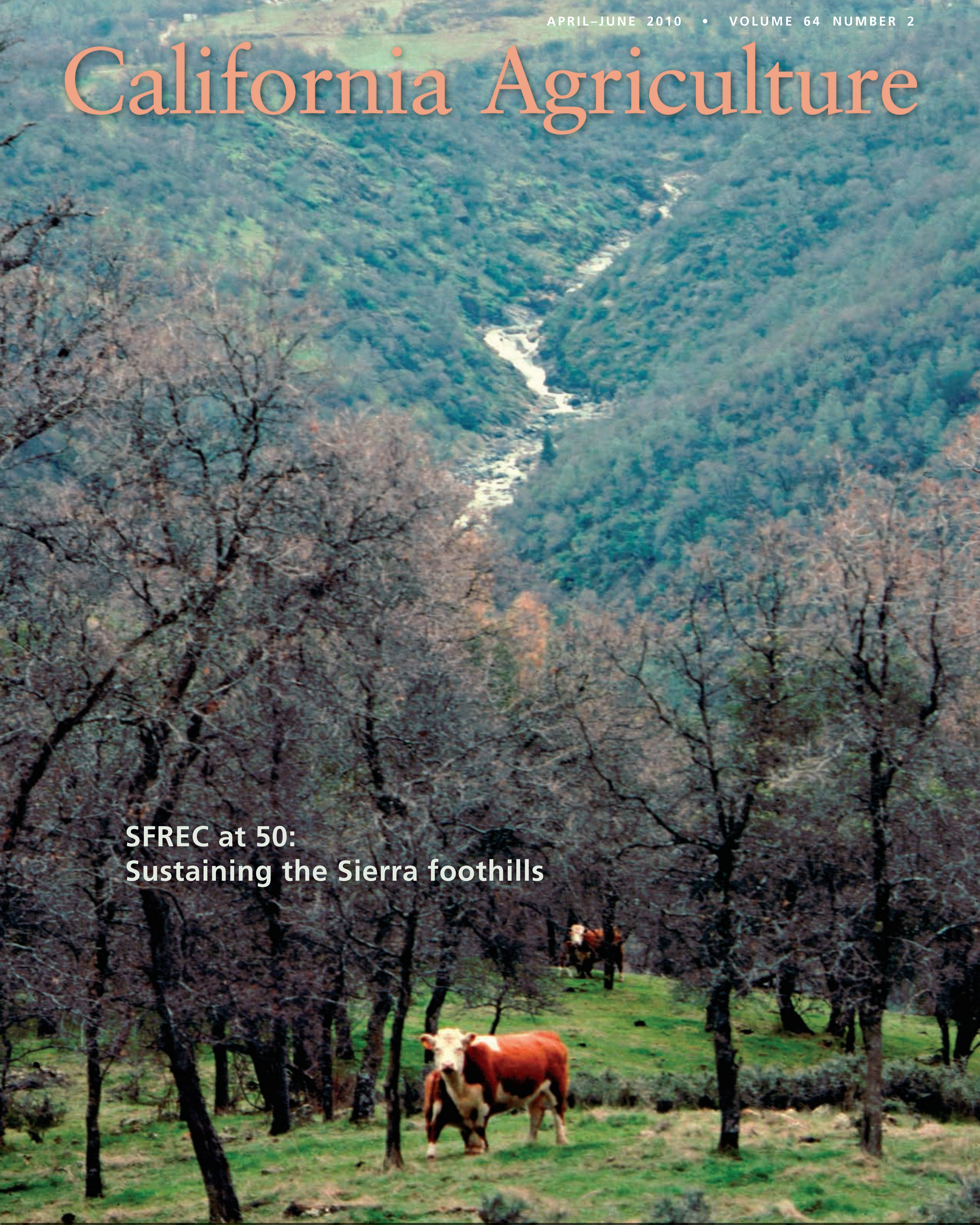
APRIL–JUNE 2010 • VOLUME 64 NUMBER 2

California Agriculture



SFREC at 50:
Sustaining the Sierra foothills

University of California | Peer-reviewed Research and News in Agricultural, Natural and Human Resources

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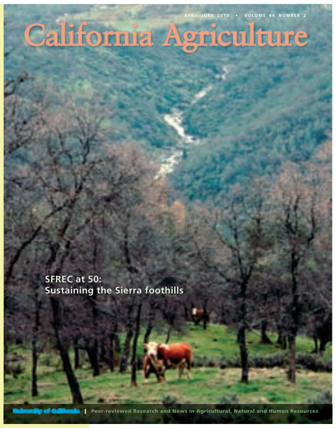

COVER: Deer Creek flows through the UC Sierra Foothill Research and Extension Center, where research on oak woodlands, rangeland, cattle management and water quality has flourished for 50 years. *Photo by Charles Raguse*

THANK YOU: The *California Agriculture* staff is grateful to SFREC director Art Craigmill and UC Cooperative Extension rangeland watershed specialist Ken Tate for their contributions to this special issue.

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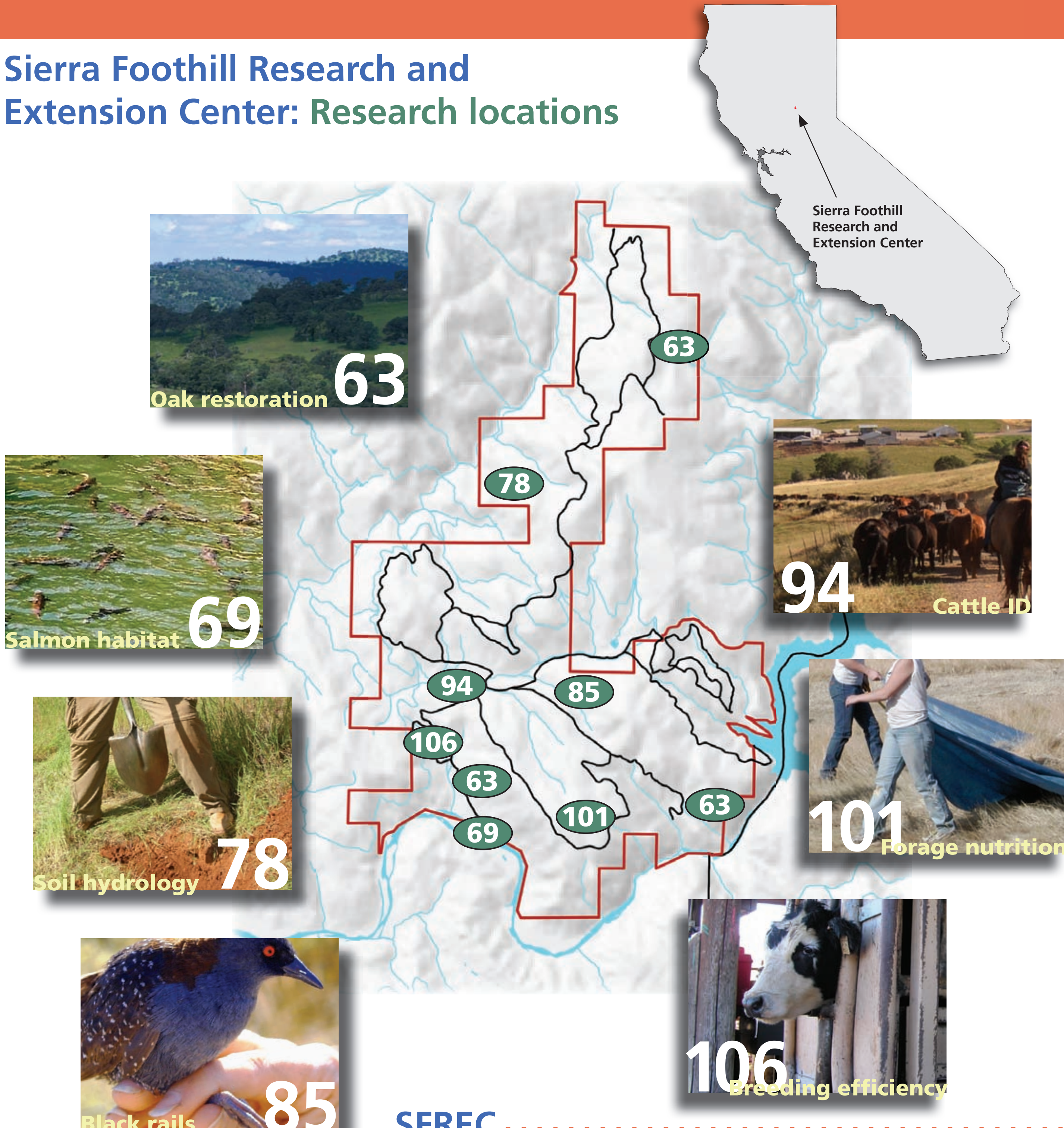

SFREC

Established: 1959
Terrain: 5,721 acres of rolling to steep terrain (220' to 2,020' above sea level)
Climate: Mediterranean — hot, dry summers; mild, rainy winters
Annual precipitation: 9" to 44"
Annual mean precipitation: 28"
Annual mean temperature: 60°F
Summer (July-August) mean maximum temperature: 90°F
Winter (November-March) mean monthly minimum: 37°F to 43°F
Soil series: Auburn, Sobrante, Las Posas, Argonaut and Wyman
Vegetation type: Mix of hardwoods, mostly oak, and annual grasslands

About California Agriculture

California Agriculture is a quarterly, peer-reviewed journal reporting research, reviews and news. It is published by the Division of Agriculture and Natural Resources (ANR) of the University of California. The first issue appeared in December 1946, making it one of the oldest, continuously published, land-grant university research journals in the country. The circulation is currently about 15,000 domestic and 1,800 international.

Mission and audience. *California Agriculture*'s mission is to publish scientifically sound research in a form that is accessible to a well-educated audience. In the last readership survey, 33% worked in agriculture, 31% were faculty members at universities or research scientists, and 19% worked in government agencies or were elected office holders.

Indexing. The journal is indexed by AGRICOLA; Current Contents (Thomson ISI's Agriculture, Biology and Environmental Sciences, and the SCIE databases); the Commonwealth Agricultural Bureau (CAB) databases; EBSCO (Academic Search Complete); Gale, including Lexis-Nexis; Google Scholar; Proquest; and others including open-access journal databases. It has high visibility in Google searches. Peer-reviewed articles are posted at the California Digital Library's eScholarship Repository.

Authors. Authors are primarily but not exclusively from UC ANR; in 2007 and 2008, 22% and 15% (respectively) were based at other UC campuses, or other universities and research institutions.

Reviewers. In 2007 and 2008, 19% and 14% (respectively) of reviewers came from universities and research institutions or agencies outside ANR.

Rejection rate. Our rejection rate ranged between 20% and 25% in the last two years, and in the year ending May 31, 2008, associate editors sent back 24% of manuscripts for major revision prior to peer review.

Peer-review policies. All manuscripts submitted for publication in *California Agriculture* undergo double-blind, anonymous peer review. Each submission is forwarded to the appropriate associate editor for evaluation, who then nominates three qualified reviewers. If the first two reviews are affirmative, the article is accepted. If one is negative, the manuscript is sent to a third reviewer. The associate editor makes the final decision, in consultation with the managing and executive editors.

Editing. After peer review and acceptance, all manuscripts are extensively edited by the *California Agriculture* staff to ensure readability for an educated lay audience and multidisciplinary academics.

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IPM for LBAM

I just read the article on integrated pest management (IPM) for the light brown apple moth (LBAM) in New Zealand, and I want to thank you for publishing this research ("New Zealand lessons may aid efforts to control light brown apple moth in California," by Lucia Varela et al., January-March 2010).

Jan.–Mar. 2010

It is such a relief and pleasure to me to see documented — in a peer-reviewed scientific journal by a team with such excellent credentials — what the literature on LBAM and the experience in New Zealand tell us about the real risk (or lack thereof) posed by LBAM and the effectiveness of simple, low-impact IPM methods for managing LBAM, if management is needed.

I sincerely hope that this research on parasitoids for LBAM will lead to a much more rigorously science-based approach that will result both in relieving farmers of burdensome quarantines and in ending the costly, unnecessary, and likely also dangerous and ineffective eradication program that the state has been promoting.

Nan Wishner, Chair Emeritus
Integrated Pest Management Task Force, Albany, CA

Amazing urban bees

The photo on the cover of the July-September 2009 issue of *California Agriculture* ("Native Bees Enrich Urban Gardens") is amazing (and many of the inside photos are great, too). Was that shot by a researcher or by someone on the magazine's staff?

July–Sept. 2009

I just wanted to let you know the magazine looks great.

Kevin Leigh Smith, Editor, Agricultural Communication
Purdue University, West Lafayette, IN

Editor's note: The cover photograph was shot by Rollin Coville, an environmental entomologist, photographer and member of Gordon Frankie's research team at UC Berkeley.

I read *California Agriculture* (July-September 2009) closely enough to have noticed the ACE award you won, so here's a hearty congratulations. Well-deserved, and has been for a long time. I was reading it while eating my bacon and eggs this morning. Not sure how holistic that is, but I thank the farmers and animals.

The article on urban bees ("Native bees are a rich natural resource in urban California gardens") is on the very cusp. I have some friends who keep bees in the suburbs here. What I loved about your bee package was how much I learned about the many varieties of bees and their different life-strategies.

Joseph A. Davis, Writer-Editor
Bethesda, MD

Cal Ag art director retires

Davis Krauter, *California Agriculture*'s art director since 2001, retired on Feb. 26 with 26 years of service to the University. He presided over more than 40 issues of the journal, including several award-winners, with his characteristically strong sense of design and color; attention to detail and the "big picture"; and plenty of wit and humor. During his tenure, *California Agriculture*'s look became more stylized, vibrant and modern, with clear and appealing figures and tables and exacting color calibration. Davis played a major role in the overhaul of the *California Agriculture* Web site to a dynamic, database-driven model. From 1984 to 2001, Krauter worked as artist and senior artist with University and External Relations in the UC Office of the President. Krauter earned a bachelor of science degree in environmental education from UC Berkeley's College of Natural Resources. Davis plans to freelance, travel, work on his Berkeley house and spend more time with his wife Kristine.

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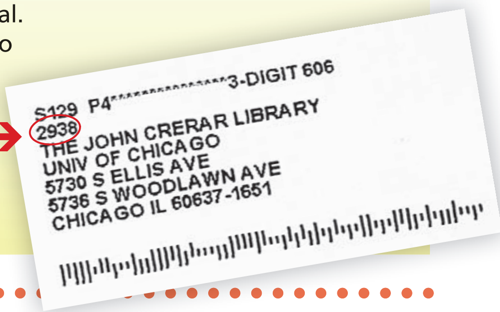
— *Editor*



Charles Raguse

Editorial overview

SFREC research sustains rangeland and oak woodlands

Sixty miles northeast of Sacramento, the land rises and folds into the Sierra foothills, a trademark California landscape. Here, largely unnoticed, are 5,700 uniquely managed and protected acres — the site of landmark UC research for the last 50 years.

The story of the Sierra Foothill Research and Extension Center (SFREC) has relevance to all Californians, because rangeland accounts for more than half of the state's 101 million acres. This land not only hosts rich biodiversity and provides forage for cattle, but also forms most of the major drainage basins of the state, constantly filtering and purifying our water supply. Almost all of California's surface water, including drinking water for millions of people, passes through it.

For half a century, SFREC has advanced understanding of this vast natural resource, with its oaks, irrigated pastures, canyons, watersheds and wildlife. SFREC research has informed oak restoration, protection of water supplies, sustainable cattle ranching and wildlife restoration here and in Mediterranean ecosystems around the world. Through its research and guidelines for sustainable practices, SFREC has guided the stewards of this land, both the ranchers who own about half of these 57 million acres, and entities such as the U.S. Forest Service, regional parks and Bureau of Land Management that manage the rest.

In tribute, this issue of *California Agriculture* features a collection of current SFREC research. Articles discuss oak woodland restoration, salmon habitat rehabilitation, stream water and soil chemistry, the threatened California black rail (a secretive marsh bird first found here in 1994), and cattle tracking, nutrition and breeding research.

Arthur L. Craigmill
Director, UC Sierra Foothill Research and Extension Center

Kenneth W. Tate
Cooperative Extension Rangeland Watershed Specialist, UC Davis

The roots of SFREC go back to 1874, when Alexander R. Forbes began raising cattle on a 160-acre homestead. During the 1900s his sons acquired neighboring properties and by the 1950s E. Floyd Forbes (Alexander's grandson, president of the Western States Meat Packing Association) had accumulated 5,014 acres, which he sold to UC in 1960. UC would acquire three more properties to complete what was then the Sierra Foothill Range Field Station.

SFREC is one of nine such UC facilities located throughout the state's diverse production and climate zones. Collectively, these centers offer unique opportunities for onsite research and education. They allow scientists to study California's diverse ecosystems and wildlife, as well as crops and livestock, in a carefully managed environment.

For example, the Schubert experimental watershed was instrumented to measure stream flow and water quality in the late 1970s. Continuous monitoring by UC scientists and staff since that time now provides a unique 30-year record that scientists use to address contemporary questions about water quality and its response to various land management regimes, as well as stream flow responses to climate change.

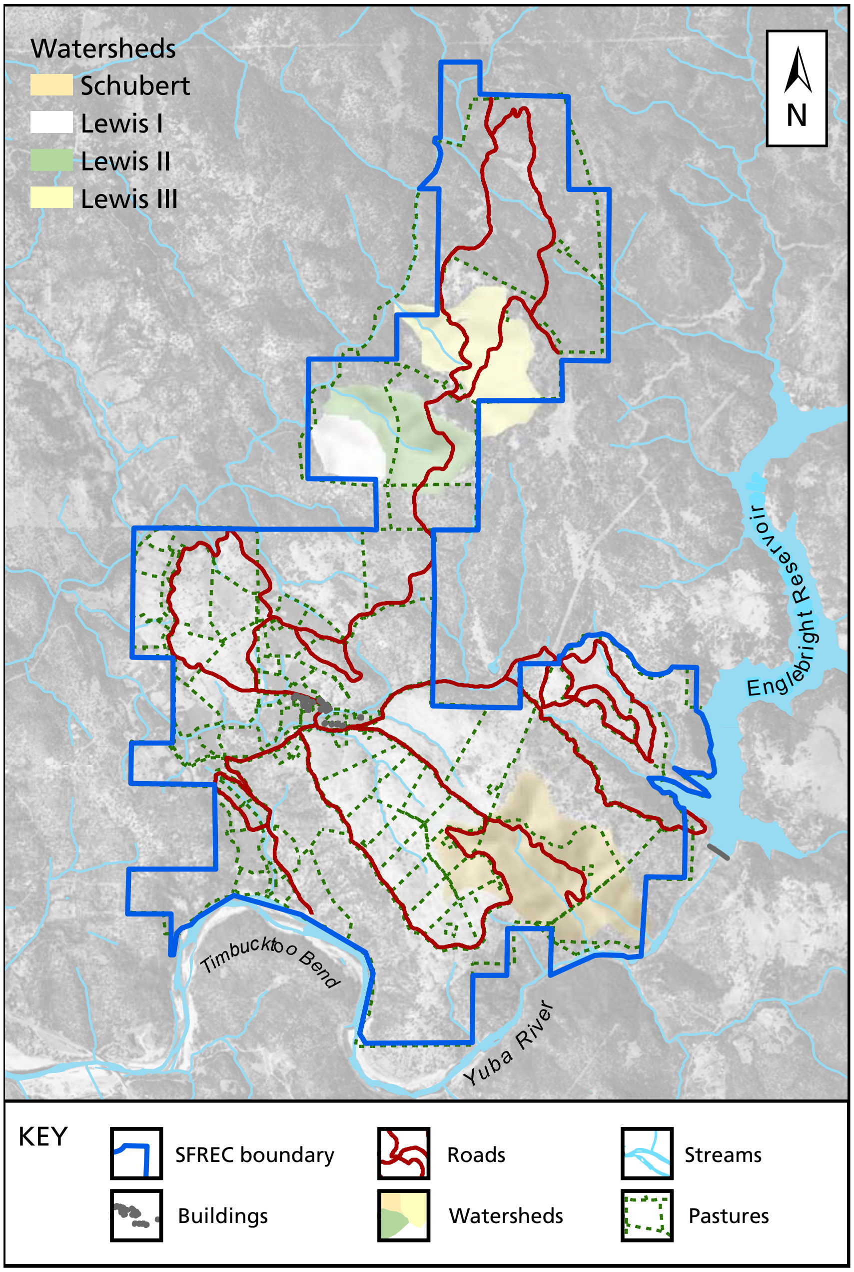
In 1995, three additional watersheds were integrated with the longer-term Schubert watershed, and researchers began collecting plant, soil, weather and water data. Over the past 15 years, these watersheds have been used to measure the effects of cattle stocking rates and prescribed fire on water quality and distribution, soil properties and plant communities. The watersheds and data sets are also used to demonstrate watershed management and monitoring to ranchers and professionals in state and federal agencies.

When it was founded in 1960, SFREC's first priority was pasture development for a thriving cattle and calf industry. Scientists recognized early on that ranchers made important contributions to the state's economy and environment. If ranchers could maintain profitable enterprises, they would also protect the open range and foothills, with all their environmental benefits, from development.

In the early 1960s, SFREC scientists cleared some pastures of native oaks and shrubs and reseeded with pasture grasses and legumes to enhance forage production for livestock grazing. Early studies supplied our fundamental understanding about the effects of sunlight, soil moisture, elevation, slope and aspect on annual rangeland productivity. Concurrent research on beef cattle production focused on breed selection, nutrition and disease control. At the same time, station scientists protected some pastures and woodlands, permitting no vegetation conversion or grazing. These provided a basis for comparing ecosystem responses with and without agricultural management.

