershed which was permitted to recover naturally to chaparral. The two watersheds had many slopes steeper than 70%, more than the angle of repose of the soil. Results six years later showed that soil slippage was increased by conversion of brush to grass (33):

| | Converted Watershed | Control Watershed |
|---|---|---|
| Total Acres | 354.1 | 357.7 |
| Average number of soil slips per acre | 2.46 | 0.48 |
| Total acres involved in the slips | 28.74 | 6.43 |

Most of the slips occurred at the lower depth of the root system of the burned brush. Others occurred to a lesser extent at the surface of bedrock or at other interfaces in the soil horizons. The number of slips on both the converted and control watersheds increased with slope, about one-half the slips on the converted watershed occurring on slopes more than 70%. Soil depth was also an important factor; generally, the number of soil slips decreased as the soil depth increased, especially for soil greater than 2' deep. All of these factors have important economic and management implications in planning and conducting prescribed burning in steep, mountainous areas.

Dry creep plays an important role in soil erosion in dry climates such as in southern California. It consists of the rolling, tumbling, downhill movement of individual soil particles ranging in size to small boulders (71). When fire removes the protective mantle of vegetation, the dry soil particles may begin their gravitational migration almost at once. Even before the fire has run its course, dry creep may be blocking roads and trails. Considerable dry soil is deposited in stream channels, providing a ready supply of sediment during subsequent periods of high rainfall and stream flow. The dry-creep effect may persist for several years following a fire and can account for as much as 45% of the total soil movement in the mountains of southern California (71).

Landslides occur less frequently than either wet soil creep or dry creep. The triggering mechanism for landslides is an extended period of intense rainfall (70). Because of water concentration, landslides tend to be concentrated close to drainages where the contours are concave on the upper slopes and near the stream channel on the slower slopes (71). Again, planning of prescribed burning must account for these potential effects.

The total production of debris from all types of erosion can be great. In the first two years following the occurrence of large fires in the San Gabriel Mountains in 1960, 33 unburned watersheds produced about 6,000 cubic yards of debris per square mile, while 16 partially or wholly burned watersheds produced about 40,000 cubic yards (68).

## Water

Using fire to remove vegetation from mountainous slopes has many diverse effects on water flow and quality (82). Not all of these effects are agreed to by researchers, and much work yet remains to be done (1). Only a few aspects of the subject will be treated here.

Generally it can be said that significant increases in total water yield can be expected from deeper soils where brush has been converted to grass (13). Further, this yield is especially significant in that it extends into the drier months of California's long dry summer. The same increase in water production cannot be expected from more shallow soils.

It has already been noted that fire may cause the formation of a water-repellent layer just a few inches below the surface of soils on which chaparral has been growing (37). The result is a large increase in surface run-off of rainfall, thereby magnifying flood waters that may occur from a high intensity storm. Even small storms exceed the capacity of the thin, wettable top layer of soil to store and transmit water (69). In an unburned watershed covered by chaparral, surface flow of water rarely exceeds 1% of the rainfall. On the other hand, up to 40% of the rainfall can be measured as surface flow during the first year following a fire (69). The increased flow can act as the agent for transporting large quantities of sediment from the watershed, resulting in huge flows of mud and water and creating damages to downstream improvements (68). Not all the sediment from these peak flows is eroded from the watershed at the time. Most of it has been accumulated in stream channels over the years since the last flood and is picked up and carried away by the increased flow of water following a fire (69).

Another study at the San Dimas Experimental Forest compared water flow from two adjacent watersheds, one of which had its protective vegetative cover destroyed by fire in December 1953 (87). Flow of water from the two watersheds had been similar prior to the fire. During the first wet season after the fire, peak flows from the damaged watershed reached a maximum 28 times as great as expected had it been unburned. Water from the damaged watershed was choked with debris washed from the burned slopes and the stream channels below. At the same time water flowing from the adjacent, unburned watershed was comparatively clear.

## Visual and Aesthetics

Not too much has been written on the reaction of California's citizens to the visual and aesthetic effects of fire on the wildland environment. The National Park Service has reported that the public seems ready to accept both the natural role of fire in the forest and the Park Service's program to restore fire to that role as nearly as possible and practical (54). No description was given as to how this conclusion was reached.

Another admittedly unscientific survey asked the public whether they supported the Forest Service's plan to convert chaparral areas to a vegetative type more suitable for man's use and safety (3). Eighty-eight percent of the respondents opposed that plan in favor of another plan which was intended to keep chaparral in more or less its natural state.