The focus has expanded over the past 30 years to include the restoration of oaks and native species, wildlife habitat improvement, weed management, and water and soil quality enhancement. Researchers have directed effort to striking a prosperous balance between livestock production and natural resource enhancement. Basic research has led to discoveries about how this ecosystem functions. Applied research elucidated how rangeland management affected ecosystems. Through educa-

◀ ***Facing page*, the Yuba River flows along the south border of the UC Sierra Foothill Research and Extension Center.**



Shane Feirer

This recent aerial image is overlaid with major topographical features of SFREC. Instruments installed on the Schubert watershed, which drains into the Yuba River, have continuously monitored water quality since the late 1970s.

Charles Raguse

Once removed to plant forage for grazing animals, oak woodlands are now being restored statewide using techniques developed at SFREC.

tional programs, SFREC personnel delivered this knowledge to the public for application.

In addition to providing a managed setting for field-scale research, SFREC serves as an outdoor classroom for learning how to restore and sustain oak woodlands, as well as how this can be done in the context of a cattle enterprise. UC Cooperative Extension advisors have conducted grazing academies to teach attendees about how to achieve multiple objectives. For more than 20 years, SFREC has hosted the annual Beef and Range Field Day (proceedings of which may be found on the center Web site).

Like the other nine centers, SFREC pursues basic and applied research designed to answer questions for Californians as a whole, and in particular for ranchers who are the stewards of rangelands. By studying problems under local conditions, UC develops information that is directly relevant to local needs and yet applicable on a global scale. For example, SFREC research directly contributed to USDA grazing guidelines for the sustainable use of foothill ranges, as well as guidelines to foster oak restoration on millions of acres, here and abroad.

Such studies are virtually impossible to conduct on private lands as they could have adverse economic effects on the owners whose lands were taken out of production; on public lands, the security of research sites and equipment is difficult if not impossible to ensure. Additionally, scientific studies require rigorous controls, usually over many seasons or years and a wide range of treatments.

Research at SFREC will become more critical in coming years, as climate changes and competition increases for limited natural resources. The crisis of water quality and quantity will continue to challenge our state, as will the need to conserve native plant and animal species. Persistent invasion by weedy plant species threatens the diversity and agricultural productivity of annual rangelands. Ongoing and new studies address these issues, as well as the interactions between them.

This living laboratory, with its well-documented physical and geographical terrain and its history of basic and applied findings, can inform new research and guide the management of our precious resources in the challenging years to come.

▶ Climate change and limited natural resources will present challenges for future generations of SFREC researchers.

Charles Raguse

Charles Raguse

This special issue in honor the 50th anniversary of the UC Sierra Foothill Research and Extension Center was the brainchild of Charles Raguse, UC Davis professor emeritus in agronomy (1964–1993). Raguse's decades of research at SFREC focused on range science, ecology and the management of grazing systems. In his busy retirement, Raguse (self-titled "The Iconoclast") is writing a history of SFREC, *Diamond in the Rough*.

Sierra foothills research center celebrates 50 years of rangeland productivity

When the UC Sierra Foothill Research and Extension Center (SFREC) was established in Yuba County in 1960, much of the focus was on increasing cattle production by improving forage. Now, as the center celebrates its 50th anniversary, its mission has expanded beyond rangeland productivity to emphasize natural resource protection and restoration.

"We want everything from rangelands all at once," says UC Davis rangeland watershed specialist Kenneth Tate. "Society expects us to graze economically, control weeds, conserve native species, produce clean water and sequester carbon."

Charles Raguse

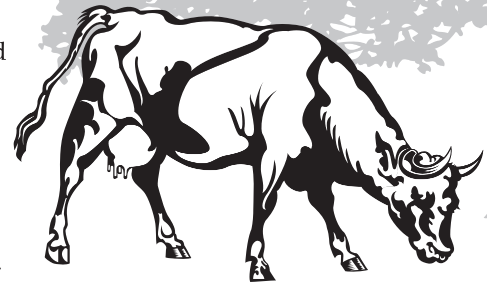
The cattle herd at SFREC is used to study production methods, grazing impacts, breeding, diseases and other animal issues.

Rangeland benefits

SFREC is the youngest of the nine UC centers that facilitate research and outreach in climatic and agricultural regions statewide. The 5,700-acre center, located in Browns Valley about 60 miles northeast of Sacramento, typifies California's foothill rangelands, with its mix of oak and annual grass rangelands and terrain that extends from about 200 to more than 2,000 feet above sea level.

"It's the perfect place for field work," says Tate, chair of the SFREC Research Advisory Committee. "It's large enough to support management-scale research, has a diversity of natural resources and has a sizeable cow herd that allows us to study grazing scenarios."

Occupying more than half of the land statewide, California's 57 million acres of rangelands provide considerable economic and environmental benefits. Nearly half of this acreage is privately owned and provides forage for nearly all of the state's cattle and calves, California's 6th-largest agricultural commodity with a value approaching $1.8 billion in 2009.



Rangelands are also key to water quality and biodiversity. Because most of the state's major drainage basins are in rangelands, almost all of the surface water passes through them. The state's 10 million acres of hardwood rangelands, or oak woodlands, provide a host of ecosystem services from protecting watersheds to improving water quality to sequestering carbon. Oak woodlands are also home to the greatest diversity of plants and animals of any major habitat in California, with about 2,000 species of plants, 4,000 insects, 60 amphibians and reptiles, 170 birds and 100 mammals. SFREC research on the California black rail has led to recommendations for managing this rare marsh bird's habitat in irrigated wetlands of the Sierra foothills (see page 85).

But these economic and environmental benefits are threatened by demand for housing and other land uses, which has made the western foothills of the Sierra Nevada among the most rapidly developed regions statewide. "The recent development boom has decreased and fragmented our rangelands," Tate says. "We need to conserve what's left."

Cattle productivity and health

SFREC's five decades of research include work on cattle breeding (see page 106), nutrition (see page 101) and health that have helped boost beef productivity on foothill rangelands. Early findings contributed to establishing today's common practices of crossbreeding cattle, which has advantages such as hybrid vigor, and of calving in the fall rather than the spring, which has advantages such as decreasing calf diseases. Nutrition work includes studies showing how to supplement feed when the range forage is dormant as well as how to supplement selenium and copper, essential nutrients that are deficient in many foothill soils.

Health research includes studies showing that epizootic bovine abortion, or foothill abortion, is

"[SFREC is] the perfect place for field work. It's large enough to support management-scale research, has a diversity of natural resources and has a sizeable cow herd that allows us to study grazing scenarios." — Ken Tate

SFREC 50 years

April 1960
UC purchases 5,014 acres for Sierra Field Station from the Forbes family.

May 1960
Ken Wagnon and Phil "Bub" Wright move 48 cows owned by UC from the U.S. Forest Service San Joaquin Range to Sierra Field Station.

June 1960
Research Advisory Committee appointed; organized research begins.

1960s
"Rangeland improvement" projects undertaken to remove native oaks and brush, and plant grass and legume species for forage.

Charles Raguse

caused by bacteria transmitted by the Pajaroello tick. "After 40 years of work, we're finally getting close to a foothill abortion vaccine," says Michael Connor, director of the center from 1983 to 2005, adding that SFREC researchers are also working on a vaccine for pinkeye.

Another current project is tracking cattle via electronic identification (EID) (see page 94). "It's very cutting edge," says Arthur Craigmill, director of the center since 2006. "EID traces them from birth to carcass." This can help improve meat quality and increase food safety by, for example, preventing or controlling disease outbreaks or microbial contamination.

Improving forage

In SFREC's first decades, much of the rangeland research focused on increasing forage productivity. "They initially tried to improve rangelands by removing oaks and introducing new forage species," Connor says. This included cutting down oaks and using herbicides to keep the stumps from resprouting, using fire and herbicides to control brush, seeding with subterranean and rose clover, and then fertilizing these nutritious and palatable forbs.

In the 1980s, Connor began collecting forage productivity data that contributed to establishing a standard for sustainable grazing and stocking levels. Called residual dry matter (RDM), the standard is based on the finding that vegetation remaining in the fall affects the forage produced in the next growing season. "It's a good way of ensuring that stocking levels won't harm rangelands or water quality," says UC Berkeley rangeland ecologist James Bartolome, who helped develop the standard (see box, page 59).

SFREC's three decades of forage productivity data also helped ranchers secure federal drought assistance in 2008. "We had the data to show that it was a bad year," says SFREC director Craigmill, adding that long-term data collection and research are among the center's greatest benefits to Californians. "There are very few places where you can do this."

Charles Raguse

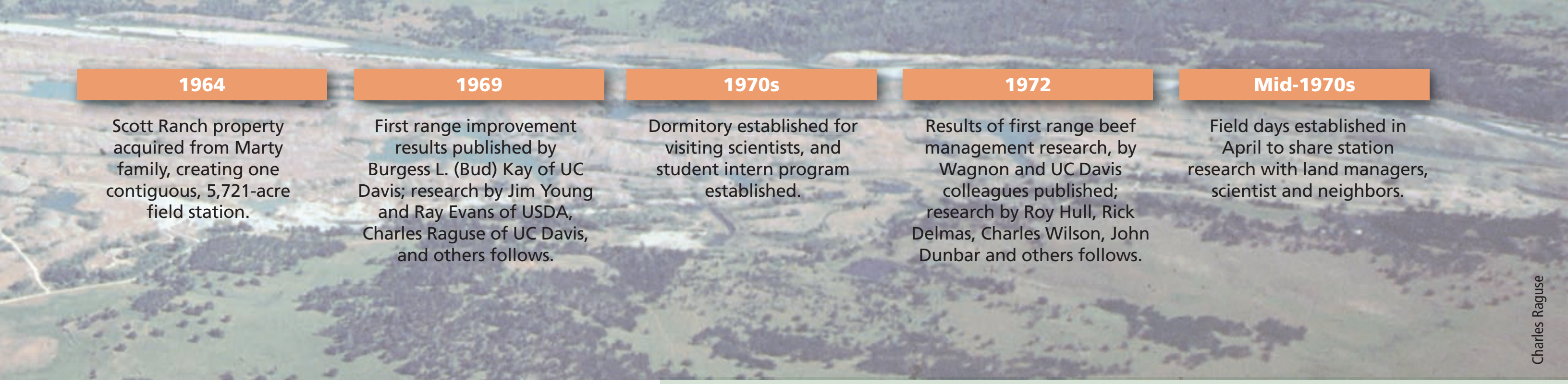
The Yuba River runs along the southern edge of SFREC; a new Yuba River Education Center overlooking the river will host students from surrounding foothills communities.

Vegetation management burns, or controlled burns, are conducted from time to time at SFREC, often to control invasive, nonnative plant species such as medusahead. In 1993, the Forbes pasture was burned.

Watersheds and ecosystem services

SFREC also has some of the state's longest-term data on watersheds. "Water quality really took legs in the late 1990s, as California as a whole began looking at improving waterways," Connor says.

This work includes studies on how water quality is affected by grazing and prescribed fire, two of the most effective and economical ways of managing rangeland vegetation. The primary water quality concerns on these rangelands are nutrients, sediment and animal-borne microbial pollutants such as fecal coliforms, a group of bacteria that indicate fecal contamination, and *Crytosporidium parvum*, a pathogenic parasite that spreads in feces and water.



Charles Raguse

1964

Scott Ranch property acquired from Marty family, creating one contiguous, 5,721-acre field station.

1969

First range improvement results published by Burgess L. (Bud) Kay of UC Davis; research by Jim Young and Ray Evans of USDA, Charles Raguse of UC Davis, and others follows.

1970s

Dormitory established for visiting scientists, and student intern program established.

1972

Results of first range beef management research, by Wagnon and UC Davis colleagues published; research by Roy Hull, Rick Delmas, Charles Wilson, John Dunbar and others follows.

Mid-1970s

Field days established in April to share station research with land managers, scientist and neighbors.

Charles Raguse

Englebright Dam was opened upstream of SFREC in 1941 as a sediment barrier; researchers are studying impacts of the dam and historic gold mining on chinook salmon.

Notably, SFREC studies by Tate and other UC researchers on pathogen transport in watersheds led to best management practices for vegetative buffer zones along streams and grazed areas that are used statewide today. Other findings include that moderate grazing, which meets RDM standards, and low-intensity prescribed fire have had minimal impact on water quality at the center. A comparison of ungrazed, moderate and heavy grazing showed that only the latter affected water quality significantly, by increasing fecal coliforms and nitrates.

The latest long-term watershed study will address how grazing affects multiple resources simultaneously. "Most research has been piecemeal, looking at the effect of grazing on a single resource such as water quality," UC Davis's Tate says. "We're taking an integrative, holistic look at watershed responses to grazing."

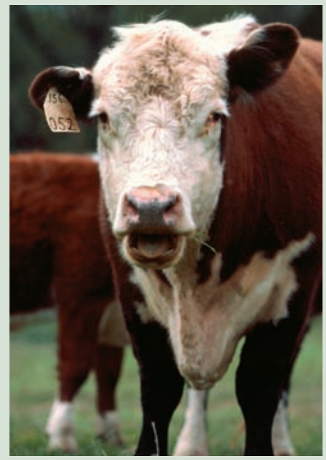
The team will evaluate how grazing affects a range of ecosystem services including forage production, water quality, biodiversity restoration, invasive weed resistance and soil carbon retention. These ecosystem services are also affected by soil properties, and recent work by UC researchers shows that the chemical and physical properties of SFREC soils can be extremely variable over short distances (see page 78).

"Ranchers are interested in conserving habitat and native species but they also have to make a profit, so we need to address both the conservation and economic aspects of grazing," Tate says.

Protecting rangelands from overgrazing

SFREC studies have tested and extended standards for safe grazing and stocking rates — called residual dry matter or RDM — that optimize forage quality and production, and protect soil from erosion and nutrient loss. RDM is rooted in observations from the 1930s and 1940s that the amount of dry vegetation left in the fall affects the next growing season's forage in California rangelands.

Used to manage grazing intensity in California for about 30 years, RDM has been widely adopted by local, state and federal land-management agencies including the Bureau of Land Management, the Forest Service and the National Park Service. This safe grazing standard has also contributed to more efficient rangeland valuation.



Charles Raguse

Forage quality and production standards developed at SFREC have aided in the management of millions of acres grazed by cattle in California.

"Grazing capacity is a major factor in rangeland values," says UC Berkeley rangeland ecologist James Bartolome, lead author of the RDM guidelines.

This is particularly true for land dedicated to agriculture under the 1965 Williamson Act, which benefits ranchers by basing taxes on farming use rather than on market value. By combining RDM with remote-sensing data and geographic information systems (GIS), UC researchers helped save millions of dollars in tax assessments of Williamson Act rangelands in San Joaquin Valley foothill counties.

RDM guidelines vary with factors such as rainfall and terrain, and in 1991 a scorecard was developed for estimating grazing capacity based on rainfall, slope and canopy cover. "It worked well when people tried it but there was little research to back it up," Bartolome says, adding that the initial standards were based largely on the study of nine sites around the state with variations in rainfall. "We reevaluated the data and identified gaps," he says. "The sites were all flat grasslands so we decided to see if RDM was affected by slope, aspect and woody cover."

To find out, Bartolome began studies on de-oaked hills at SFREC in the late 1990s. "Surprisingly, slope and aspect had little effect," he says. This work was incorporated into the latest RDM guidelines, which were set in 2006 and vary according to land type, from dry annual grassland to annual grassland/hardwood range to coastal prairie.

To see how woody cover affects RDM recommendations, Bartolome began studies on SFREC oak woodland watersheds in 2001. "We have not found the expected link between RDM and understory vegetation, which suggests that RDM may not work in oak woodlands," he says. "But the jury is still out."

— Robin Meadows

1976

Committee led by Raguse proposes criteria for rangeland improvement projects that take into account ecological concerns such as soil erosion, water quality and wildlife habitat.

1980

Results of rangeland beef nutrition work by James G. Morris of UC Davis published, followed by James Oltjen, Roberto Sainz and others.

1980

First journal publication of beef veterinary work by Norm Baker, Dave Baker and Laura Gershwin, and later John Maas and Lisle George, all of UC Davis.

1980

First publication of rangeland water quality research by Mike Singer of UC Davis; others follow, including Ken Tate, Rob Atwill and Mel George of UC Davis, and James Bartolome and Barbara Allen-Diaz of UC Berkeley.

1986

Integrated Hardwood Range Management Program established by UC and California Department of Forestry; Doug McCreary hired to lead research and extension program at Sierra Field Station.

SFREC directors

Ken Wagnon, 1960

Joe Guild, 1964

Paul Rowell, 1973

Mike Connor, 1983

Art Craigmill, 2006

SFREC employees wtih 30 years or more of service

Don Springsteen hired, 1961; retires as principal superintendent of agriculture, 1993.

Dave Labadie hired, 1963; retires as principal superintendent of agriculture, 2003.

Erle "Ed" Coffin hired, 1968; retires as herdsman, 2004.

Martin Beaton hired, 1978; currently serves as equipment manager.

Oak regeneration

After decades of eradicating oaks, SFREC researchers shifted their focus to restoring them. Growth of new blue oaks at the center and elsewhere around the state had become alarmingly low. During a 23-year study of how oak removal affected forage production, "there was a complete absence of regeneration from acorns," wrote UC Davis range scientist Charles Raguse and colleagues in a 1990 *California Agriculture* special issue celebrating SFREC's 30th anniversary.

"You'd see seedlings but they'd never make it to saplings," says Dustin Flavell, who has been superintendent of the center since 2003 and has participated in much of the hands-on research since beginning his career there as a summer intern in 1999.

Concern over the poor regeneration of several common oak species in the state helped lead to the establishment of the UC Integrated Hardwood Range Management Program (IHRMP) in 1986, which focused on ensuring the sustainability of oak woodlands. Although the program was discontinued in 2009 due to budget cuts and the resolution of many of the problems that had led to its establishment, former IHRMP specialists and advisors continue working on hardwood rangeland issues.

Douglas McCreary, who led IHRMP during its final decade, worked on artificial blue oak regeneration at SFREC for nearly 25 years (see page 63). This entailed first collecting and planting acorns, and then nurturing seedlings until they grew into saplings. Successful regeneration strategies include keeping seedlings weed-free and sheltering them from being eaten by livestock, deer and other herbivores.

However, artificial oak regeneration can be too time-consuming and costly to be feasible on a large scale. McCreary is now testing the strategies developed for artificial regeneration on naturally occurring seedlings at six sites representing the blue oak's range. Because acorn collection and planting are no longer necessary, natural oak regeneration could save considerable time and money. This could make ranchers more likely to restore blue oaks, which is critical because they own most of California's oak woodlands. The first three years of the study suggest that weed control and tree shelters increase natural oak regeneration, particularly in open areas.

"The results have been favorable but this has been during drought years," says McCreary, UC Berkeley area natural resources specialist in the North Sierra Region. "We're hoping for even better results if precipitation is up this year."

Claudia Stein

Cowboy Justin Tindall herded cattle for a study of native grass restoration in SFREC's lower Scott field in March 2009.

Weed control

California's rangelands are widely infested with yellow starthistle, a nonnative weed that crowds out desirable plants including native perennial grasses and the forbs and annual grasses that provide high-quality forage. Yellow starthistle also consumes up to two-thirds of the water held in soil after the rainy season, reducing its flow into streams and rivers.

While this noxious weed can be controlled either by burning or application of the selective herbicides aminopyralid and clopyralid, these methods take several years. "We wanted to find an integrative approach that would decrease the time it took to control yellow starthistle," says UC Davis weed specialist Joe DiTomaso. "Herbicide alone killed all the yellow starthistle but noxious non-

1992
Station renamed UC Sierra Foothill Research and Extension Center.

1992-99 / 2003-present
California Grazing Academy held at SFREC; more than 500 people from five to seven states attend.

1995
SFREC develops rangeland water-quality management plan, which becomes part of the Rangeland Water Quality Management Plan adopted by the State Water Resources Control Board.

1996
Porter Creek Nature trail established by McCreary.

April 7, 2010
Center celebrates 50th anniversary.

Charles Raguse

native grasses often filled in — and we knew that burning controlled those."

This work showed that the optimal approach was burning the first year, which stimulated yellow starthistle germination and so depleted its seed bank faster, and then treating with herbicide the second year. "It was perfect. There was hardly any yellow starthistle and few nonnative grasses," he says.

Native grass restoration

DiTomaso is now working on native grass restoration, starting with controlling medusahead, a noxious, nonnative, annual grass that has invaded much of SFREC. "The native perennial grasses are very slow-growing in the first few years and until they become established, it's hard to control the annual grasses," he says. "How do you kill one grass species growing among other grasses?" A promising approach entails clearing medusahead with the herbicide glyphosate, planting native perennials and then treating them with aminopyralid, a pre-emergent herbicide that keeps medusahead from germinating but does not harm the young perennials.

Another approach to perennial grass restoration involves shifting the balance from nonnatives back to natives. "Restoration is like a reverse invasion," says UC Berkeley plant ecologist Katharine Suding. "We're trying to get native perennial grasses to invade nonnative annual grasslands."

SFREC has two groups of nonnative grasses: palatable annuals that were introduced to the state 150 years ago for forage, and newer invasive annuals that cattle won't eat such as medusahead. Because grazing may have facilitated the transition from natives to nonnatives, grazing may also be able to facilitate the reverse transition.

"Just stopping grazing is not enough because the rangeland gets stuck in its degraded, exotic state," Suding says. Four years into the study, the findings suggest that while grazing fails to help native grasses invade stands of medusahead, moderate levels do help the natives invade stands of the palatable nonnative annuals.

Rancher and school group outreach

To help put its research results into practice, SFREC has updated landowners on the latest best management practices via annual field days since the mid-1980s as well as an annual 3-day grazing academy since mid-1990s. The latter includes a demonstration that "shows the different levels of RDM from ungrazed all the way to over-

Photos: Charles Raguse

Over the past 50 years, hundreds of scientists, students and interns have conducted research at the center. *Top left*, Ray Evans of the USDA Agricultural Research Service, Reno, installs thermocouples to monitor soil temperatures; *top right*, staff research associate Ken Taggard (back) and a student harvest and count subclover seedheads to estimate how much seed is needed per unit ground surface area; *above left*, Taggard uses a single-probe, electronic capacitance meter to measure forage mass, the basis for monitoring and adjusting stocking rate; *above right*, an employee gives a calf a milk substitute with essential supplements.

Charles Raguse

Field days at SFREC have helped to disseminate new, science-based information about oak restoration, range management, water quality and other rangeland issues.

grazed," former SFREC director Connor says. "It is especially important for training people not to overgraze so they can protect resources." Other outreach includes special field days on water quality, weed control and oak regeneration.

Photos: Charles Raguse

Improvement in the amount and nutritional quality of cattle forage has been an important line of research at SFREC. *Top left*, rose clover is an Australian species that was introduced for reseeding rangeland; *top right*, cow's teat clover, a rare native annual, resembles a cow's udder; *above left*, in a lightly stocked field, cattle preferred low-growing subclover to resident grasses and rose clover; *above right*, perennial ryegrass and orchardgrass emerge in an irrigated pasture early in the season.

SFREC also offers two educational resources for school groups. Established in the late 1980s by oak expert McCreary, the mile-long Porter Creek Nature Trail features stations explaining the ecology of the Sierra foothills as well as the many ways Native Americans used native plants, including a grinding stone to make acorn meal. "It's a good drawing card for classes," SFREC director Craigmill says.

Last year, Craigmill established another attraction for school groups: the Yuba River Education Center, which was donated by local philanthropist Ned Spieker and overlooks the river. The center has a curriculum that aligns with state educational standards, such as posters on wildflowers and watersheds. Students lucky enough to visit during the fall chinook run may get an extra treat. "We have a very special stretch of the river," Craigmill says. "It is one of the few in California where salmon spawn naturally, and they can be quite spectacular" (see page 69).

Just as it has over the last 50 years, SFREC will continue providing rangeland research and outreach to meet the needs of society, from ranching to drinking water to biodiversity. "What the public and landowners think is important," Connor says. "The emphasis of research reflects interests in the state."

— Robin Meadows

For more information

UC Sierra Foothill Research and Extension Center
http://groups.ucanr.org/sierrafoothill

UC ANR Research and Extension Center System
http://groups.ucanr.org/anrrec/Research_and_Extension/Overview.htm

A quarter century of oak woodland research in the Sierra foothills supports oak restoration

by Douglas D. McCreary

During the last 25 years, a wide variety of oak woodland research has been conducted at the UC Sierra Foothill Research and Extension Center. A substantial portion of this research has focused on developing procedures for artificially regenerating native California oaks. Results indicate that oaks can be successfully established with sufficient care and protection, including thorough weed control and protection from damaging animals. Tree shelters, or grow tubes, have proven particularly useful in getting seedlings to about 6.5 feet (2.0 meters), where they are relatively resistant to cattle browsing. These findings have been disseminated through training sessions and written materials and have been widely adopted by restoration practitioners, improving the overall success rate of oak plantings in California.

Jack Kelly Clark

Cattle graze a typical oak woodland at the UC Sierra Foothill Research and Extension Center. Approximately 80% of the oak woodlands in California are privately owned and most are managed for livestock.

IN 1986, the University of California, in cooperation with the California Department of Forestry (now CalFire) and the California Department of Fish and Game, established the Integrated Hardwood Range Management Program (IHRMP) to address statewide concerns about oak woodland management and to promote woodland conservation (Passof 1987). This program funded five new Cooperative Extension specialists stationed throughout the state. In 1986, I was one of the new hires and was housed at the UC Sierra Foothill Research and Extension Center (SFREC) as a natural resources specialist for the northern Sierra region. This afforded an excellent opportunity to conduct oak woodland research in the foothills of the Sierra Nevada.

One of our main goals was to evaluate alternative oak-seedling production and planting techniques and develop practical methods for successfully regenerating native California oaks. The need for this research was based on one of the primary reasons cited for establishing the IHRMP: the widespread view that several species of California oaks, including blue oak (*Quercus douglasii*) and valley oak (*Q. lobata*), were not regenerating adequately. Poor natural regeneration raised the specter that some oak stands could convert to grasslands or shrublands. The concern was grave because woodlands provide critical habitat for a large and diverse assortment of wildlife; protect the quality of the state's water resources by anchoring the soil, preventing erosion and sedimentation; and provide beautiful scenery and opportunities for recreation (Bolsinger 1988).

Early oak regeneration research

Even before the IHRMP was founded there had been several projects at SFREC to examine natural oak regeneration patterns. In the mid-1960s, Burgess L. (Bud) Kay, a UC Davis range science specialist, established plots to evaluate the effects of blue oak removal on a variety a factors, including oak regeneration (Kay 1987). He found that about half of the untreated stumps sprouted following the experimental harvest, but that no new blue oak seedlings actually established in the plot area during the 23 years since harvesting.

In the early 1980s, UC Berkeley range student Mitch McClaran conducted his Ph.D. dissertation research at SFREC on the age structure of blue oak in relation to livestock grazing and fire (McClaran 1986). This research contributed to a better understanding of oak reproduction patterns. McClaran found that oaks had established at SFREC irregularly but continuously over a very long time interval and that pulses of apparent regeneration were associated with the occurrence of fire. This was because fires often killed the aboveground portion of the plant, and these damaged trees became re-established by sprouting from their bases.

Several years after McClaran initiated his research, the late Theodore (Ted) Adams Jr., a Cooperative Extension rangeland specialist at UC Davis, began trials to evaluate the effects of seedling protection and weed control on oak establishment (Adams et al. 1987). At that time, little was known about oak seedling physiology or planting methods, so some of these early trials resulted in high mortality. But the results were still useful for subsequent research because they identified some of the critical obstacles.

Immediately after the program began, IHRMP funded competitive grants to address critical hardwood issues. The first round of funding in 1986 supported a large research project by UC Davis range scientists Kevin Rice, John Menke and Jeff Welker on the ecology and regeneration of hardwood rangelands, and the role of grazing and introduced Mediterranean annuals on oak seedling establishment. This research was undertaken at SFREC and two other field sites. It showed that livestock grazing had both direct and indirect effects on oak regeneration. Cattle adversely affected oak seedlings directly via browsing, but grazing also indirectly limited recruitment by reducing organic matter and compacting the soil (Welker and Menke 1987). This and subsequent research also suggested that the widespread introduction of Mediterranean annuals throughout the state since European settlement probably also adversely affected natural oak regeneration by changing soil-water relations (Gordon and Rice 1993). A study several years later found that SFREC, like numerous other woodland sites throughout the state, had a paucity of blue oak saplings (Swiecki et al. 1997), implying that the bottleneck to successful tree replacement was from the seedling to the sapling stage.

Since most of the hardwood rangelands in California are privately owned, it is important to develop oak regeneration procedures that allow livestock operators to continue grazing their woodlands.

Oak woodland ecology studied

In addition to research on oak regeneration, other studies at SFREC in the late 1980s and early 1990s addressed various aspects of oak woodland ecology. A study in the Schubert watershed reported that partial tree harvesting had relatively little impact on water quality and yield (Singer et al. 1990). Major storm events, such as the warm spring storm in early 1986, contributed far more sediment to streams than any oak removal. Other studies evaluated nutrient relations and the chemical composition of woodland soils. Researchers found increased rates of nutrient cycling under trees (compared to open pastures) and reported that oak woodlands retained more nutrients than cleared areas (Jackson et al. 1990; Dahlgren and Singer 1991) (see page 78).

There were also studies on the relationship between woodland characteristics and wildlife use. One determined that removing approximately 23% of the basal area (the sum of the cross-sectional area of all trees measured at breast height, 4.5 feet or 1.37 meters above the ground) in 7.7-acre plots (3.1 hectares) did not significantly affect the abundance or use of woodlands by most bird species (Aigner et al. 1997). Another reported that the wide diversity of habitats found at SFREC supported a wide range of wildlife and that no habitat types were unused (Block and Morrison 1990). This study reaffirmed the idea that woodland wildlife benefit from both vertical and horizontal structural plant diversity and that widespread tree removal can adversely affect populations of a range of wildlife species.

In the last 10 to 15 years, other questions about oak woodland ecology and management have been addressed. A group from UC Davis — including Caroline Bledsoe and co-investigators Robert Zasoski, William Horwath, David Rizzo and their students — focused on the belowground control of nitrogen uptake by ectomycorrhizal oak and pine roots. (Mycorrhiza refers to the symbiotic association between higher plant roots [hosts] and specific fungi that aid plants in the uptake of water and nutrients and may offer protection against

The cover of *California Agriculture* in 1989 (Vol. 43, No. 1) showed the initial planting of oaks at SFREC by the Integrated Hardwood Range Management Program. Oak seedlings were covered with tubes of aluminum window screen, which were commonly used to protect oaks at that time.

Jack Kelly Clark

Tree shelters helped to get blue oak seedlings established and growing rapidly in an oak regeneration plot at SFREC.

soilborne organisms.) They discovered that oaks and pines have a diverse fungal community on their roots that aids in nutrient uptake. Mycorrhizae also play a critical role in oak establishment (Berman and Bledsoe 1998), water uptake (Millikin and Bledsoe 1999) and nitrogen capture (Cheng and Bledsoe 2004).

Kevin Rice and students from UC Davis have looked at blue oak pollen distribution and discovered that isolated blue oaks may have a limited ability to exchange pollen with relatively distant neighbors, suggesting that the continuing fragmentation of woodlands could have serious and adverse impacts on genetic diversity within this species (Knapp et al. 2001). And Barbara Allen-Diaz and students from UC Berkeley evaluated springs within oak woodlands and found that moderate grazing in these systems had relatively little impact on soil chemistry, water quality or invertebrate populations (Allen-Diaz et al. 2004).

Artificial regeneration of oaks

The first research project initiated at SFREC by the IHRMP was a planting in 1987 to determine how to successfully grow and establish blue oaks. One hundred and twenty 1-year-old seedlings were planted and given thorough weed control, protection from potentially damaging animals and initial irrigation to ensure adequate moisture. In this rather pampered environment almost all the seedlings survived, providing a bank of young plants for subsequent studies (McCreary 1989). This study provided a baseline for determining which factors were most critical to oak establishment. Subsequent research indicated that weed control and animal protection were usually essential, but that irrigation was often not necessary (at least at SFREC), as long as competing weeds were controlled. Three years later, the seedlings in this initial planting were part of a study that evaluated seasonal growth patterns of blue oak and valley oak (McCreary 1991).

During the next 10 years additional studies were initiated that examined different aspects of oak regeneration, including when to collect and how to store acorns (McCreary and Koukoura 1990), when to directly sow acorns in the field (McCreary 1990), the effects of acorn size on seedling morphology and field performance (Tecklin and McCreary 1991), the effects of top-pruning young seedlings prior to field planting (McCreary and Tecklin 1993), lifting (removal from the ground) and storage intervals for seedlings produced in bare-root nurseries (McCreary and Tecklin 1994), the effects of augering and fertilization on field growth and survival (McCreary 1995) and the effects of radicle (initial seedling root) pruning on seedling performance (McCreary 1996).

In brief, these studies demonstrated the following:

- Healthy blue oak acorns can be collected over a 6-week interval in the fall, but allowing acorns to dry out can be lethal to subsequent germination.
- Large acorns initially produce larger seedlings than small acorns.
- The early sowing of acorns results in early germination and root growth, resulting in better field performance.
- Top-pruning tall and lanky container seedlings can help them become established after field planting.
- Bare-root blue oak seedlings can be stored for up to 2 months after lifting, but it is important to plant seedlings by early January.
- Augering and fertilization both stimulate more rapid initial field growth of seedlings.
- Radicle pruning prior to planting has relatively little impact on subsequent seedling growth.

All of these findings, as well as results from other regeneration-related research in California, were summarized

Healthy cattle, healthy oaks

Prior to the mid-1970s, oaks in California were often considered undesirable weeds that prevented other, more productive uses of the land. This led to federal cost-share programs to remove oaks and other woody vegetation from foothill properties so that forage production for livestock could be enhanced. Between 1945 and 1973, approximately 1.9 million acres of hardwoods and chaparral were cleared for "rangeland improvement" projects (Bolsinger 1988).

Oak woodlands were further affected in the early 1980s when whole sections (640 acres) of rangelands, especially in the northern Sacramento Valley, were clear-cut for firewood. Both of these practices have now been largely discredited and discontinued. Today, oak removal that does take place for firewood harvesting is much more likely to be a thinning, where numerous trees are retained. Research by Rick Standiford, UC Cooperative Extension forestry specialist at UC Berkeley, and others at SFREC and elsewhere has helped to identify growth rates on which to base harvesting levels, so that stands can be managed more sustainably (Standiford 1997; Standiford et. al 1996).

Oak regeneration in California is much more successful today because of research at SFREC. It is now well recognized that eliminating competing vegetation near seedlings and protecting young oaks from damaging animals are essential. Tree shelters are now widely used, and it is common practice to leave them in place for several years after the seedlings have emerged through the tops. Popular and scientific publications promoting weed control and animal protection — based on SFREC research — have been widely distributed, and this information has also been presented at SFREC oak regeneration field days as well as scores of workshops and symposia.

Cattle ranchers own a majority of oak woodlands in the state, and in general they are good stewards of their land and want to maintain or enhance their oak resources. Research at SFREC has provided guidance for how to do this. Studies have indicated the best times to graze woodlands so that young oak seedlings are less likely to be damaged. Research has also identified the general size that oaks need to be to withstand animal impacts. Such information helps landowners manage their oaks and livestock together without the need to remove land from production.

— D.D. McCreary

in a 2001 publication designed to help practitioners successfully regenerate rangeland oaks (McCreary 2001). The research results were also presented at semiannual oak regeneration field days at SFREC targeted to restoration professionals.

Protecting seedlings from animals

The studies were established within large fenced areas that prevented damage from livestock, deer and other browsers. This made these studies easier to conduct but it did not mimic natural conditions, where both natural and planted oaks face a plethora of animals intent on eating them. A series of studies aimed at evaluating alternative methods for protecting young oaks from animal damage was therefore initiated. This research soon began to focus on using tree shelters, or grow tubes, to protect seedlings, since they seemed more effective than other devices previously used such as cylinders of aluminum window screen or plastic mesh.

Tree shelters are generally solid, double-walled plastic tubes that are placed over individual seedlings. Several manufacturers make such shelters, including Treessentials, Tree-Pro, Blue-X and Plantra. Their products vary in the type and thickness of the plastic used and in physical design and construction. Some are rigid and come nested, while others are flat and assembled on site. They not only protect seedlings from a wide range of animals including livestock, deer, rabbits, voles and grasshoppers, but also alter the environment and stimulate rapid height growth (McCreary 1997). This growth promotion results from changes in the microenvironment inside the shelter, including reduced wind and transpiration, and increased temperature, humidity and carbon dioxide concentration (Potter 1991).

Studies were also initiated to determine the most effective shelter size and the influence of shelters on shoot height and diameter growth (McCreary and Tecklin 2001). The latter study demonstrated that the length of time tree shelters are left in place can be critical. Seedlings in tree shelters initially have rapid height growth, but this usually occurs at the expense of diameter growth, which causes the seedlings to grow very tall and spindly. If the shelters are removed before the seedlings grow to the tops of the tubes, the seedlings often cannot support themselves and will fall over unless they are staked. However, research demonstrated that once seedlings reach the tops of the shelters, height growth diminishes and diameter growth accelerates. After 2 or 3 years growing above the shelters, the seedlings develop sufficient girth to remain upright, even after the shelters are removed. Based on these findings, leaving shelters in place for at least 2 years after the seedlings grow to the shelter top is recommended.

Another study evaluated how seedlings respond when shelters are added several years after the initial planting. In this "retrofitting" experiment, shelters were placed over seedlings that had been planted 2 years earlier, but had languished with little growth. Almost immediately after having the shelters placed over them, the seedlings began to grow rapidly; 2 years later, average seedling height was nearly 4 feet (1.3 meters). By comparison, nonretrofitted control seedlings grew very little and remained less than a foot (0.3 meter) tall (Tecklin et al. 1997).

One significant advantage of tree shelters is that in lightly to moderately grazed pastures, they can also protect seedlings from livestock. Since most of the hardwood rangelands in California are privately owned and livestock grazing is the primary management activity, it is important to develop oak regeneration procedures that allow livestock operators to continue grazing their woodlands. Research has indicated that in some situations tree shelters can successfully protect seedlings from livestock damage without the need for fences and animal exclusion (McCreary 1999).

Tree shelters are widely used by CalTrans and by the vineyard industry for establishing vines, and are also used in various mitigation projects with oaks and other tree species. They are occasionally used by private landowners, including ranchers, but generally on a small scale. However, tree shelters are not inexpensive. The current price for 4-foot (0.3 meter) Treessentials shelters is more than $4

Decades of research at SFREC have helped to establish guidelines for regenerating oaks in grazed woodlands. Staff research associate Jerry Tecklin demonstrates that blue oaks more than 6.5 feet (2 meters) tall are relatively resistant to cattle impacts, while seedlings shorter than 6.5 feet are adversely affected.

each, so using them over large areas would likely be prohibitively expensive for most private landowners. Cost-share programs (that help subsidize the cost of purchasing and installing tree shelters) to encourage hardwood restoration are common in Great Britain and other parts of Europe, but are generally not available in California (McCreary and Kerr 2002).

Another important question related to artificially establishing oaks in areas grazed by livestock is the size that seedlings, or in this case, saplings, have to be before they are relatively resistant to livestock impacts. A recent study at SFREC evaluated cattle impacts on blue oak seedlings and saplings ranging in height from a foot (0.3 meter) to more than 10 feet (3 meters). These seedlings were left over from an integrated pest management (IPM) research project that Ted Adams had established at SFREC in the early 1990s. The results indicated that once seedlings attain a height of about 6.5 feet (2 meters), they are relatively resistant to livestock damage and continue to grow and prosper. If they are less than this height when they are exposed to grazing, however, they continue to be severely affected by cattle, with minimal growth and high mortality (McCreary and George 2005).

Evaluating natural regeneration

Recently, a study evaluating another approach to oak regeneration was initiated at SFREC. This study, replicated at five other sites throughout California, examines the use of natural or “volunteer” blue oak seedlings as part of a strategy to enhance oak regeneration. The UC Agriculture and Natural Resources Core Grants Program funded a 2006 proposal, “Evaluating Techniques to Enhance Natural Blue Oak Regeneration.” The project is evaluating several treatments, including weed control and tree shelters, to determine if taking steps to enhance the growth and survival of natural seedlings can get them to the sapling stage where they are less vulnerable to damaging factors. Preliminary results suggest that tree shelters can greatly aid in this effort.

Long-term woodland conservation

The research-based information generated from studies at SFREC has been extremely important in developing management recommendations consistent with long-term woodland conservation. This review has focused on oak regeneration research where SFREC has led the way in producing practical guidelines for those interested in restoring California’s oak woodlands. But SFREC has also been the site of woodland research on a wide range of other subjects including wildlife, hydrology, fire, edaphic (soil community) characteristics and range management. This research has been instrumental in developing practical management guidelines for woodland owners and managers (see sidebar). While UC oak researchers have answered many fundamental questions about regeneration and range management in the last 25

References

Adams TE, Sands PB, Weitkamp WH, et al. 1987. Enemies of white oak regeneration. In: Plumb TR, Pillsbury NH (tech. coords.). Proc Symp Multiple-use Management of California's Hardwood Resources. US Department of Agriculture, Forest Service Gen Tech Rep PSW-100. p 459–62.

Aigner PA, Block WM, Morrison ML. 1997. Effect of firewood harvesting on birds in a California oak-pine woodland. J Wildlife Manage 62(2):485–96.

Allen-Diaz B, Jackson R, Bartolome J, et al. 2004. Long-term grazing study in spring-fed wetlands reveals management tradeoffs. Cal Ag 58:144–8.

Berman JT, Bledsoe CS. 1998. Soil transfers from valley oak (*Quercus lobata* Nee) stands increase ectomycorrhizal diversity and alter root and shoot growth on valley oak seedlings. Mycorrhiza 7:223–35.

Block WM, Morrison ML. 1990. Wildlife diversity of the central Sierra foothills. Cal Ag 44(2):19–22.

Bolsinger CL. 1988. The Hardwoods of California's Timberlands, Woodlands and Savannas. US Department of Agriculture, Forest Service Pacific Northwest Research Station, Res Bull PNW-148. 148 p.

Cheng XM, Bledsoe CS. 2004. Competition for inorganic and organic N by blue oak (*Quercus douglasii*) seedlings, an annual grass, and soil microorganisms in a pot study. Soil Bio Biochem 36:135–44.

Dahlgren R, Singer MJ. 1991. Nutrient cycling in managed and unmanaged oak woodland-grass ecosystems. In: Standiford RB (tech. coord.). Proc Symp on Oak Woodlands and Hardwoods Rangeland Mgmt. US Department of Agriculture, Forest Service Gen Tech Rep PSW-126. p 337–41.

Gordon DR, Rice KJ. 1993. Competitive effects of grassland annuals on soil water and blue oak (*Quercus douglasii*) seedlings. Ecology 74(1):68–82.