## Property and Improvements

The removal of vegetation from the mountainous areas of California by fire can have a disastrous effect on property and improvement values lying downslope from the burned area. In the discussions related to the effects of fire on soil and water, it has been described how fire in chaparral, for instance, can result in tremendously increased flows of water and debris. As this viscous mixture flows out of a burned watershed, it can fill reservoirs, destroy roads, and inundate homes and agricultural areas, causing many millions of dollars of damage and taking the lives of people (26, 32, 68, 75).

The fire that swept the San Dimas Experimental Forest in 1960 cost public agencies some $917,000 (1960 dollars) to repair roads and flood control structures and to clean out debris basins (68). Following a fire in Palmer Canyon in 1953, heavy rains and debris-laden floods destroyed a canyon road, washed away homes, and damaged several others (75). A fire in the Big Sur Area in 1972 was followed a month later by heavy rains. Damages to highways, homes and other property amounted to about $1,750,000 according to estimates made later (32). Still another fire in Yolo County in 1972 resulted in damages to roads and orchards estimated to be about $500,000 following intense winter rainfall (26).

The months of August and September in 1955 have been described as comprising the worst period in thirty years, up to that time, from the standpoint of occurrence of disastrous fires (29). In eighteen days there were 436 wildfires in the State, 41 of which became 300 acres or larger in size. That included an 87,000 acre timber and brush fire in Siskiyou County and a 75,000 acre fire in chaparral in Santa Barbara County. All together the fires laid waste to some 141,000 acres of timber and 166,000 acres of critical watershed that had been covered by woodland, brush and grass. Rainfall in December 1955 and January 1956 was especially heavy, although not as intense as in some previous years. The denuded slopes played an important role in the floods and disaster that followed: more than 75 lives were lost, many hundreds of homes and places of business were swept away or inundated by water or mud, several thousand head of cattle and sheep drowned and many millions of dollars damage were caused to other resources and improvements. The cost of repairing public roads alone was estimated at that time to be more than 31 million dollars.

These potential and real damages are among the effects that must be considered in the planning and conducting of prescribed burns.

## USES OF FIRE

California's range improvement program, authorized by the Public Resources Code, has produced the following results from 1945 through 1973:

| | |
|---|---|
| Total number of burns . . . . . . . . . . . . | 8,910 |
| Total acres burned under permit . . . . . . . . | 2,533,904 |
| Excess acres burned by escaped fire . . . . . | 191,406 |
| Acres reburned under permit . . . . . . . . . | 780,363 |
| Acres seeded with grass . . . . . . . . . . . | 755,956 |

Most of the prescribed burning has been for the purpose of converting brush to grass for forage for domestic livestock (17, 20). Some burns, however, have been for the primary or combined purposes of improving wildlife habitat (9), or of destroying noxious weeds (50). Regardless of the primary purpose, nearly all burns have produced a net decrease of fine fuels, a result of benefit to the wildland fire protection problem in California (67).

Records are not kept regularly of the cost of range improvement burns conducted under the State's range improvement program. Early in the program, however, a study was made of 190 prescribed burns which showed the following costs (74) (dollars are shown at 1947 and 1948 levels):

(1) As size of fire increased from 40 to 440 acres, the permittee's cost of conducting the burn decreased rapidly from $2.95 to $0.45 per acre; when the burned area increased from 440 to 640 acres, the cost increased to $0.80 per acre.

(2) The relationship of costs to the State was almost the same as for the permittee. As size of the burn increased from 40 to 440 acres, the cost to the State for administration and standby of suppression crews decreased from $0.70 to $0.15 per acre; as size of the burn increased from 440 to 640 acres, the cost rose to $0.40 per acre.

(3) The curves described by these costs to the permittee and the State closely correlated with the curve of cost to the State of suppressing wildfire: about $5.50 per acre for fires of 40 acres in size, to about $1.00 per acre for fires of 440 acres in size, to about $2.00 per acre for fires of 640 acres.

In 1966 costs of burning piled or bunched slash from logging operations were reported as varying from $5.00 to $75.00 per acre, depending on conditions (topography, amount and sizes of slash, age and density of timber stand, etc.) The costs of broadcast-burning clear-cut blocks of slash ranged from $5.00 to $25.00 per acre (58).

The cost of using broadcast fire to maintain fuelbreaks in mixed conifer in the central Sierra-Nevada was reported in one study in 1970 as averaging $4.24 per acre (81).