Jackson LE, Strauss RB, Firestone MK, Bartolome JW. 1990. Influence of tree canopies on grassland productivity and nitrogen dynamics in deciduous oak savanna. Ag Ecosys Env 32:89–105.

Kay BL. 1987. Long-term effects of blue oak removal on forage production, forage quality, soil, and oak regeneration. In: Plumb TR, Pillsbury NH (tech. coords.). Proc Symp Multiple-use Management of California's Hardwood Resources. US Department of Agriculture, Forest Service Gen Tech Rep PSW-100. p 351–7.

Knapp EE, Goedde MA, Rice KJ. 2001. Pollen-limited reproduction in blue oak: Implications for wind pollination in fragmented populations. Oecologia 128:48–55.

McClaran MP. 1986. Age structure of *Quercus douglasii* in relation to livestock grazing and fire. Ph.D. thesis, UC Berkeley. 119 p.

McCreary DD. 1989. Regenerating native oaks in California. Cal Ag 43(1):4–6.

McCreary DD. 1990. Acorn sowing date affects field performance of blue and valley oaks. Tree Planters Notes 41(2):6–9.

McCreary DD. 1991. Seasonal growth patterns of blue and valley oaks established on foothill rangelands. In: Standiford RB (tech. coord.). Proc Symp on Oak Woodlands and Hardwoods Rangeland Mgmt. US Department of Agriculture, Forest Service Gen Tech Rep PSW-126. p 36–40.

McCreary DD. 1995. Augering and fertilization stimulate growth of blue oak seedlings planed from acorns, but not from containers. West J Appl For 10(4):133–7.

McCreary DD. 1996. The effects of stock type and radicle pruning on blue oak morphology and field performance on oak morphology. Annales Sciences Forestieres 53(2-3):641–8.

McCreary DD. 1997. Tree shelters: An alternative for oak regeneration. Fremontia 25(1):26–30.

McCreary DD. 1999. Restoration of a grazed riparian area. In: Rose RR, Haase DL (coords., eds.). Proc Symp, Native Plants: Propagating and Planting. Dec 9–10, 1998, Corvallis, OR. p 86–91.

McCreary DD. 2001. Regenerating Rangeland Oaks in California. UC ANR Pub 21601. 62 p.

McCreary DD, George M. 2005. Managed grazing and seedling shelters enhance oak regeneration on rangelands. Cal Ag 59(4):217–22.

McCreary DD, Kerr G. 2002. A comparison of the history and management of oak woodlands in Britain and California. In: Standiford RB, McCreary DD, Purcell KL (tech. coords.). Proc Fifth Oak Symposium: Oaks in California's Changing Landscape. Oct. 22–25, 2001, San Diego, CA. US Department of Agriculture, Forest Service Pacific Southwest Research Station, Gen Tech Rep. PSW-GTR-184. p 529–39.

McCreary DD, Koukoura Z. 1990. The effects of collection date and pre-storage treatment of the germination of blue oak acorns. New Forests 3:303–10.

McCreary DD, Tecklin J. 1993. Top pruning improves field performance of blue oak seedlings. Tree Planters Notes 44(2):73–7.

McCreary DD, Tecklin J. 1994. Lifting and storing bareroot blue oak seedlings. New Forests 8:89–103.

McCreary DD, Tecklin J. 2001. The effects of different-sized tree shelters on blue oak growth. West J Appl For 16(4):153–8.

Millikin CS, Bledsoe CS. 1999. Biomass and distribution of fine and coarse roots from blue oak (*Quercus douglasii*) trees in the northern Sierra Nevada foothills of California. Plant Soil 214:27–38.

Passof PC. 1987. Developing an educational program to address the management of California's hardwood rangelands. In: Plumb TR, Pillsbury NH (tech. coords.). Proc Symp Multiple-use Management of California's Hardwood Resources. US Department of Agriculture, Forest Service Gen Tech Rep PSW-100. p 394–9.

Potter MJ. 1991. Treeshelters. *Forestry Commission Handbook 7*. London: HMSO Pub Cent. 48 p.

Singer MJ, Huang X, Epifanio C. 1990. Selective oak removal does not harm water quality. Cal Ag 44(2):17–8.

Standiford RB. 1997. Growth of blue oak on California's hardwood rangelands. In: Pillsbury NH, Verner J, Tietje WD (tech. coords.). Proc Symp Oak Woodlands: Ecology, Management, and Urban Interface Issues. US Department of Agriculture, Forest Service Gen Tech Rep PSW-GTR-160. p 169–76.

Standiford RB, McCreary DD, Barry S, et al. 1996. Impact of firewood harvesting on hardwood rangelands varies with region. Cal Ag 50(2):7–12.

Swiecki TJ, Bernhardt EA, Drake C. 1997. Stand level status of blue oak sapling recruitment and regeneration. In: Pillsbury NH, Verner J, Tietje WD (tech. coords.). Proc Symp Oak Woodlands: Ecology, Management, and Urban Interface Issues. US Department of Agriculture, Forest Service Gen Tech Rep PSW-GTR-160. p 147–56.

Tecklin J, Connor JM, McCreary DD. 1997. Rehabilitation of a blue oak restoration project. In: Pillsbury NH, Verner J, Tietje WD (tech. coords.). Proc Symp Oak Woodlands: Ecology, Management, and Urban Interface Issues. US Department of Agriculture, Forest Service Gen Tech Rep PSW-GTR-160. p 267–73.

Tecklin J, McCreary DD. 1991. Acorn size as a factor in early seedling growth of blue oaks. In: Standiford RB (tech. coord.). Proc Symp Oak Woodlands and Hardwoods Rangeland Mgmt. US Department of Agriculture, Forest Service Gen Tech Rep PSW-126. p 48–53.

Welker JM, Menke JM. 1987. *Quercus douglasii* seedling water relations in mesic and grazing-induced xeric environments. In: Proc Int Conf on Measurements of Soil and Plant Water Status, Vol. 2, Plants, July 6–10, 1987, Logan, UT. Utah State Univ. p 229–34.

years, there is still much to be discovered and understood about woodland ecology and conservation. We still cannot explain why oaks naturally regenerate on some sites but not on others, and more research is needed to fully understand how to regenerate whole plant communities rather than single species. SFREC will likely continue to play a critical role in addressing these questions as well as others, and in disseminating answers to the public.

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grateful to the UC Division of Agriculture and Natural Resources (ANR) for financial support through an ANR Core Grant that funded the installation and early measurements for the natural oak regeneration study; Jerry Tecklin, Staff Research Associate at SFREC for many years, who did much of the field work on the projects described; and the management and staff at SFREC who provided invaluable help and support throughout the past two decades.

Yuba River analysis aims to aid spring-run chinook salmon habitat rehabilitation

by Gregory Pasternack, Aaron A. Fulton *and* Scott L. Morford

Spring-run chinook salmon historically migrated far upstream into Sierra Nevada rivers but are now confined to gravel-limited reaches below large dams ringing the Central Valley. In this study, topographic analysis and photo interpretation reveal the 100-year history of channel conditions in the bedrock canyon on the Yuba River below Englebright Dam, which also abuts the UC Sierra Foothill Research and Extension Center. Historical evidence shows that alluvial bars provided spring-run chinook salmon habitat in the reach prior to gold mining and that the influx of hydraulic mining debris dramatically expanded it. However, when Englebright Dam was completed in 1941, shot rock was left in the canyon and allowed to migrate downstream, where it buried gravel bars. We recommend that shot rock be removed to exhume a pre-existing large gravel bar and that new river gravels be placed in the canyon to create salmon habitat.

Courtesy of Ralph Mullican

Adult spring-run chinook salmon hold in the Englebright Dam Reach of the lower Yuba River.

Most large tributaries to the Sacramento and San Joaquin rivers, which drain the Sierra Nevada, have large dams. Immediately downstream of several of these structures there are continuous stretches (greater than 0.31 miles [0.5 kilometers]) of exposed (or covered by a transient sediment veneer) bedrock channel (Wohl and Tinkler 1998). These stretches occur on the Sacramento River as well as the Feather, Yuba, Calaveras and Stanislaus rivers. In some cases a bedrock canyon may always have existed (e.g., Yuba), while in others, channel and floodplain sediments were scoured away by long-duration low flows that focused on riffles (a river's higher elevation areas; pools are lower elevation) and infrequent floods that affected other channel land forms after the dam cut off the resupply of sediment (e.g., Feather).

Four distinct races of anadromous chinook salmon occupy the Sacramento/San Joaquin river system (Banks et al. 2000), but for spawning they all prefer common physical attributes of a river: cool temperature, gravel and cobble bed material, low depth (about 0.5 to 4 feet) and moderate velocity (2 to 4 feet per second). The spring-run chinook salmon is a federally threatened species that is differentiated by the time at which adults migrate from the ocean to fresh water systems (Yoshiyama et al. 1996). Spring-run chinook salmon generally enter fresh water between April and June and oversummer in cool, high-elevation pools before spawning on main-stem gravel riffles in August and September. Before dams blocked their migration, this life-history strategy enabled spring-run chinook salmon to migrate to gravel riffles high up in Sierra Nevada watersheds during snowmelt events, because high flows inundate natural cascades enough to allow fish to swim over them. Later runs of chinook salmon encounter the same features at low flows, when the channels form nearly dry, impassable cliffs (Yoshiyama et al. 1996). The dramatic decline in spring-run chinook salmon in California has been attributed to dams, which block up to 80% of their historic habitat (Wheaton et al. 2004a).

Under a regulated flow regime, spring-run chinook salmon migrate to the bedrock reaches at the base of large water-supply dams in the spring and summer and hold in pools supplied with cold water releases from the bottom of reservoirs. In the early fall they attempt to spawn, but the absence of gravel to hold and protect embryos causes spawning to fail. On Butte Creek, a small stream with warm water at the time spring-run chinook salmon oversummer, a large minority (38%) were reported in 2007 to abandon upward migration and head back downstream to spawn in suitable gravel-bed habitat (McReynolds and Garman 2008). However, while there is more spawning habitat downstream, the warmer temperatures are unfavorable. The majority of salmon attempt to spawn because

Glossary

Alluvial (alluvial fill): Loose, unconsolidated sediment moved by water.

Backwater: Shallow, very slow (or stagnant) flow adjacent to the main flow and separated from it by a peninsula.

Bars (gravel, alluvial, shot rock): Deposits of alluvial sediment.

Base flow: Low water discharge in a river fed by groundwater during dry periods.

Chute: Fast, steep and moderately deep flow.

Emergent alluvial point bars: Point bar that is not underwater.

Forced pool: Deep-water area adjacent to a bedrock outcrop.

Geomorphic: Changes to the surface of the Earth.

Glide: Shallow, slow flow.

Hyporheic: Water moving through sediment below the riverbed.

Point bar: Sedimentary deposit on the inside of a meander bed in a river.

Pool: Deep-water area surrounded by alluvial sediment.

Reach (gravel-limited reach): Section of a river defined by its geomorphic attributes such as slope, degree of bedrock exposure, bed material size, width, width-to-depth ratio and degree of channel entrenchment.

Recirculation: Upstream-directed flow usually behind a flow obstruction.

Riffle (main-stem gravel riffle): Flow that is shallow and fast as it goes downhill.

Riffle entrance: Transitional area between an upstream pool and a downstream riffle.

Riverbed: Bottom boundary between liquid and solid media in a channel.

River slope: Change in elevation per unit length down a channel.

Run: Moderately fast, moderately steep, and moderately deep flow.

Secondary channel: A smaller channel that flows perennially and is connected at both ends to the main channel.

Substrate size classes (boulder, cobble/gravel, sand/mud): Sand is 64 microns to 2 millimeters; gravel is 2 to 64 millimeters; cobbles are 64 to 256 millimeters; boulders are more than 256 millimeters.

Wall slope: Change in elevation per unit length down a hillside toward a river.

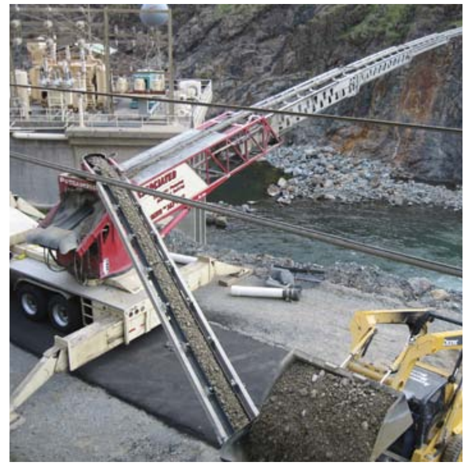
Source: Pasternak 2008

cold water is more amenable for holding adults. In perennial cold-water streams like the Feather and Yuba, downstream migration may be even less likely. For example, in 2007 the authors observed spring-run chinook salmon attempting to spawn on bedrock covered with a thin veneer of angular gravel on the Yuba River below Englebright Dam. Overall, bedrock reaches at the base of large dams can play a key role in spring-run chinook salmon viability.

An assessment of the bedrock reach below Englebright Dam on the Yuba River has been ongoing (Fulton 2008; Pasternack 2008). Detailed hydrodynamic, sedimentary and biological assessments of current conditions have been made. However, current conditions often reflect both natural history and human impacts, which are difficult to explicitly incorporate into predictive models, although they do constrain future outcomes. Our study focuses on channel changes in a key spring-run chinook salmon spawning zone below Englebright Dam on the Yuba River (fig. 1). We document human impacts arising from gold and gravel mining, and the building of the Englebright Dam in 1941. The study area includes the tributary junction with Deer Creek. The north bank of the Yuba River at this location, including the Sinoro Bar, is owned by UC and operated as part of the UC Sierra Foothill Research and Extension Center. This facility provided logistic support for our research. Together with other property owners, they also provided essential access to the site. Based on our analysis of the study area, we offer specific management recommendations.

Englebright Dam Reach

The 1,350-square-mile (3,490-square-kilometer) Yuba River basin (fig. 1, inset) has hot, dry summers and cool, wet winters. Relative to other Sierra basins, its mean annual precipitation is among the highest (greater than 59 inches [1,500 millimeters]), so its development for hydropower, water supply, flood regulation, gold mining and sediment control (James 2005) is not surprising. During the Gold Rush (mid- to late 19th century), hillsides were hydraulically mined until the practice was outlawed in 1884. In the absence of dams, vast



In 2007, the U.S. Army Corps of Engineers injected about 450 metric tons of gravel and cobble below the Englebright Dam in order to mitigate impacts to spring-run chinook salmon, which need gravel to spawn.

hillside-mining sediments — about 684 million cubic yards (522 million cubic meters) — moved freely down the river network filling in valleys, smothering aquatic habitat and deterring salmon from entering the system (Curtis et al. 2005). At the time, salmonid populations had plenty of alternative rivers in California to use to survive this localized disturbance. Today, flow regulation, bank alteration, channelization and in-channel gold and gravel mining also affect the rivers.

These forces starve rivers of sediment. Englebright Dam (capacity of just 108 million cubic yards [82.6 million square meters]) was built as a sediment barrier on the mainstem, downstream of the confluences with major tributaries, to stop sediment from further filling in rivers on the floor of the Central Valley and causing costly flooding and damage to agriculture there. In 1971, 30 years later, the New Bullards Bar Reservoir (capacity of 1.56 billion cubic yards [1.19 billion cubic meters]) was built on the North Yuba for water supply and flood control. The Englebright and New Bullards Bar dams restrict salmon access to 73% of historic habitat areas. A remnant population of less than 1,000 spring-run chinook salmon persists below Englebright Dam compared to a combined average remnant population of 14,000 fall and late-fall chinook salmon. There are no estimates for pristine, historic salmonid populations on the Yuba, but Yoshiyama et al. (1996) reported qualitative historic information suggesting that they were much larger. Were it not for the presence of the historic gold-mining debris, sal-

The impact of mechanized instream mining was significantly greater than the impact of Englebright Dam on changing the geometry and structure of Sinoro Bar.

monid habitat conditions today would be dramatically worse than they are, as is evident for other rivers in the region.

Stream flow is recorded at the U.S. Geological Survey's Smartville gage (#11418000), 0.3 mile (0.5 kilometer) downstream of Englebright Dam. Between 1942 and 1971, the statistical bankful discharge (Q_b, defined as the flow that fills the geometric shape of a channel and approximated by the event with a 1.5-year probabilistic recurrence interval) at Smartville gage was 11,600 cubic feet per second (328.5 cubic meters per second). In the period since 1971, the gage's Q_b has been 5,620 cubic feet per second (159.2 cubic meters per second). Given that the Middle and South Yuba tributaries lack large reservoirs, winter storms and spring snowmelt produce floods that overflow the top of Englebright Dam and flow into Englebright Reach.

The lower Yuba River is about 24 miles (38 kilometers) long from Englebright Dam to its junction with the Feather River. Steelhead trout and chinook salmon utilize the lower Yuba River for spawning, rearing and migration. The habits and life-cycle patterns of spring-run chinook salmon are poorly documented on the lower Yuba River, which is managed by diverse local, state and federal entities.

The Englebright Dam Reach extends from Englebright Dam down to the junction with Deer Creek (fig. 1). It is a relatively straight bedrock canyon with a veneer of "shot rock" debris. Shot rock is irregular-shaped angular cobbles and boulders blasted from surrounding hillsides. In this reach, shot rock was generated and spread by two distinct processes: rock excavation during the construction of Englebright Dam and hillside scouring during major floods. Englebright Dam Reach is also influenced by a backwater effect imposed by Deer Creek, since flood pulses out of Deer Creek usually come ahead of the larger and more snowmelt-driven inflows from the Yuba River.

There are three shot-rock deposits in the Englebright Dam Reach (fig. 1). The largest is a mixture of angular cobbles and boulders deposited as a point bar upstream of the junction with Deer Creek on the north bank. This point bar has recently been named Sinoro Bar to symbolize the lack of gold expected in it.

On Nov. 29, 2007, the U.S. Army Corps of Engineers put about 450 metric tons (360 cubic yards) of rounded gravel and cobble into the river below Englebright Dam. That experiment aims to ascertain the likely fate of larger amounts of gravel to be added into the river in the future as a dam-mitigation effort required by a National Marine Fisheries Service biological opinion (USACE 2007). The goal is for injected material to move downstream and form spring-run chinook salmon habitat in the canyon.

River dynamics and salmon spawning

The goal of our study was to characterize historical sedimentary and geomorphic changes in the vicinity of Sinoro Bar in the Englebright Dam Reach, because this area is a preferred spawning location for spring-run chinook salmon. Although the bar itself is

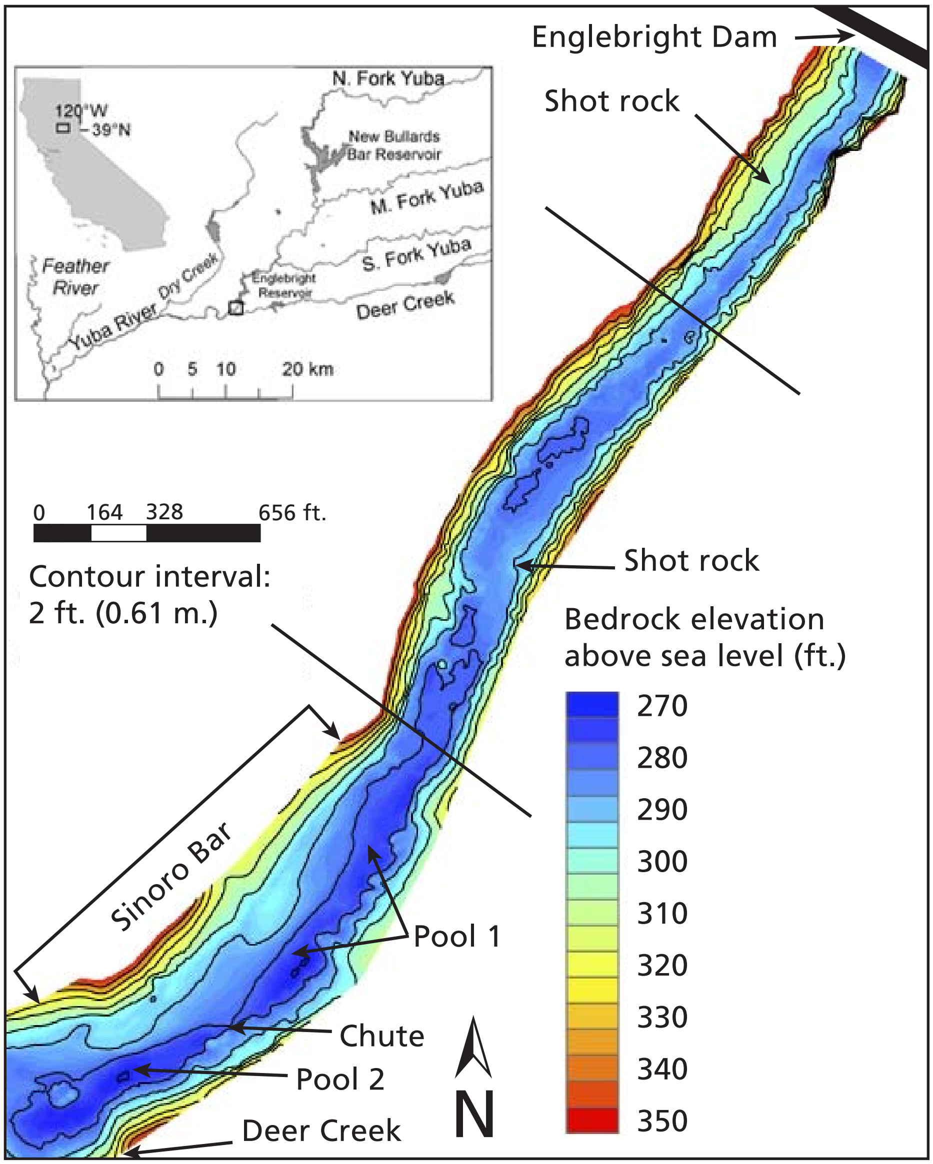


Fig. 1. Topographic map of the Englebright Dam Reach with inset map showing the canyon in the Yuba River basin. Total station-survey horizontal and vertical errors were typically within 0.2 to 0.8 inches (0.5 to 2 centimeters). RTK-GPS precisions was in the same range. A topographic digital elevation model (DEM) was produced using Geostatistical Analyst in ArcGIS 9.2. The build was performed via the radial basis function (tension with spline), yielding a mean vertical error of 1 centimeter and a vertical root mean square of 0.36 meter.

TABLE 1. Days in which peak discharge was greater than 1,840.6 m^3/s (65,000 cfs) at Smartville gage, Yuba River

Date	Discharge
	m^3/s
March 19, 1907	2,831.7
Jan. 15, 1909	3,143.2
March 26, 1928	3,398.0
Dec. 11, 1937	2,101.1
Jan. 21, 1943	2,296.5
Nov. 21, 1950	3,086.5
Dec. 23, 1955	4,190.9
Feb. 8, 1960	2,435.2
Feb. 1, 1963	4,247.5
Dec. 22, 1964	4,842.2
Jan. 21, 1970	2,664.6
Feb. 19, 1986	2,831.7
Jan. 2, 1997	4,360.8
Dec. 31, 2005	2,707.1

alluvial, understanding its persistence and transformation within the bedrock canyon over known history would aid habitat rehabilitation for spring-run chinook salmon. We developed a conceptual understanding of dynamics in the Englebright Dam Reach by integrating a quantitative topographic analysis with an interpretive evaluation of historical channel conditions based on photographs.

Topographic analysis. To produce a detailed topographic map, three data sets were combined: (1) 9,283 ground elevation points on the surrounding hills digitized from 2-foot (0.67-meter) contour lines mapped in 1999 by the Army Corps of Engineers, (2) a terrestrial land survey inside the Englebright Dam Reach canyon using real-time kinematic global positioning system (RTK-GPS) and Robotic Total Station technology and (3) a boat-based fathometer survey of the submerged riverbed (Pasternack 2008).

We established local surveying benchmarks on the ground to form a rigorous control network, which tied together the boat and terrestrial surveys. The ground- and boat-based surveys obtained 55,739 points in the typical autumn low-flow, wetted channel. The mean point density of the data set calculated using Spatial Analyst in ArcGIS 9.2 (Environmental System Research Institute [ESRI], Redlands, CA) was one point every 1.6-by-1.6 square meters, with substantially higher density in the channel and lower density on the hillside.

Alluvial fill and bedrock. Spring-run chinook salmon require rounded gravel and cobble submerged under moderately fast water to spawn. Shot rock is not suitable for spawning, because its angular edges are sharp enough to mortally wound females as they repeatedly pound it to create a depression to lay their eggs, and then pound again to cover over eggs. Consequently, the shot rock in the Englebright Dam Reach needs to be removed as one phase in rehabilitating habitat. The first step in planning the removal is to evaluate the volume of alluvial fill. After removal, a similar volume of sediment — but high-quality, rounded river gravel and cobble — would need to be installed in the river to form riffles and bars with a more suitable geometry than that of Sinoro Bar. To estimate the spatial pattern of fill depth and total volume of sediment stored in Sinoro Bar, digital elevation model (DEM) differencing was performed in ArcGIS 9.2. DEM differencing involves subtracting an historic topographic map or a map of the estimated underlying bedrock surface from the modern topographic map to get either a channel-change map or an alluvial-fill volume, respectively. In this study the goal was to estimate total alluvial-fill volume to constrain the scope of shot rock removal cost at Sinoro Bar.

The challenge with this analysis was that the depth to bedrock under Sinoro Bar is unknown. The sediment on the bar is too coarse for seismic surveys, but ground-penetrating radar might work — though that method is also highly interpretive and uncertain. Ideally, excavation pits would be used alone or with ground-penetrating radar to determine shot-rock thickness, underlying alluvial thickness and the elevation of bedrock. Unfortunately, no funds were available for such a sophisticated assessment.

As a useful first estimate to guide further investigation, the elevation of the underlying bedrock relative to the North American Vertical Datum of 1988 was assumed to be a horizontal plane with an elevation based on that of the lowest elevation in the deepest pool adjacent to the bar, 269.30 feet (82.083 meters). This deep pool appears to have been artificially excavated, so it is the best estimate of the full thickness of the alluvial fill. Other sections in the reach show a horizontal bedrock bench with a very rough (i.e., not smooth) surface across the entire width of the river, so a U-shaped rather than a V-shaped cross section was thought to be the best assumption for a first estimate. Further, although the river does meander gently at this location, the bedrock itself may or may not be sloped from a high point on the hillside to a low point out in the channel. In fact, the next two bedrock meanders downstream do not show any side slope from the hillside into the channel. Instead, the hillside drops steeply to the riverbed. In this analysis, the spatial pattern of Sinoro Bar's topography at an elevation above 269.30 feet (82.083 meters) was determined, and was assumed to be all fill. The bar is too short for adjustment for lengthwise river slope in the plane to be worthwhile. In some areas bedrock may be deeper or shallower, yielding uncertainty.

There is no way to know if this value is an over- or underestimate. If an underlying bedrock platform or gentle side slope exists on the north bank, then this analysis overestimates fill volume locally along that flank. If the alluvial fill is deeper than the deepest pool depth, then this analysis underestimates fill volume overall. Fill depths per square yard were summed to obtain total fill volume. Perhaps the uncertainty in this estimate will motivate a future excavation to obtain a more accurate number.

Photographic analysis. UC Berkeley professor G.K. Gilbert took ground-based photos in 1909. For comparison, modern photos of the river were taken in 2008 from similar vantage points. Several other historical photos taken by a local landowner from 1960 to 2008

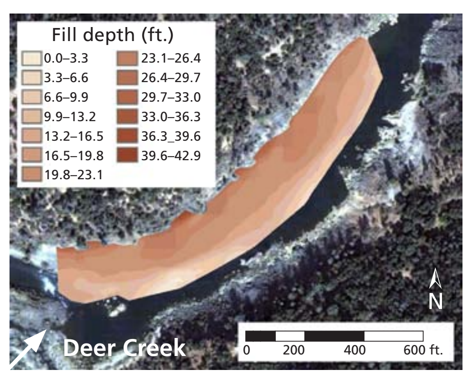


Fig. 2. Estimated sediment fill-depth map of Sinoro Bar, relative to a horizontal bedrock surface at 269.3 feet above sea level.

were inspected as well. In addition, nine aerial photos of the Englebright Dam Reach — georeferenced into the California State Plane Zone II horizontal coordinate system — were taken by various local, state and federal agencies at irregular intervals between 1937 and 2006. All photos were taken during base-flow conditions of less than 3,000 cubic feet per second (cfs) (85 cubic meters per second [m^3/s]), so they are comparable. The dates and mean daily discharges of peak flows during the largest historical floods were recorded by the Smartville gage (table 1).

Photo interpretation was used to determine what land forms and physical habitat conditions were present historically, focusing on Sinoro Bar and its vicinity. Substrate size classes (e.g., boulder, cobble/gravel, sand/mud), grains that are freshly turned over by flow, and the presence or absence of vegetation were visually evident in the photos. Aquatic physical habitat was defined as the assemblage of substrate, cover, water depth and water velocity. When interpreted at the scale of one channel width, the assemblage of features is termed "mesohabitat." A mesohabitat classification for the lower Yuba River, developed by Pasternack (2008), was used to describe elements in the photos.

The key units relevant to this study were emergent alluvial point bars and (in decreasing order of water depth) forced pool, pool, chute, recirculation, run, riffle entrance, glide, backwater and riffle (see glossary, page 70). There is a strong association between mesohabitat and spawning preference on the lower Yuba River, with chinook salmon preferring riffles the most, followed by riffle entrances, runs and secondary channels (Pasternack 2008). Interpreting changes to mesohabitats is predictive of changes in chinook utilization of the riverbed.

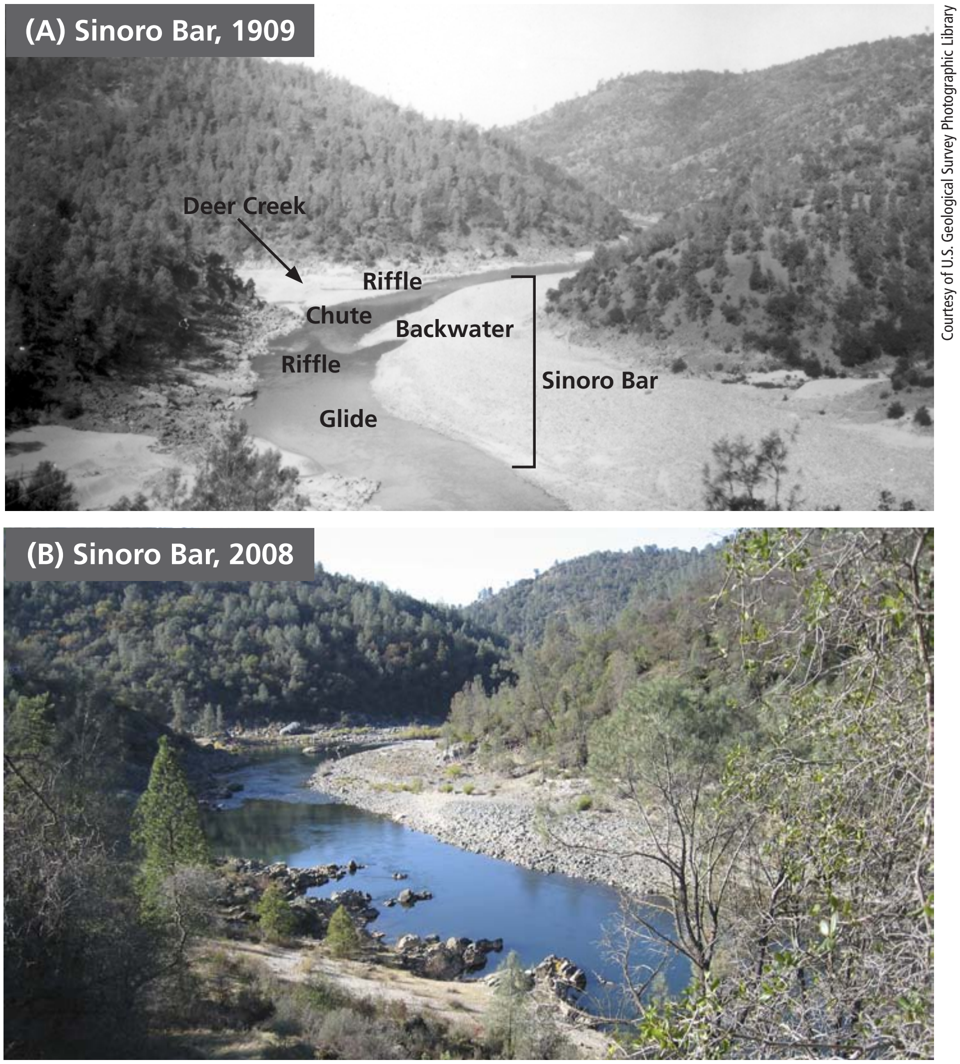


Fig. 3. (A) The 1909 image shows a sequence of mesohabitats. The upper riffle is located at the bedrock high point near the apex of the point bar, and the other riffle is adjacent to the mouth of Deer Creek. The bedrock high point does not appear to resemble any feature typical of alluvial meanders with tributary junctions, and instead appears to be related to the characteristics of the bedrock. The 1909 photo shows relatively little lateral and longitudinal elevation change in the channel — the entire area looks relatively flat. (B) The structure of physical habitat is different in 2008, with the upper riffle degraded to a chute composed of exposed bedrock and boulders with almost no gravel. The water looks slower and deeper upstream of the upper riffle. The surface of the point bar is still relatively flat, but the cross-channel relief is much greater, suggesting that the bar is less connected with the channel than in the past and that incision (a drop in elevation) of the riverbed due to erosion has occurred. Also, some vegetation is established on the point bar.

Topography of the reach

The Englebright Dam Reach is divided into three sections on the basis of canyon and channel widths (fig. 1). Half of the canyon width in the first 660 feet (200 meters) downstream of Englebright Dam is filled in with shot rock, so the channel is narrow and incised to bedrock. Then both the canyon and wetted channel widen, and the second shot-rock site is located at a bump in the bed that constricts flow two-thirds of the way downstream. Finally, canyon width increases abruptly in the third section, and Sinoro Bar is located in the widest area. The two deepest pools in the reach, other than a scour hole at the base of the dam, are both adjacent to Sinoro Bar. One is upstream and one is downstream of the constricted chute opposite the apex of Sinoro bar (fig. 1). A bedrock high point explains why the chute is not as deep as the alluvial pools upstream and downstream of it.

DEM differencing yielded an estimated total alluvial volume of 168,650 cubic yards (128,940 cubic meters) for Sinoro Bar. Fill depth ranged from 0 to 39.7 feet (12.1 meters). Fill-depth contour lines were roughly parallel to the bank, decreasing toward the deepest part of the channel (fig. 2). Although the assumption of a horizontal bedrock surface underlying the bar at an elevation of 269.30 feet (82.083 meters) is uncertain, the resulting estimate of fill provides a useful constraint on the scope of shot rock removal and replacement with a similar volume of rounded river gravel/cobble.

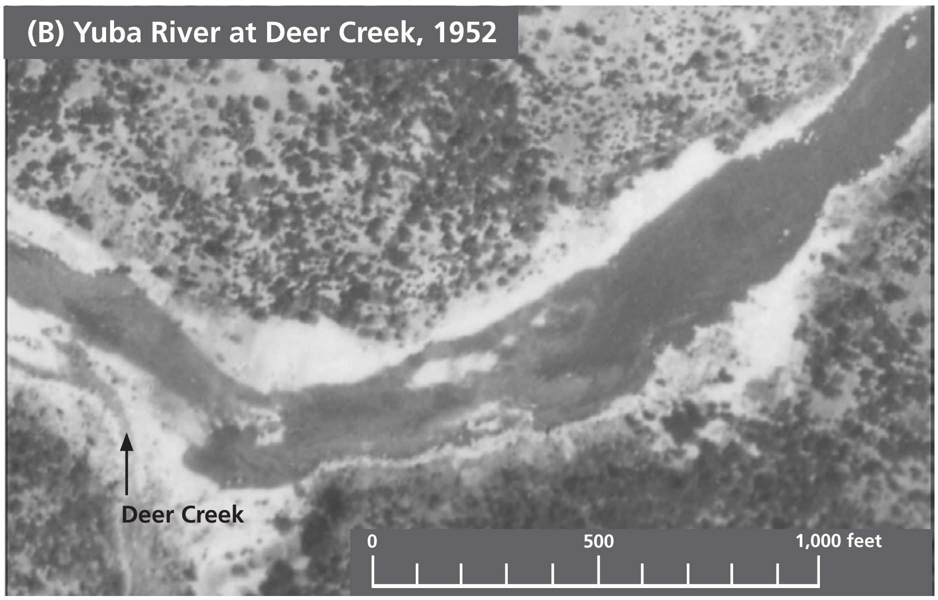


Fig. 4. (A) Since this photo predates Englebright Dam, the water could be turbid from the small peak of 692 cfs (19.6 m^3/s) on Oct. 15 (that event was still receding when the photo was taken) or simply a result of licensed hydraulic mining going on upstream at the time of photo acquisition. (B) By 1952, sediment has disappeared from the mouth of Deer Creek. Up until that time, the creek meandered through a substantial bar and terrace that was present on its river right (north bank). A large flood with an estimated peak discharge of 109,000 cfs (3,086.5 m^3/s) occurred between 1947 and 1952. It was the largest flood to have occurred since Englebright Dam was built, and could account for the loss of sediment.

Images reveal history of change

Earliest images. A direct comparison of the 1909 and 2008 ground-based photos of Sinoro Bar shows dramatic change (fig. 3). The Smartville gage discharge record shows that water rose on Jan. 2, 1909, peaked on Jan. 15 at about 111,000 cfs (3,143.1 m^3/s), and did not drop below 4,000 cfs (113.3 m^3/s) until June 27. Gilbert's photo (fig. 3A) appears to have been taken after flows receded. It shows a large point bar on river right composed of well-rounded gravel, cobble and sand likely from hydraulic mining.

The bright surface of the bar and lack of shrubs suggest that the surface sediment was freshly deposited, consistent with 1909 being a flood year. Also, there is a large amount of hydraulic mining debris in the mouth of Deer Creek in the photo. In contrast, the 2008 photo (fig. 3B), coupled with direct visual observations, reveals angular boulders and cobbles overlying a mixture of sand, gravel and cobble. The downstream riffle is composed of boulders and cobble and it has steepened into a rapid with standing waves that indicate velocities too high for spawning salmon.

1937, 1947 and 1952. The first aerial photo is from autumn 1937, when flow was extremely low, just 140 cfs (3.96 m^3/s) (fig. 4A). It shows hydraulic mining sediments on the entire point bar as well as in the mouth of Deer Creek. The two riffles that were visible in the 1909 oblique photo are also evident. Despite the low flow, the water in the photo has the characteristic brightness and lack of contrast known to indicate high turbidity.

Overall, it appears that the same conditions present in 1909 persisted to 1937, because the dam was not yet built, and a large amount and a wide mix of sedimentary material was coming down from hydraulic mining sources. Given that the discharge was very low and the channel was visibly very wide compared to its present condition, it can be inferred that the water was shallow. Dark splotches on Sinoro Bar are indicative of vegetation establishment.

Despite being blurry and of low resolution, a 1947 photo (not shown) depicts hydraulic mining debris on both sides of the river. The water still looks turbid even though the dam was in place. The wetted channel is wider throughout the photo, consistent with the higher discharge at the time (1,500 cfs [42.48 m^3/s]). The photo also shows a large new deposit of sediment at the mouth and just downstream of Deer Creek. One of two sizable floods between 1937 and 1947 must have been responsible for this deposit.

The 1952 aerial photo (fig. 4B) is the first to show darkly colored, clear water. The discharge was the highest among all photos examined (2,860 cfs [80.99 m^3/s]), but was only about 25% of modern Q_b. The wetted channel was a lot wider, and a noticeable amount of mining debris was gone. Also, three riffles were present instead of two. Based on the uniformity of pixel brightness, these riffles look like they still consisted of cobble, gravel and sand. Some of the material in the mouth of Deer Creek was gone, possibly due to a large flood event.

1952 to 1986. There is a large gap in the aerial photo record from 1952 to 1986. Although photos were taken in 1957 and 1984, images of Sinoro Bar are lacking. However, ground-based photos provide some information. For example, a photo taken by a local landowner in 1960 shows a gold-mining operation in which coarse river sediment and shot rock were pushed out into the flow to expose underlying finer sediment (fig. 5). A turbidity plume downstream of the bulldozer demonstrates that mud existed in Sinoro Bar. The height of the bulldozer relative to the bar surface provides a vertical scale indicating that Sinoro Bar was high and its surface was already armored with shot rock in 1960. According to the oral history obtained from a local landowner, mining from 1937 to 1960 was limited to hand-based activity until a bulldozer arrived at the end of that period. Ground-based photos from 1971 also show large shot-rock boulders on Sinoro Bar.

Courtesy of Ralph Mullican

Fig. 5. A gold mining operation with a bulldozer at Sinoro Bar circa 1960.

Significant change took place between 1952 and 1986 (fig. 4B and fig. 6A). In aerial photos, the number of riffles decreased from three to two, and the original upstream riffle dating back to 1909 disappeared. The second historic riffle was the primary one at the site in 1986, but it appeared constricted due to the bulldozer pushing the bar further into the channel. Standing waves and white water indicate high velocities unsuitable for salmon spawning. The glide-riffle transition was abrupt in 1986, providing less spawning habitat than is evident in prior photos. The riffle at the end of Sinoro Bar was still wide and gravel-dominated in 1986, with little visual evidence of boulders or large cobble. In terms of the bar itself, a lot of mining sediment and increased vegetation were present on the downstream half of the bar. However, the upstream third of the bar was reduced in size and all material in the mouth of Deer Creek was gone.

Both of those locations appear to have been affected by mining. A mining pit was present on the upstream side of Sinoro Bar, as evidenced by the square shape of the wetted area in the hole and its unnatural position away from any scouring forces of river flow. In the mouth of Deer Creek a road was present. Four large floods occurred in the long period between photos, including two of the three largest on record, and one just 8 months before the 1986 photo was taken (table 1). Given both natural floods and extensive mining activity, it is difficult to say which caused more change, but the net effect is that Sinoro Bar and the mouth of Deer Creek lost a considerable amount of sediment, and overall, preferred spring-run chinook salmon habitat decreased substantially.

1986 to 1996. The period from 1986 to 1996 was characterized by very low flows on the river, except for moderate peaks in May 1995 and May 1996. A summer 1996 aerial photo (not shown) depicts similar conditions for the upstream half of Sinoro Bar and the adjacent channel to those evident in 1986. The same two riffles are present, but the downstream one is narrower. Also, Sinoro Bar sediment still looks like a mix of cobble, gravel and sand. Vegetation still appears to be widespread on Sinoro Bar. The main change during this 10-year period was that the downstream half of the bar was visibly affected by mining, with a new hole and several vehicle tracks visible.

Ground-based photos confirm that extensive mining occurred in the mouth of Deer Creek and on the bar just downstream during this period. Mining included searches for gold in the historic hydraulic-mining sediments underlying the shot rock, and a bedrock and boulder harvesting operation for "Yuba Blue," a blue-green basalt rock of value in landscaping.