Prescribed burning in California is not inexpensive, and it does have important potential for damaging ecological values. Therefore, the decision to use fire for various purposes of land management must be weighed very carefully. And consideration must be given to alternative means of changing the wildland environment.

## ALTERNATIVES TO PRESCRIBED BURNING

Several techniques have been developed in California and elsewhere as alternatives to prescribed burning or as aides to making prescribed burning more safe or more effective.

Effectiveness of prescribed burning can be increased considerably or replaced by crushing brush or thinnings in young-growth timber. Some of these techniques include using a bulldozer with raised blade (18, 40); a heavy brush disc (43); ball and chain (19, 45); brush cutter-crusher (7, 40); and chipper (76). Other alternatives to prescribed burning include burying of cut vegetation (79) and the possibility of using chaparral as a source of pelleted roughage for cattle of resins for varnish or medicine, of tannins or waxes, or of cellulose for chipboard (10).

One study has attempted, without success, to use chemicals to accelerate the decomposition of logging slash (52). Also, field studies of logging slash in the mixed-conifer type of the Sierra Nevada in northern California over a 34-year period showed that breakdown and decay of the slash occurred at a much slower rate than previously reported for softwoods and hardwoods in other regions of the United States (94). Incense cedar had the slowest rate of decay followed in order by sugar pine, and white fir. In California a span of at least thirty years was needed to lower the fire hazard from the Forest Service's rating of "extreme" (immediately following logging) to a rating approximately comparable to that observed in the stand before logging took place.

When considering the use of prescribed burning, land managers should always look at available, alternative means of achieving objectives. This step is especially desirable if the use of fire has a high potential for unacceptably damaging resources, life and property, or if there are important doubts about the potential effectiveness of prescribed burning for achieving objectives.

## SUMMARY AND RECOMMENDATIONS

Most private and public land managers in California agree that prescribed burning does indeed have a role in land management. But many of them have doubts about the cost-effectiveness of prescribed burning in specific situations; they feel that there is not enough precise, dependable knowledge of how to apply and manage fire in a broad variety of environmental situations consistently and safely (14, 22, 73).

There is also support for finding alternative ways of achieving land management objectives other than through the use of prescribed burning.

Following the disastrous fire season of 1970 in California (63), the State Secretary for Resources appointed a Task Force to Solve California's Wildland Fire Problem. After a year and a half of study and deliberation, the Task Force reported a series of recommendations intended to help solve the State's fire problem (8). These recommendations included a series on fuel management and hazard reduction:

(1) Prepare hazard reduction standards for wildland subdivisions.

(2) Encourage land management agencies to use prescribed burning techniques to selectively reduce fuel hazards consistent with management objectives and laws and with due concern for environmental quality.

(3) Provide standards for locating and constructing fuelbreaks and green-belts.

(4) Increase the number of men available for building fuelbreaks and other fire control facilities.

(5) Urge fire prevention organizations to give increased emphasis to fuel management and fuel hazard reduction.

(6) Investigate current insurance practices covering prescribed burning operations on privately owned wildlands and determine the fiscal liability of private individuals for costs of suppression and damages in the event of the escape of a prescribed fire.

(7) Determine the legal responsibility of public fire protection agencies for fuel hazard reduction on private lands.

(8) Demonstrate fuel management techniques in high fire hazardous areas.

(9) Implement fuel management programs in the California State Park and Recreation System for fire prevention and hazard reduction purposes.

(10) Urge county road departments to implement fuel hazard reduction programs for all county-maintained roads located in high fire hazardous areas.

(11) Strengthen legal requirements for clearance of hazardous wildland fuels adjacent to structures beyond property lines.

(12) Strengthen research and action programs related to "fire resistant" plants.

(13) Find new ways of controlling brush growth.

(14) Synthesize and summarize all fuel management and hazard reduction information for all wildland vegetative types in California and recommend action programs for each type.

(15) Establish an ad hoc Fuel Management and Hazard Reduction Action Committee to coordinate implementation of these fuel management and hazard reduction recommendations.

Since 1972 most of the recommendations have been wholly or partially implemented through an Action Committee appointed for that purpose. Today the Action Committee continues its task and is focusing its efforts toward the demonstration of fuel management techniques, including the use of prescribed burning, at two locations: the Laguna-Morena Fuel Management Demonstration Area in San Diego County in southern California, and the Blodgett Forest Fuel Management Demonstration Area in El Dorado County in the central Sierra-Nevada. Work in these two areas is just getting started but holds much promise of finding some of the answers that land managers in California need about the safe, economical and effective use of prescribed burning and other fuel management techniques.

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