1997 to present. A rain-on-snow flood occurred Dec. 27, 1996, through Jan. 14, 1997, with the peak discharge occurring on Jan. 2 (table 1). That peak has the second-highest estimated flow in the entire historical record. There are no photos immediately following, but there is a ground-based photo from July 2, 2001, and a high-quality aerial photo taken in 2002 (fig. 6B). The 2002 aerial shows fresh deposits of sediments of a wide range of sizes, including shot rock. Mining pits on the bar were partially filled in. Image pixels of new debris show strong brightness contrast, indicative of coarse size and angular shape. Former pits are presently filled with 20 to 26 feet (6 to 8 meters) of fill due to the 1997 flood. Shot rock buried most of the vegetation evident in earlier photos. In terms of mesohabitats, the primary riffle present in 1986 was degraded to a chute by 2002. Also, the riffle at the end of the bar became heavily armored, with larger standing waves and more white water. It probably received a lot of coarse boulders and cobble that replaced preexisting finer gravels.

Photos from 2004, 2005 and 2006 (not shown) do not indicate much change from 2002. A large flood occurred Dec. 26, 2005, through Jan. 7, 2006, which caused the deposition of more shot rock on Sinoro Bar where mining pits used to be. There is no indication that 1997 shot rock was removed by the 2006 flood, suggesting that this is a highly stable deposition site.

Factors affecting habitat

The Englebright Dam Reach of the lower Yuba River is a bedrock canyon that contains remnant alluvial fill. No imagery of this reach predates hydraulic mining, but the history of gold mining at Landers Bar confirms that alluvium existed in the canyon. Hydraulic mining debris formed deep

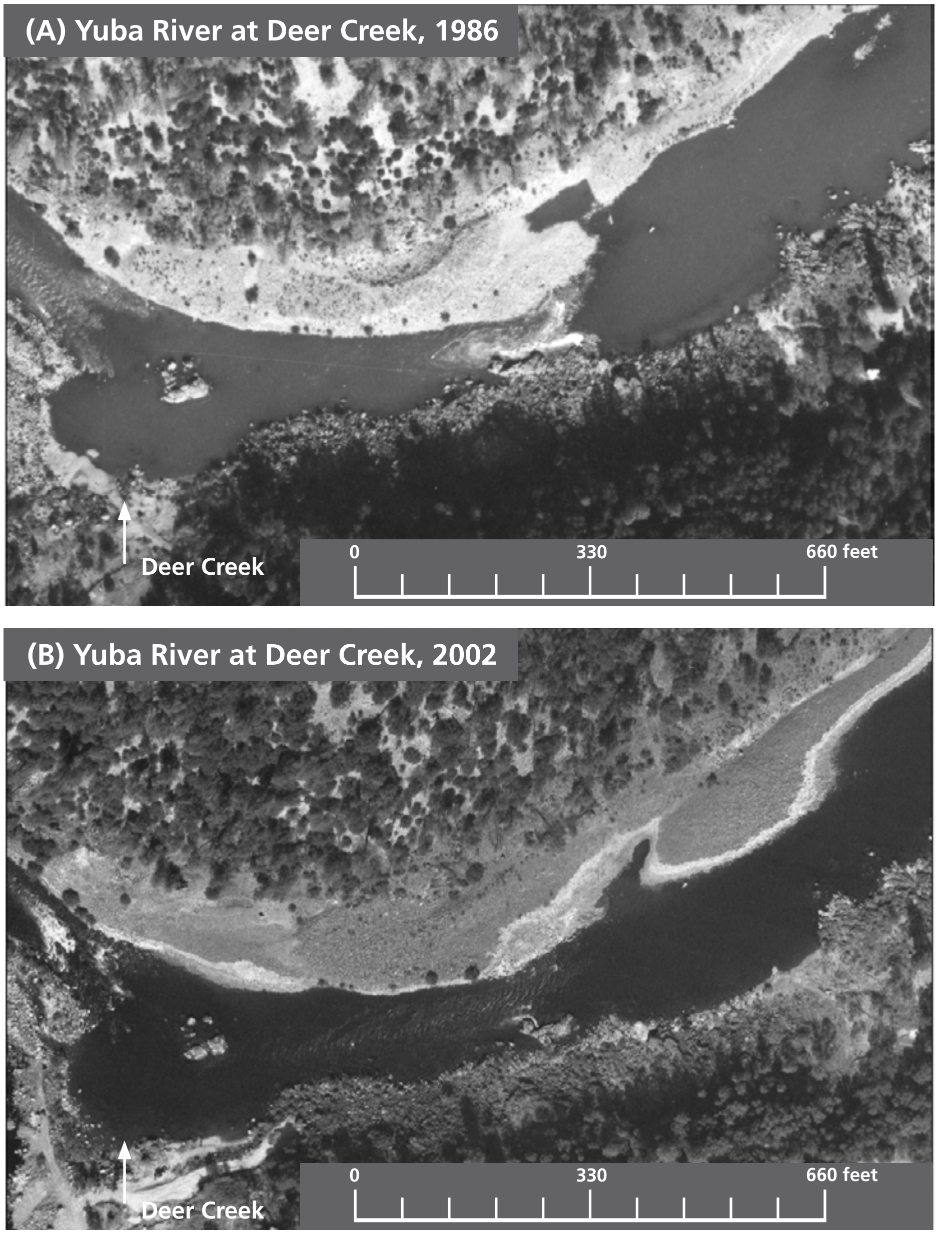


Fig. 6. Aerial photos of Sinoro Bar.

alluvial deposits in the reach, including multiple gravel-bedded riffles. Based on the size and shape of the riffles evident in the imagery, they would have provided spawning habitat for spring-run chinook salmon. As a reference for the scale of historic gravel input to the Englebright Dam Reach, a sediment-budget analysis found that on average about 77,520 metric tons per year of gravel and cobble (not counting sand and mud) deposited in Englebright Lake from 1942 to 2004 (Pasternack 2008; Snyder et al. 2004). A supply of at least that magnitude was responsible for forming Sinoro Bar in the first place, but it was so large that it filled in the entire river corridor from Narrows Pool down to Marysville.

After Englebright Dam was built, a large quantity of highly angular shot rock was introduced to the canyon and allowed to migrate downstream in floods, even as the upstream supply of gravel was cut off. The burial and replacement of gravel bars by shot rock since 1942 has degraded salmon spawning habitat. More historic shot rock and recently excavated cobble-sized angular rock are present below Englebright Dam and could cause future degradations, depending on how well the bars are protected from erosion during large floods.

Gold mining on Sinoro Bar became mechanized around 1960 and was responsible for degrading salmon habitat. Prior to mining with bulldozers, glide-riffle transitions were gradual, enabling fish to select among a diverse range of local hydraulic conditions. Bulldozer debris constricted the channel significantly, induced abrupt hydraulic transitioning and caused the main riffle at the apex of the bar to degrade into a chute unsuitable for spawning. In addition, mining operations evacuated the majority of alluvium at the mouth of Deer Creek, destroying what was likely a hotspot for biological productivity and salmon spawning. Shot rock has not filled in the hole in the outer bed of the river but has filled in mining holes on Sinoro Bar, consistent with well-known channel-bed hydrodynamics and sediment transport patterns. Overall, the impact of mechanized in-stream gold mining was significantly greater than the impact of Englebright Dam on changing the geometry and structure of Sinoro Bar.

The Englebright Dam Reach locations where shot rock deposited in the past may be viewed as a natural sediment transport "experiment" revealing the fate of coarse sediment introduced on the hillside adjacent to Englebright Dam. Large floods pick up alluvium in the highly constricted top 660 feet (200 meters) of the reach and primarily deposit them in the widest section of the canyon, which also happens to occur in the backwater zone associated with Deer Creek floods. Sinoro Bar is located in this zone. Thus, Englebright Dam has affected the Englebright Dam Reach by causing angular boulders and cobbles to be torn off the hillside and lifted off bedrock terraces to end up on Sinoro Bar. Based on the historical deposition pattern of hydraulic mining sediment and shot rock, gravels injected at Englebright Dam and mobilized by future floods are most likely to deposit at Sinoro Bar. Even though shot rock takes up space where gravel might go, there is still room in the wide section of Englebright Dam Reach for gravel to deposit.

Rehabilitating Sinoro Bar

Large floods do not appear to scour Sinoro Bar, but rather to add more shot rock to it. Thus, rehabilitation of salmon spawning habitat requires shot-rock removal. Merely exhuming gravel-rich hydraulic mining debris will not yield salmon habitat in and of itself, because historic mining operations reconfigured the bar to an unsuitable geometry. Furthermore, there is little gravel at the mouth of Deer Creek due to local mining and an upstream dam that should be addressed. These findings suggest that shot-rock removal should only be undertaken if it is combined with large-scale gravel placement and spawning habitat rehabilitation (Wheaton et al. 2004a, 2004b). The scale of initial gravel placement ought to be about 130,000 cubic yards (100,000 cubic meters) — roughly two-thirds the volume of Sinoro bar itself. It would also be sensible to investigate methods for preventing future spills over the dam from tearing rock off the hillside.

Suitable rounded river gravel is available from a quarry near the Highway 20 bridge as well as numerous tailing berms downstream. These materials can be sorted and thoroughly washed to remove mercury-bearing clay and fine silt prior to reintroduction to the channel. Even if some mercury is reintroduced, the water, riverbed and hyporheic zone are well oxygenated in the river between Englebright Dam and the Highway 20 bridge, so there is little risk of forming hazardous methylmercury in that segment. Downstream of the Highway 20 bridge, there are ample sources of mercury in terraces composed of hydraulic mining sediment (James et al. 2009) and likely in the alluvial fill underlying the riverbed, which is composed of the same source material. Exposure and reworking of one small bar of historical sediment would likely have a negligible effect on possible mercury contamination, relative to the existing large inventory of mercury available downstream.

Once the site is rehabilitated, gravel injection at Englebright Dam could sustain it. Existing shot rock and friable hillsides at the dam should be further stabilized to reduce erosion. Then a gravel injection program should be established to feed gravel to the Sinoro Bar area. This has the benefit of possibly yielding smaller pockets of deposition further up in the canyon behind local obstructions (Fulton 2008) and avoids impacts on local landowners adjacent to Sinoro Bar. Based on our experience with gravel injection in California, about 13,000 cubic yards (10,000 cubic meters) per year (in conjunction with rehabilitation of the Sinoro Bar site) would promote sustainable deposition behind flow obstructions and would be large enough to support a spring-run chinook salmon population of about 4,000 fish as well as replenish any losses to mesohabitat in the Sinoro Bar area.

If no large-scale gravel placement is done at Sinoro Bar at the time of shot-rock removal, then injection of about 26,000 cubic yards (20,000 cubic meters) per year at the dam would likely be large enough to yield sustainable gravel bar and riffle formation down at Sinoro Bar in 5 to 15 years, depending on the flood regime. After that, the injected amount could be reduced to a maintenance level of about 13,000 cubic yards (10,000 cubic meters) per year. However, direct gravel placement would have the benefit of providing immediate spring-run chinook salmon habitat for all freshwater life stages with much less uncertainty.

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References

Banks MA, Rashbrook VK, Calavetta MJ, et al. 2000. Analysis of microsatellite DNA resolves genetic structure and diversity of chinook salmon (*Oncorhynchus tshawytscha*) in California's Central Valley. Can J Fish Aquat Sci 57:915–27.

Curtis JA, Flint LE, Alpers CN, Yarnell SM. 2005. Conceptual model of sediment processes in the upper Yuba River watershed, Sierra Nevada, CA. Geomorphology 68:149–66.

Fulton AA. 2008. Gravel for Salmon in Bedrock Channels: Elucidating Mitigation Efficacy Through Site Characterization, 2D-Modeling, and Comparison along the Yuba River, CA. Master's thesis, Department of Hydrologic Science, UC Davis, CA. 110 p.

James LA. 2005. Sediment from hydraulic mining detained by Englebright and small dams in the Yuba basin. Geomorphology 71:202–26.

James LA, Singer MB, Ghoshal S, Megison M. 2009. Sedimentation in the lower Yuba and Feather rivers, California: Long-term effects of contrasting river management strategies. In: James LA, Rathburn SL, Whittecar GR (eds.). *Management and Restoration of Fluvial Systems with Broad Historical Changes and Human Impacts*. Geological Society of America, Boulder, CO. p 57–82.

McReynolds TR, Garman CE. 2008. Butte Creek spring-run Chinook salmon, *Oncoryhnchus tshawytscha*, pre-spawn mortality evaluation, 2007. California Department of Fish and Game, Ranco Cordova, CA. Inland Fisheries Report No. 2008-2.

Pasternack GB. 2008. SHIRA-based river analysis and field-based manipulative sediment transport experiments to balance habitat and geomorphic goals on the lower Yuba River. Cooperative Ecosystems Studies Unit (CESU) 81332 6 J002, Final Report. UC Davis, CA.

Snyder NP, Rubin DM, Alpers CN, et al. 2004. Estimating accumulation rates and physical properties behind a dam: Englebright Lake, Yuba River, Northern California. Water Resources Research 40(W11301):1–19. doi: 10.1029/2004WR003279.

[USACE] US Army Corps of Engineers. 2007. Lower Yuba River pilot gravel injection project, Yuba and Nevada counties, California — draft environmental assessment. Sacramento District, CA. p 59.

Wheaton JM, Pasternack GB, Merz JE. 2004a. Spawning habitat rehabilitation-I. Conceptual approach and models. Int J River Basin Manage 2(1):3–20.

Wheaton JM, Pasternack GB, Merz JE. 2004b. Spawning habitat rehabilitation-II. Using hypothesis development and testing in design, Mokelumne River, California, USA. Int J River Basin Manage 2(1):21–37.

Wohl E, Tinkler KJ. 1998. A primer on bedrock channels. In: Wohl E, Tinkler KJ (eds.). *Rivers Over Rock: Fluvial Processes in Bedrock Channels*. American Geophysical Union, Washington, DC.

Yoshiyama RM, Gerstung ER, Fisher FW, Moyle PB. 1996. Historical and present distribution of chinook salmon in the Central Valley drainage of California. UC Centers for Water and Wildland Resources, Davis. In: Brown RL (ed.). *Contributions to the Biology of Central Valley Salmonids. Vol. 1*. California Department of Fish and Game, Fish Bulletin 179, p 71–176.

Research connects soil hydrology and stream water chemistry in California oak woodlands

by Anthony T. O'Geen, Randy A. Dahlgren, Alexandre Swarowsky, Kenneth W. Tate, David J. Lewis *and* Michael J. Singer

The UC Sierra Foothill Research and Extension Center (SFREC) is located in the heart of typical California blue oak and live oak woodlands within metavolcanic terrain of the Sierra Nevada foothills. These types of woodlands often exist at the interface between urban, wild and agricultural lands and are used extensively for livestock grazing, wildlife habitat and surface water supply. Soil surveys for this region and within SFREC depict relatively few soil types compared to areas that support more-intensive agricultural land uses. Despite this inferred homogeneity, our study showed that the biogeochemical and physical properties of soils vary sharply over short distances of less than 10 feet and also experience changes by season and as a result of storm events. An understanding of soil variability in this setting is important to assess rangeland productivity, perennial grass and oak restoration potential, carbon sequestration, stream flow generation and stream water chemistry.

UC Davis undergraduate Tony Orozco installs a sensor in the Lewis-1 watershed at the UC Sierra Foothill Research and Extension Center.

▲ The bracket shows an abrupt clay increase associated with the upper boundary of the claypan in a typical soil profile at SFREC.

Oak woodlands are a patchy array of open grassland and oak canopy. The presence or absence of trees is one factor that imposes spatial variability in soil characteristics. Oak trees change the properties of soils beneath their canopies through a variety of nutrient-cycling processes, such as annual inputs of litter fall (Dahlgren et al. 2003). As leaves drop and decompose at the soil surface, organic matter and nutrients are resupplied to the upper soil horizons, creating islands of fertility and enhanced soil quality. Physical (bulk density, water infiltration rates), chemical (nutrient enrichment, pH, cation exchange capacity) and biological (microbial biomass, soil respiration) properties are enhanced in soils under oak canopies (Dahlgren et al. 1997). In contrast, soils forming under annual grasses in the absence of oak canopy are less fertile, have higher bulk density and are more susceptible to surface-water runoff.

Soil processes exhibit unique patterns in Mediterranean ecosystems such as California, due to the timing of precipitation. Summers are warm and dry, and most of the rain falls in winter months when vegetation is dormant and the temperature is low. Most biogeochemical processes require hospitable temperatures and an adequate water supply. Interactions between the ecosystem services that soils provide, such as nutrient cycling and the regulation of water quality and quantity, are strongly influenced by the seasonality of climate and individual storm events.

Together, (1) the Mediterranean climate, (2) the inferred spatial homogeneity of soils and (3) oak tree–induced differences in soil properties, pose an interesting challenge for understanding the ecosystem services that soils provide and subsequent management implications.

Our primary objective was to examine the linkages between nitrogen cycling and soil hydrology in a manner that considers how the temporal and spatial variability of soil properties govern these processes and ultimately the soil's ability to regulate stream water quantity and quality in oak woodlands. We present results from multiple long-term monitoring projects at the UC Sierra Foothill Research and Extension Center (SFREC) that integrate soil, ecology and water-resources data from the area's California blue oak (*Quercus douglasii*) and live oak (*Q. wislizeni*) woodlands. The ability to co-locate these projects is rare and would not be possible without the support of the SFREC infrastructure and staff.

A natural laboratory

SFREC has served as a natural laboratory to study soils, ecology, hydrological processes and land management effects for many years. There is a nearly 30-year record of water flow and water quality for its Schubert watershed (Lewis et al. 2000, 2006). Schubert watershed is 255 acres in size, with tree coverage of approximately 50%, predominantly blue oak. A similar experimental 90-acre watershed at SFREC, called Lewis-1, was instrumented in 2002. These paired watersheds are within 3 miles of each other, and are two of four watersheds at SFREC that we have been monitoring for stream flow and water quality. They were chosen because they are similar in elevation, topography, geology, soils and vegetation (type and canopy coverage). The main difference between Lewis-1 and Schubert is size, Lewis-1 being 90 acres and Schubert, 255 acres. As part of a project beginning in 2002, Lewis-1 has been ungrazed for about 10 years, and Schubert has been heavily grazed.

In the experimental Lewis-1 watershed, we installed a weather station, 400 soil-moisture sensors, a perched water monitoring infrastructure and a stream-flow monitoring network. A perched water table occurs during the rainy season above a relatively impermeable clay-rich horizon situated approximately 10 inches below the soil surface. This infrastructure has allowed us to document the relationships between rainfall, soil moisture storage, lateral flow through soils and stream flow at 15-minute intervals since summer 2006.

Glossary

Biogeochemistry: The study of chemical, physical, geological and biological processes on Earth.

Bulk density: The mass of dry soil per unit volume of soil.

Genetic soil horizon: A layer of soil often occurring parallel to the soil surface that differs from adjacent soil layers in physical, chemical and biological properties or morphological features such as color, structure or roots.

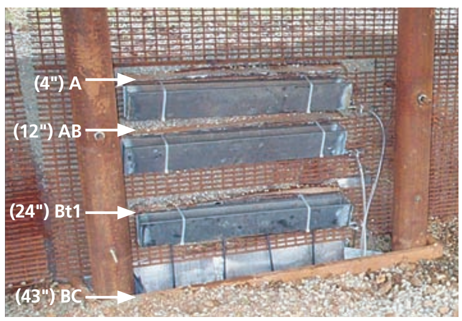
Litter fall: Dead plant residues that accumulate on the soil surface annually.

Metavolcanic: Metamorphosed, igneous, extrusive bedrock.

Nitrogen cycling: The cyclical transformations and translocations of nitrogen from the atmosphere (N_2), to plant and microbial tissues, to inorganic nitrogen (NO_3 and NH_4).

Perched water table: A discontinuous saturated zone in soil that occurs when vertically percolating water reaches a slowly permeable soil horizon.

Soil profile: An excavation in the soil approximately 3 feet long by 3 feet wide by 5 feet deep used to describe and sample soils.



Above, **the Lewis-1 watershed at SFREC was equipped with instruments in 2002 to sample and monitor the interactions between soil and stream water.** ***Top left***, **a perched water monitoring trench uses trays to collect water samples from different soil horizons (A, AB, Bt1 and BC).** ***Top right***, **tipping buckets are mounted on the blue containers to measure lateral water flow.**

To understand the temporal and spatial patterns in water content, sensors were placed in 100 soil profiles, typically at depths of 4, 12, 20 and 40 inches. Perched water flow was monitored continuously from a trench that contained three soil profiles fitted with water-collection trays inserted at four depths: 4 inches (bottom of A horizon), 12 inches (bottom of AB horizon), 24 inches (upper boundary of the clay pan) and 43 inches (below the clay pan). Water flow rates were recorded from each layer using tipping buckets, and water chemistry samples were collected in plastic drums. Stream flow was monitored continuously using water-height sensors connected to a combination V-notch weir for measurement at low-flow conditions, and a Parshall flume was used for high-flow measurements. Automated samplers were used to collect water samples from streams on an hourly basis during storm events, and base flow was collected periodically between storms.

The soil and ecological data that we collected reflects a variety of experiments that have been conducted at SFREC over the last two decades, including at Schubert watershed. Soil profiles under the oak canopy and open grasslands were sampled by genetic soil horizon to determine the effects of oak nutrient cycling on soil characteristics. Organic matter concentrations (total carbon and nitrogen) were determined for each soil horizon, and these values were converted to an area basis using the soil bulk density, horizon thickness and rock content. Two representative blue oaks (70 and 92 years old with 11.5- and 19-inch-diameter breast heights, respectively) were destructively sampled, and all aboveground components were dried and weighed to determine the size of the carbon and nutrient pools. Root biomass and nutrient concentrations were calculated from root quantification studies conducted for these same sites (Millikin and Bledsoe 1999). To document temporal changes in soil solution chemistry, 1.5-to-1 water extracts were prepared for each soil horizon monthly to determine the concentrations of soluble nutrients in soil horizons beneath the oak canopy and in adjacent grasslands.

Soil profile	Under tree (inches)	lbs. N/acre	Under grass (inches)	lbs. N/acre
A	0–3	2,513	0–2	1,368
AB	3–11	2,813	2–15	2,057
Bt1	11–22	1,641	15–22	754
Bt2	22–31	937	22–29	823
BC	31–40	469	29–38	342
Whole profile	0–40	8,373	0–38	5,344

Fig. 1. Nitrogen cycling with major pools of nitrogen (pounds/acre) for an oak woodland–grassland ecosystem in the Schubert watershed at SFREC.

Soil properties

Soils at SFREC and throughout the metavolcanic terrain within the foothill region are moderately deep to very deep, ranging from 20 inches to more than 60 inches. Soils possess a distinctive red color due to the high iron content of the parent material that is released through weathering. A typical soil profile has the following genetic horizon sequence: A-AB-Bt1-Bt2-BC-Cr or R.

The A and AB horizons have a clay-loam texture and appreciable soil organic-matter enrichment. Under oak trees, A horizons are thicker (4 versus 2 inches), with higher organic matter and lower bulk density compared to those in open grasslands (Dahlgren et al. 1997). The A and AB horizons are porous and extensively burrowed by pocket gophers. Soils with Bt1 and Bt2 horizons represent an accumulation of clay (about 35% to 50%, maximum) transported from overlying horizons by percolating water. Bt horizon textures range from clay loam to clay depending on the landscape position. Claypans (Bt2) are a subset of Bt horizons that have an abrupt clay increase (more than 20% relative to the overlying horizon) over a short vertical distance (less than 1 inch). Soil profiles containing claypans occupy less than half of the landscape area in the experimental watershed and tend to occur on level or gently sloping hillsides and land forms that accumulate water. Clay content decreases below the Bt horizons, resulting in a transition horizon (BC). The soil interface with bedrock is described by either Cr (soft bedrock) or R (hard bedrock) horizons.

Nitrogen cycling

Nitrogen cycling within the landscape is directly linked with the oak canopy distribution and hydrologic cycle. The majority of nitrogen is present as soil organic matter stored in the A and AB horizons (approximately the upper 15 inches of soil). We found that the major nitrogen pool is contained in soil profiles under oak trees at about 8,373 pounds per acre (fig. 1). The nitrogen pool contained within the oak trees was approximately 14% of the total soil nitrogen pool. Nitrogen stored in blue oak was about 1,138 pounds per acre (931 aboveground plus 207 pounds per acre in roots belowground), while understory components (e.g., grasses and herbs) added 39 and 53 pounds per acre under the oak canopy and in open grasslands, respectively. The soil nitrogen pool was nearly 1.6 times greater (8,373 versus 5,344 pounds per acre) in

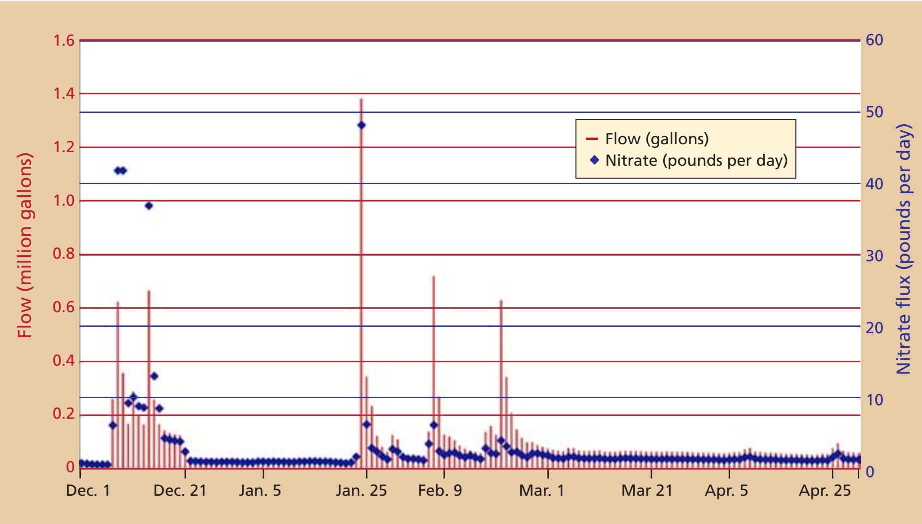


Fig. 2. Stream flow and nitrate-nitrogen (NO_3-N) load in the 1992–1993 water year, Dec. 1 through April 30, at the Schubert watershed.

soils beneath the oak canopy compared to open grasslands (fig. 1).

Organic matter. The ability of oaks to alter their soil environment occurs primarily through the addition of organic matter and nutrient cycling. During a 3-year (1990–1992) study period, oaks returned about 4,008 and 75 pounds per acre annually of organic carbon and nitrogen, respectively, to the soil surface through aboveground litter fall. Belowground carbon inputs through oak and annual grass root turnover also contributed an appreciable amount of organic matter (Jackson et al. 1990; Millikin and Bledsoe 1999). An additional 5.3 pounds per acre of nitrogen was added annually to the soil surface by canopy throughfall (canopy drip) and stem flow (water flowing down the tree trunk). Nutrient flux in the canopy throughfall originates from the capture of atmospheric aerosols, gases and particulate matter, as well as from root uptake with subsequent foliar leaching.

Roots. In addition, oaks are rooted considerably deeper than annual grasses, which reduces deep leaching and the loss of nutrients beneath the oak canopy. About 70% of the oak root biomass occurs within the upper 20 inches of the soil profile (Millikin and Bledsoe 1999). Oak roots also extend well beyond the edge of the canopy, where they can sequester nutrients from grassland soils. Over time, they concentrate these nutrients beneath the oak canopy in the form of litter fall and canopy throughfall. Given the organic-matter enrichment in soils and oak vegetation, there is considerable potential for carbon sequestration (about 89 tons per acre) associated with the conversion of grasslands to oak woodlands. To ensure long-term carbon sequestration, oak trees must be protected. Organic carbon and many of the enhanced soil properties are lost within 20 to 30 years following an oak's removal (Dahlgren et al. 2003).

Climate and seasons. The Mediterranean climate contributes to strong spatial and seasonal patterns in soil-solution and stream nutrient concentrations, as illustrated by nitrate concentrations during the winter/spring rainy season (figs. 2 and 3). Peak soil-solution nitrate concentrations occur in fall and late spring and are considerably higher in soils under oak canopy during these times (fig. 3).

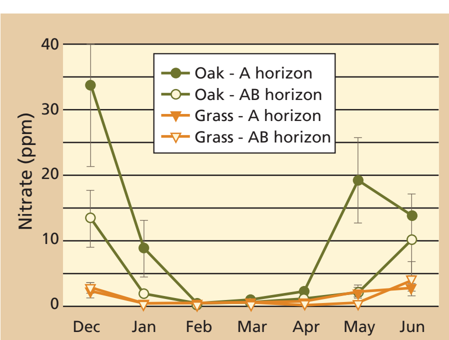


Fig. 3. Nitrate-nitrogen (NO_3-N, parts per million) concentrations in soil pore water under oak canopy and open grassland.

In contrast, nitrate concentrations are very low and similar between oak and open-grassland soils during the winter months when soil moisture storage and leaching are at their peaks, and soil temperatures and microbial activity are low.

In addition, annual grass growth and oak foliage production results in strong demand for biological nutrients in spring, further depleting the soil nitrate pool in spite of favorable moisture and temperature conditions for microbial mineralization. The increase in soil nitrate in late spring coincides with the senescence (die off) of annual grasses, which results in a decrease in nitrogen uptake demands coupled with the release of nitrogen from dead annual grass roots by microbial decomposition. Dry conditions in the upper soil profile throughout summer result in low nitrogen uptake by oak roots.

Instead of continuous nitrogen feedback among senescing plants, their soils and new growth, nitrogen is mineralized and accumulates in soils during the dry summer and fall months (Hart et al. 1993). Throughout summer, organic and inorganic nitrogen accumulates in the soil, and there is little plant growth to sequester these nutrients. Early fall rains (September to October) cause the leaching of ammonium, nitrate and dissolved organic nitrogen (DON) from annual grass residues (more than 50% of total DON) while senescent oak foliage accounts for more than 70% of total DON after the first storm (Chow et al. 2009). High concentrations of DON combined with water availability and warm residual soil temperatures lead to an explosion of microbial activity that results in rapid nitrogen mineralization and the accumulation of nitrate in the upper soil horizons.

An asynchrony within nutrient cycles occurs in the Mediterranean climate, causing a marked nitrate spike in stream water during the onset of the rainy season (December to January) (Holloway and Dahlgren 2001). Nitrate leaching from oak woodland watersheds at SFREC is strongly linked to the hydrologic cycle at time scales ranging from storm events (hours) to years. Pulses in stream nitrate concentrations are observed that match those observed in soil pore water in the fall. Each storm progressively flushes this nitrogen pool, so that by March there is little nitrate found in soils and stream water (figs. 2 and 3).

Hydrologic flow paths

Stream flow and water quality are related to soil water storage and hydrologic flow paths through soils. Our conceptual model of the dominant hydrologic flow path in soils of this area is lateral, perched water flow through the upper soil layers (A and AB horizons) following watershed priming. Approximately 7 to 10 inches of precipitation are required to bring the watershed soils to their maximum water-holding capacity before stream flow generation begins (Lewis et al. 2000). With the onset of winter storms, water infiltrates and percolates through the highly permeable A and AB horizons. The vertical percolation of water is impeded by the presence of the claypan approximately 24 inches below the soil surface. The claypan is slowly permeable to water, and as a result saturated conditions develop at the upper boundary of the claypan during storms. A saturation zone (perched water table) forms at the claypan boundary and extends upward into the A and AB horizons as precipitation continues. Once they are saturated, water moves with the force of gravity (down slope) through the highly permeable A and AB horizons, rapidly delivering water as lateral flow to streams.

Storm events. The hydrologic monitoring infrastructure within the experimental watershed demonstrated the connectivity of lateral flow in soils with stream flow during a typical storm (fig. 4). The timing of stream and perched water flow during the course of a storm was similar. Peak stream flow was sustained for approximately 3 hours from 7 p.m. to 10 p.m. during a storm in January 2007 and corresponded with the initiation of lateral flow through the AB horizon located above the claypan. Perched water flow through the AB horizon was the dominant flow path. During this storm event the AB horizon delivered 60% of the total water volume, measured from the perched water monitoring infrastructure. The other horizons contributed relatively equal water volumes ranging from 10% to 17% (fig. 5). An additional line of evidence is apparent from the slope characteristics associated with the rising limb of the hydrographs, where the stream and AB horizon have nearly identical slopes, suggesting that the rapid increase in stream flow is a result of water transport through the AB horizon (fig. 4).

The AB horizon supplied more water to the stream for a variety of reasons. The AB horizon is more permeable than the Bt and BC horizons, because it contains less clay, better soil structure and more large pores (e.g., gopher burrows and decayed root channels) to conduct water rapidly. While the permeability of the AB horizon is similar to that of the A horizon, the AB horizon supplied more water because it was saturated longer due to its proximity to the underlying water-restrictive clay layer. The delay in flow of the A relative to the AB horizon represents the time it took for the perched water table to extend upward into the A horizon. The AB horizon is also thicker than the A horizon (8 versus 4 inches), resulting in a greater cross-sectional area to deliver water.

Water quality. The hydrologic flow paths through soils at SFREC directly affect water quality. With their permeable nature, surface horizons convey water rapidly to streams in large volumes. Infiltration rates range from 1 to 4 inches per hour, and as a result, surface runoff is rare when soils are not saturated (Lewis et al. 2000). Because plants are not actively transpiring during the rainy season, the soil water-storage capacity is frequently exceeded, which results in the transport of water via

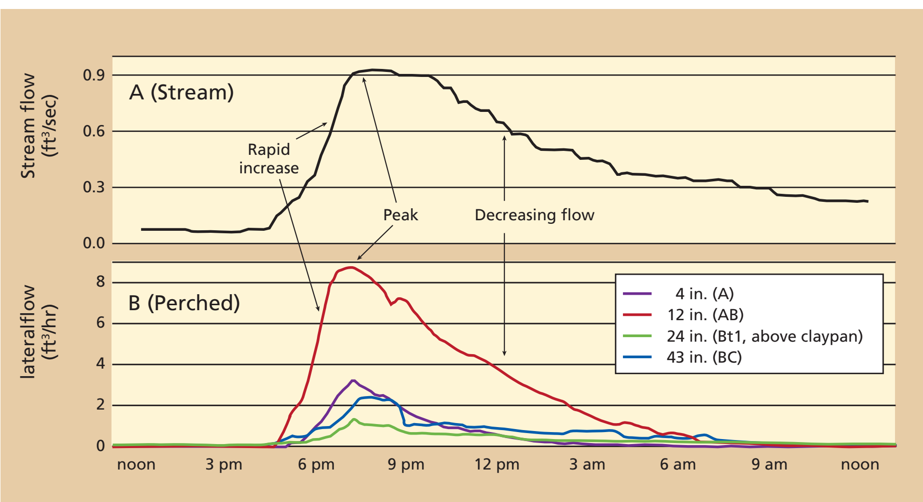


Fig. 4. (A) Stream and (B) perched water hydrographs during the first stream flow event of 2007.

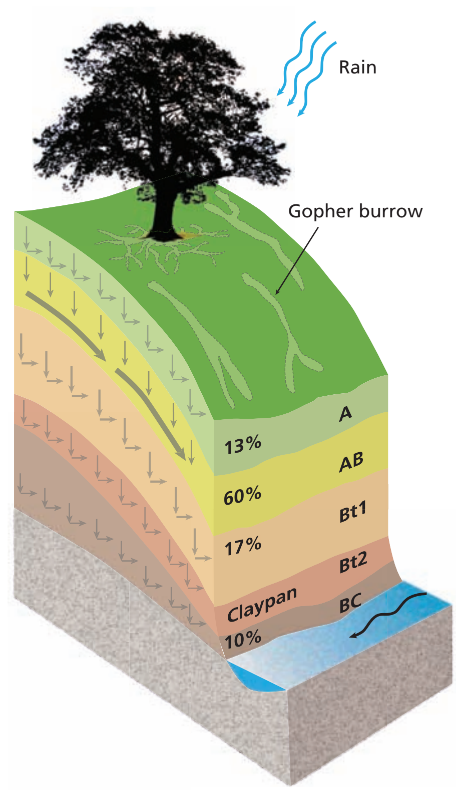


Fig. 5. Contribution of hydrologic flow paths in soils at SFREC. Percentages refer to the total lateral flow contributed by each soil layer during a typical storm event.

More than two-thirds of California's drinking-water supply passes through or is stored in oak woodlands.

lateral flow through the nutrient-rich A and AB horizons, directly to the stream. The nitrate accumulated in the A and AB horizons is susceptible to leaching because little plant uptake occurs during the winter months. The shift to laterally dominated flow paths during storms results in elevated nitrogen concentrations in stream water as nitrate, which is leached directly to the stream via lateral subsurface flow through the A and AB horizons (figs. 4, 5 and 6). In contrast, elements that are associated with groundwater and chemical weathering in the lower Bt and BC horizons (e.g., calcium and sodium) display a distinct decrease in concentration during storms as the hydrologic flow path is short-circuited through the upper soil horizons (fig. 6).

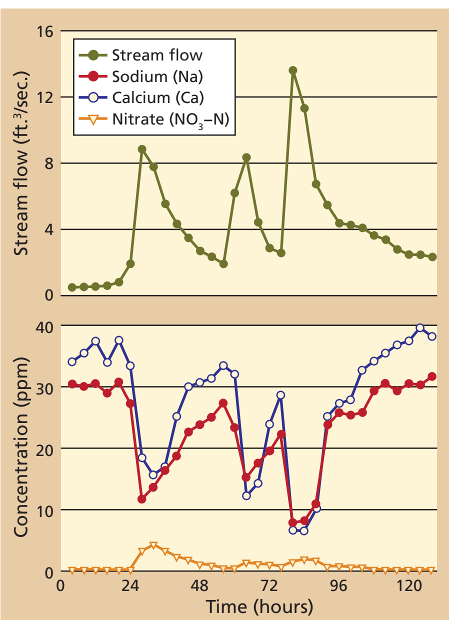


Fig. 6. Changes in stream water chemistry during an early-season (Jan. 2007) storm event.

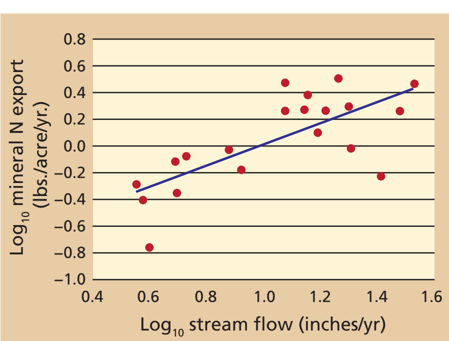


Fig. 7. Relationship of stream nitrate fluxes and stream flow volume (water flux) for a 20-year period (1981–2000) in the Schubert watershed at SFREC; r^2 = 0.52; P < 0.001.

Nitrate variability. There is considerable year-to-year variability in nitrate leaching from oak woodland watersheds (fig. 7). The mean annual nitrate-nitrogen (NO_3-N) export from the Schubert watershed was 1.4 pounds per acre annually (ranging from 0.16 to 3.2 pounds per acre annually) (Lewis et al. 2006). While annual nitrate-nitrogen flux at Schubert reached values as high as 3.2 pounds per acre annually, the loss of nitrate-nitrogen from the watershed was substantially less than atmospheric inputs of mineral nitrogen (ammonium [NH_4] plus nitrate [NO_3]) in the bulk precipitation (mean 8.4 pounds per acre annually). As a result, there was a net retention of mineral nitrogen within the Schubert watershed, assuming no loss of nitrogen through denitrification or volatilization. The annual nitrate-nitrogen load was positively and significantly ($P < 0.05$) related to both annual precipitation and stream flow (Lewis et al. 2006). Nitrate fluxes were a function of total stream flow volume and the timing of storm-flow events throughout the season. Years with high rainfall and runoff, combined with high runoff during the early portion of the rainy season — when nitrate concentrations are highest in the soil profile — resulted in the largest fluxes of nitrate-nitrogen from the watershed.

Differences in stream nitrate flux (figs. 2 and 6) can also be explained by the extent of the perched water table within the watershed and its connectivity to the stream. The observed variation in stream nitrate flux is a result of flushing of the A and AB horizons by the lateral flow path, because these horizons contain most of the nitrogen. The degree of flushing is a function of the amount and intensity of rainfall, the seasonal distribution of rainfall, the spatial extent of the claypan, and the soil moisture content prior to a storm event.

Perched water table. Figure 8 shows the extent and connectivity of the perched water table within the AB horizon as indicated by saturated conditions (water content greater than 35%) during peak stream flow for two storms: (A) Jan. 4, with a large stream nitrate concentration and (B) Feb. 27, with a low stream nitrate concentration. The spatial extent of the perched water table was 59% of the watershed area during the first storm (fig. 8A) compared to 36% during the second storm (fig. 8B). The perched water table was connected to the stream, as indicated by the overlap of regions shaded in green with blue flow lines, which were generated from a digital elevation model to predict the routing of water by topography, using the slope and curvature of the landscape (fig. 8).

The perched water table during the second storm occupied isolated areas with less connectivity to the stream, as indicated by areas of yellow (unsaturated) and green (saturated) intersecting the blue flow lines (fig. 8B). This suggests that the dominant source area of stream flow was limited to the center of the watershed during the Feb. 24 storm, when saturated conditions coin-

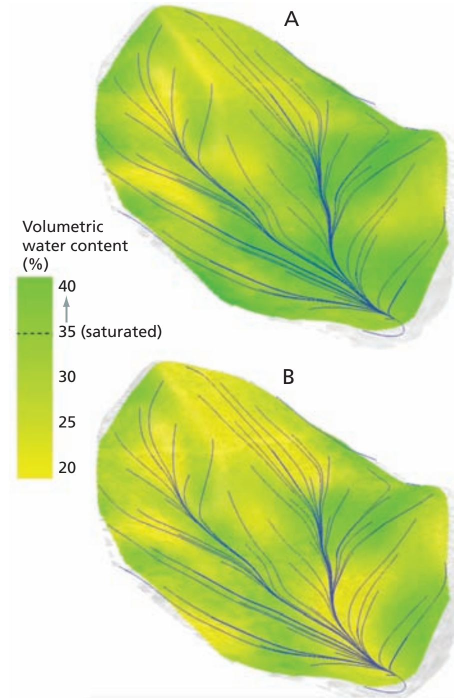


Fig. 8. Extent of saturated conditions in the experimental watershed within the AB horizon during peak flow of two storm events: (A) Jan. 4 and (B) Feb. 27, 2008. Saturated conditions are depicted in green where water content is 35% ± 3%.

▶ **Two-thirds of California's drinking water passes through or is stored in oak woodlands. Detailed knowledge about soil properties can help rangeland managers to assess the impacts of grazing on water supply and quality.**

cided with the main flow lines. Thus, variation in nitrate flux observed over a season (figs. 2 and 3) and during a storm (fig. 6) is a result of the sequential flushing of nitrate from the soil over time and the area of the watershed that is leached, determined by the spatial extent of the perched water table and its connectivity to streams.

Soils and rangeland management

More than two-thirds of California's drinking-water supply passes through or is stored in oak woodlands. Despite the seasonal peaks in nitrate in streams at SFREC, the concentrations are low relative to drinking-water standards (10 parts per million [ppm] nitrate-nitrogen). However, the temporal and spatial patterns between soils and streams observed in this study are relevant to understanding how soils affect water supply and its quality, and can help to guide rangeland management practices such as the stocking rate, season and location of livestock congregation activities (supplemental feeding stations).

In some instances, the variability of soil properties at SFREC and in the Sierra Foothill region exceeds our ability to document them at scales relevant to rangeland management. Key soil properties, however, such as the distribution of claypans, should be documented by soil surveys in order to understand the spatial connectivity of hydrologic-transport processes (surface runoff, subsurface flow, stream flow) within watersheds. Currently, California's soil surveys in rangelands are not mapped at scales fine enough to portray these soil features across landforms and their connectivity to streams. It is important that stakeholders communicate this concern to the U.S. National Cooperative Soil Survey to focus soil survey updates in these important landscapes. This level of detail is warranted to better understand patterns in oak regeneration, perennial-grass restoration, forage productivity, rainfall-to-runoff characteristics and water-quality dynamics.

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References

Chow AT, Lee S, O'Geen AT. 2009. Litter contributions to dissolved organic matter and disinfection byproduct precursors in California oak woodland watersheds. J Env Qual. 38:2334–43.

Dahlgren RA, Horwath WR, Tate KW, Camping TJ. 2003. Blue oak enhance soil quality in California oak woodlands. Cal Ag 57(2):42–7.

Dahlgren RA, Singer MJ, Huang X. 1997. Oak tree grazing impacts on soil properties and nutrients in a California oak woodland. Biogeochemistry 39:45–64.

Hart SC, Firestone MK, Eldor PA, Smith JL. 1993. Flow and fate of soil nitrogen in an annual grassland and a young mixed-conifer forest. Soil Biol Biochem 25:431–42.

Holloway JM, Dahlgren RA. 2001. Seasonal and event-scale variations in solute chemistry for four Sierra Nevada catchments. J Hydrol 250:106–21.

Jackson LE, Strauss RB, Firestone MK, Bartolome JW. 1990. Influence of tree canopies on grassland productivity and nitrogen dynamics in deciduous oak savanna. Agric Ecosyst Env 32:89–105.

Lewis D, Singer MJ, Dahlgren RA, Tate KW. 2000. Hydrology in a California oak woodland watershed: A 17-year study. J Hydrol 240:106–17.

Lewis DJ, Singer MJ, Dahlgren RA, Tate KW. 2006. Nutrient and sediment fluxes from a California rangeland watershed. J Env Qual 35:2202–11.

Millikin CS, Bledsoe CS. 1999. Biomass and distribution of fine and coarse roots from blue oak (*Quercus douglasii*) trees in northern Sierra Nevada foothills of California. Plant Soil 214:27–38.

California black rails depend on irrigation-fed wetlands in the Sierra Nevada foothills

by Orien M.W. Richmond, Stephanie K. Chen, Benjamin B. Risk, Jerry Tecklin *and* Steven R. Beissinger

After California black rails were discovered at the UC Sierra Foothill Research and Extension Center in 1994, an extensive population of this rare, secretive marsh bird was found inhabiting palustrine emergent persistent (PEM1) wetlands throughout the northern Sierra Nevada foothills. We inventoried a variety of PEM1 wetlands to determine which habitats would likely support black rails. Black rails were positively associated with larger PEM1 wetlands that had flowing water, dense vegetation and irrigation water as a primary source; they were negatively associated with fringe wetlands and seasonal water regimes. Recommendations for managing black rail habitat in the northern Sierra foothills include prioritizing the conservation of PEM1 wetlands with permanently or semipermanently flooded water regimes and shallow water zones (less than 1.2 inches), especially those that are greater than 0.25 acres in size; avoiding wetland vegetation removal or overgrazing, especially during the black rail breeding season (approximately March through July); maintaining and improving wetland connectivity; ensuring that impacts to black rails are considered in the environmental review process for development projects; and integrating management guidelines for black rails into existing wetland conservation programs.

Over the past decade, the threatened, secretive California black rail has been found at more than 160 wetlands in the Sierra Nevada foothills.

The rare, secretive California black rail depends on emergent wetland habitats for all stages of its life cycle. It is the smallest rail in North America and has a patchy and poorly understood distribution. In western North America, it is found in saltwater, brackish and freshwater marshes along the Pacific coast from Bodega Bay to northwest Baja California, in the the San Francisco Bay-Delta Estuary (where it is most abundant), inland in small numbers in the Salton Trough and along the lower Colorado River, and in the northern Sierra foothills of Butte, Nevada, Placer and Yuba counties, where it was recently discovered (Aigner et al. 1995; Conway and Sulzman 2007; Eddleman et al. 1994; Evens et al. 1991; Richmond et al. 2008).

After California black rails (*Laterallus jamaicensis coturniculus*) were discovered at the UC Sierra Foothill Research and Extension Center (SFREC) in 1994 (Aigner et al. 1995), an extensive search for this species — which is on California's list of threatened species (CDFG 2008) — was carried out throughout the Sacramento Valley and Sierra foothills. While information on the foothill population's distribution has been published (Richmond et al. 2008), a detailed description of the habitats occupied by black rails in the foothills is lacking.

Study area and data collection

Little information is available for the state's small (< 25 acres [< 10 hectares]), inland, palustrine emergent persistent (PEM1) wetlands (Cowardin et al. 1979). Also known as marshes or fens, PEM1 wetlands are nontidal and dominated by perennial, erect, rooted, herbaceous hydrophytes (plants able to grow in water or on a substrate that is at least periodically deficient in oxygen due to flooding, excluding mosses and lichens) that normally remain standing from the end of one growing season until the beginning of the next (Cowardin et al. 1979).

We surveyed a network of 228 PEM1 wetlands spanning approximately 400 square miles (1,036 square kilometers) in Butte, Nevada and Yuba counties in the

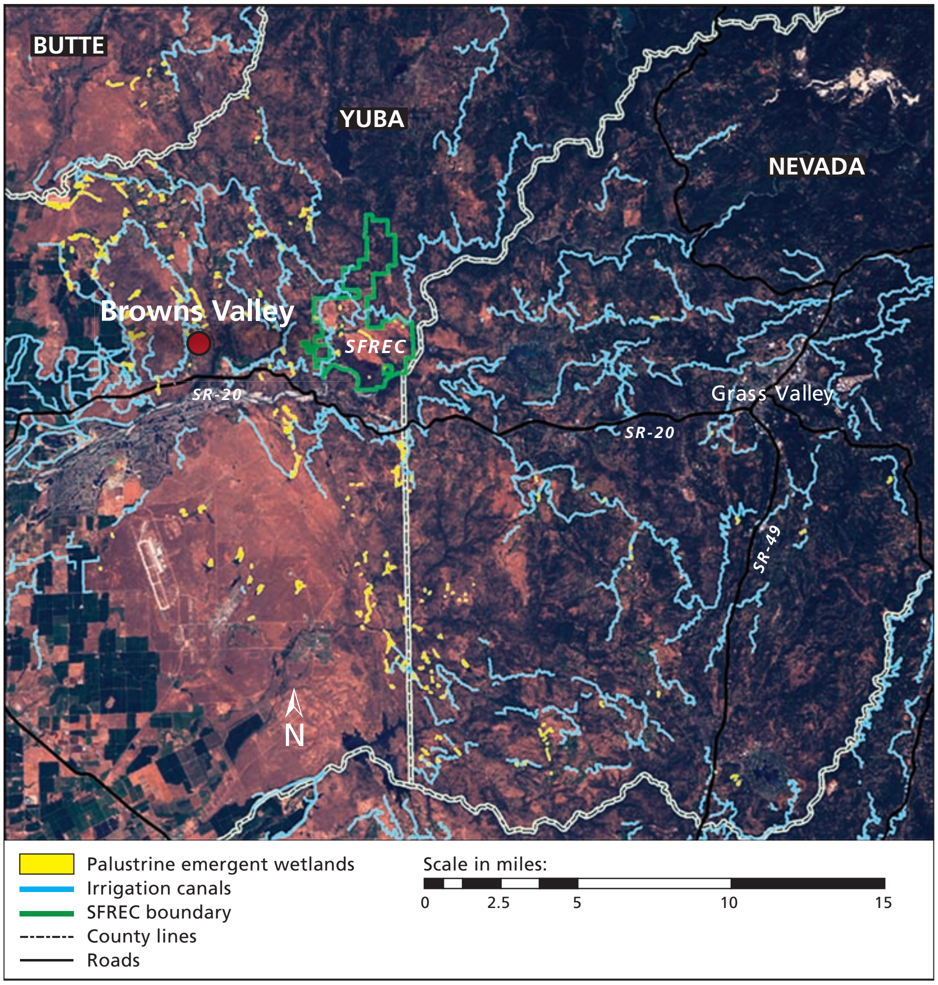


Fig 1. Distribution of surveyed palustrine emergent (PEM1) wetlands and irrigation canals in the northern Sierra Nevada foothills.

northern Sierra foothills, from 2002 to 2008 (fig. 1). The region's Mediterranean climate is characterized by hot, dry summers and cool, wet winters with an average annual precipitation of approximately 30 inches (76 centimeters), with approximately 90% falling between October and March (Lewis et al. 2000). We identified candidate PEM1 wetlands in the foothills using U.S. Geological Survey (USGS) topographic quad maps, aerial photographs and U.S. Fish and Wildlife Service National Wetland Inventory maps; we also encountered many sites during field surveys.

We focused on wetlands from 50 to 3,000 feet in elevation with water regimes (temporal patterns of water flow) consistent with previous descriptions of rail habitat, including those that appeared to be permanently, semipermanently and seasonally flooded, intermittently exposed, and saturated. We also surveyed wetlands with water regimes that were less likely to support black rails, including ones that were temporarily and intermittently flooded (Cowardin et al. 1979).

Wetland mapping. We mapped all surveyed wetlands in the field using a backpack Trimble Pro XR GPS (global positioning system) receiver and TDC1 Asset Surveyor data collector. We delineated wetland boundaries by including all areas that appeared permanently or seasonally flooded with shallow water depths where hydrophytes composed more than 50% of the vegetation. We focused our mapping and analysis on vegetated wetland zones and excluded areas of open water, because black rails are not known to use open-water habitats. We obtained geospatial data on irrigation canals from the USGS National Hydrography Dataset (http://nhd.usgs.gov/data.html). We attempted to survey all PEM1 wetlands identified in our study area, but were sometimes unable to access sites on private lands.

Habitat assessment. We conducted habitat assessments between June 1 and Aug. 31 from 2002 to 2008 and recorded water source, geomorphic setting, evidence of a seasonal water regime, and hydrological conditions at each wetland. We visually determined the primary water source at each wetland as irrigation canal, rainfall, spring or stream. In some cases, flows or downslope seepage from irrigation canals augmented natural stream or spring flows. We considered a wetland to be primarily stream-fed if it was situated along a stream channel, and primarily spring-fed if it received most of its water from subsurface sources.

Hydrology. We assigned each wetland to one of four geomorphic setting categories: (1) slope wetlands formed by the discharge of water to the surface on sloping land, (2) depressional wetlands situated in local depressions with closed elevation contours, (3) fluvial wetlands situated along stream channels and (4) fringe wetlands bordering water bodies such as ponds, lakes or rice fields (see page 91). We recorded whether sites exhibited evidence of a seasonal water regime — indicating that they might become dry for at least a part of the year — by noting dried portions of sites, dead or stressed hydrophytic vegetation, encroachment of upland vegetation, or reduced water levels that exposed bare mud. We assessed the presence of flowing water, standing water, saturated mud and firm mud. A "wettest hydrology rating" was determined for each wetland according to the following sequence: flowing water, standing water, saturated mud, firm mud and dry. For example, a wetland that had standing water, saturated mud and firm mud present would have a wettest hydrology rating of standing water.

To examine relationships between annual rainfall and wetland hydrological characteristics, we obtained precipitation data from California Irrigation Management Information System (CIMIS) station 84 in Browns Valley, Calif., which was situated in the central part of the study area (www.cimis.water.ca.gov).

Plant species. We collected data on plant species diversity in 2007 at a subset of 20 PEM1 wetlands ranging in size from 0.7 to 3.2 acres (0.3 to 1.3 hectares). Within each wetland we surveyed four randomly placed 10.9-yard (10-meter) transects and identified all plants to genus or species that touched a vertical pole held at ten 3.3-foot (1-meter) intervals along each transect.

We collected additional hydrological and vegetative data at randomly sampled points at a subset of 184 PEM1 wetlands in 2008. We generated 10 random points within wetland boundaries for sites greater than 0.62 acre (0.25 hectare), eight points for sites from 0.25 to 0.62 acre (0.1 to 0.25 hectare) and five points for sites less than 0.25 acre (0.1 hectare). At each point, we recorded the hydrology/substrate (flowing water, standing water, saturated mud, firm mud, dry wetland), water depth and dominant vegetation using nine broad vegetation groups: cattails (Typhaceae), cutgrass (*Leersia oryzoides*), forbs, hardstem bulrush (*Scirpus acutus*), Himalayan blackberry (*Rubus discolor*), other grasses (Poaceae), other sedges (Cyperaceae), rushes (Juncaceae) and willows (*Salix* spp.). At each point we also measured vegetation density (or cover) in six height strata by recording whether or not any vegetation touched a vertically held 3.9-foot (1.2-meter) pole (vegetation present or absent). We estimated vegetation heights using the midpoint of the tallest height strata with vegetation present at each point.

Call-playback surveys. Concurrent with the habitat assessments, we conducted call-playback surveys between June 1 and Aug. 31 from 2002 to 2008, to determine black rail occupancy. We played recorded rail vocalizations at stations spaced 44 to 55 yards (40 to 50 meters) apart at each wetland (details in Richmond et al. 2008). Sites were visited up to five times in 2002 and up to three times from 2003 to 2008 using a removal design: in each year, we did not revisit a site after we detected black rails. The average probability of detecting occupancy at a site after multiple visits (three or five) was extremely high (0.99) from 2002 to 2006 (Richmond et al. 2008).

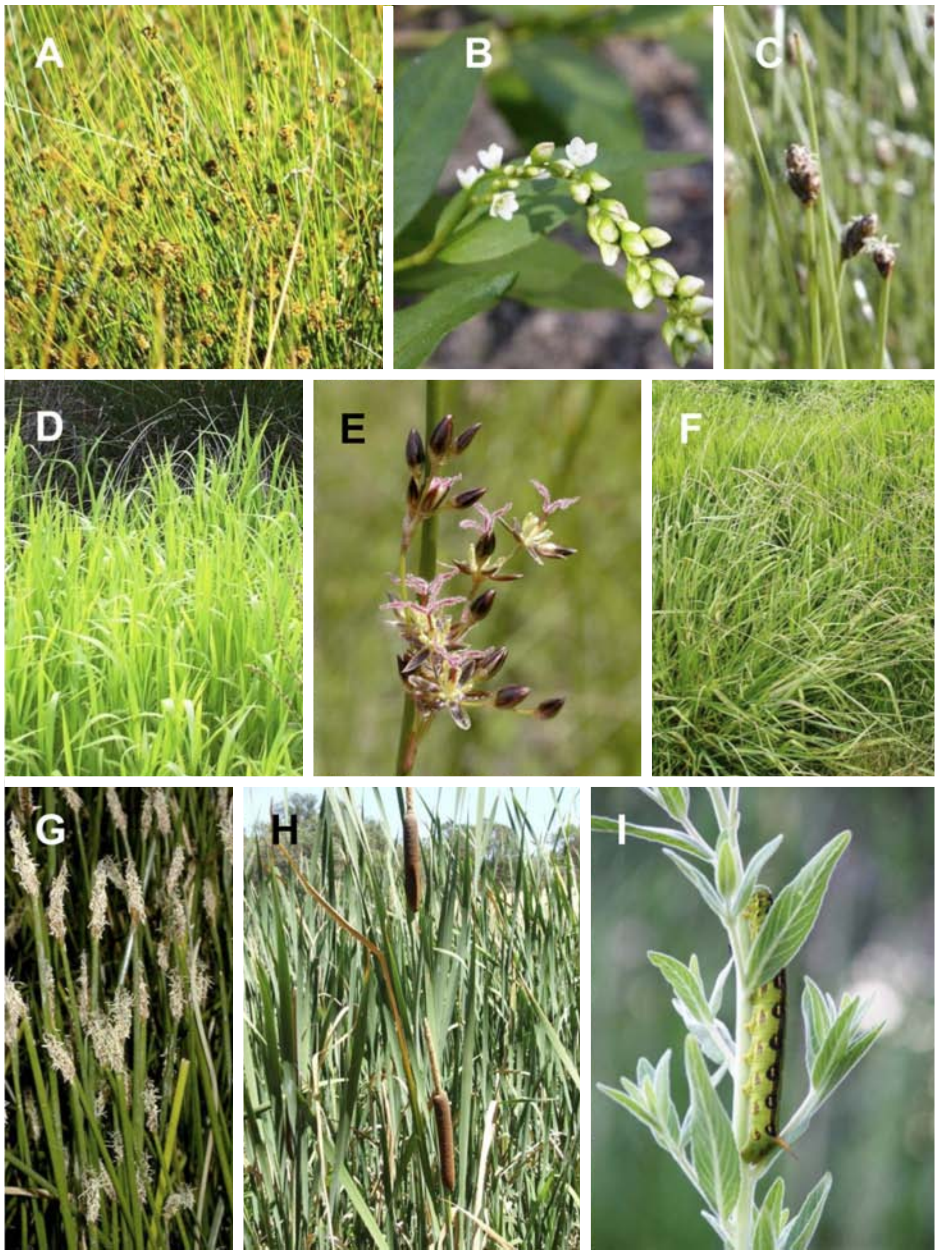
All statistical analyses were performed using Program R (R Development Core Team 2008). Unless otherwise noted, we report means ± S.E.

Distribution of PEM1 wetlands

PEM1 wetlands in the northern Sierra foothills were generally small (less than 25 acres [10 hectares]), patchy ecosystems surrounded by a matrix of mixed vegetation communities (oak woodland, annual grassland, riparian forest) and land uses (rangeland, agricultural, residential). Wetlands were distributed along the western edge of the northern Sierra Nevada foothills (fig. 1) and ranged from 79 to 2,582 feet (24 to 787 meters) above sea level, with a mean elevation of 545 ± 30 feet (166 ± 9 meters). PEM1 wetlands averaged 2.62 ± 0.25 acres (1.06 ± 0.10 hectares) in size, with a positive skew (median = 1.16 acres [0.47 hectare] range = 0.02 to 23.2 acres [0.01 to 9.39 hectares]). Most (89%) PEM1 wetlands were located less than or equal to 547 yards (500 meters) from irrigation canals (fig. 1). Most (63%) PEM1 wetlands were on private lands, while 37% were on public lands including Beale Air Force Base, Daugherty Hill Wildlife Area, SFREC and Spenceville Wildlife Area.

Hydrological features

Irrigation water was the most common water source for the PEM1 wetlands that were surveyed, with 68% of wetlands primarily fed by irrigation



B, E, G, Keir Morse; C, Joseph A. Marcus

The nine most-common plant species found in 20 PEM1 wetlands in the northern Sierra foothills were (not in order of prevalence) (A) common rush, (B) water smartweed, (C) sand spikerush, (D) rice cutgrass, (E) Baltic rush, (F) dallis grass, (G) common spikerush, (H) cattail and (I) willowherb.

TABLE 1. PEM1 wetlands with wettest hydrology ratings averaged across wetlands and years, for wetlands fed primarily by irrigation water vs. nonirrigation sources* during wetter and drier rainfall years

Wettest hydrology rating	Wetter years: 2002–2006† Irrigated (n = 128)	Wetter years: 2002–2006† Not irrigated (n = 64)	Drier years: 2007–2008‡ Irrigated (n = 134)	Drier years: 2007–2008‡ Not irrigated (n = 68)
	%		%	
Flowing water	72	56	73	46
Standing water	15	35	18	41
Saturated mud	9	5	3	2
Firm mud	1	0	3	3
Dry wetland	4	3	3	7

* Spring, stream or rainfall.
† In wetter years (2002–2006) total September through August rainfall averaged 31.2 ± 2.4 inches (79.2 ± 6.1 centimeters).
‡ In drier years (2007–2008) total September through August rainfall averaged 16.5 ± 1.9 inches (41.9 ± 4.8 centimeters).

canals, 22% by springs, 6% by streams and 4% by rainfall. Irrigation water is collected from the Sierra snowpack, stored in reservoirs, transported through a network of canals and delivered to customers who use it mainly for flood irrigation of pastures for livestock grazing. Of the wetlands primarily fed by irrigation canals, we calculated that 84% were fed by deliberate irrigation and 16% by unintentional canal leaks.

The most common geomorphological setting for PEM1 wetlands was slope (47%), followed by depressional (20%), fluvial (19%) and fringe (14%). Fringe wetlands were typically located at lower elevations — closer to the valley floor — averaging 413 feet (126 meters) above sea level, while the other wetland types were found at higher elevations and averaged 564 feet (172 meters) above sea level.

Hydrological conditions in PEM1 wetlands differed significantly by water source. Most PEM1 wetlands (66%) had a wettest hydrology rating of flowing water, 23% standing water, 6% saturated mud, 1% firm mud and 4% dry, averaged over the 2002 to 2008 study period. The percentage of wetlands with flowing water was higher at irrigated sites versus nonirrigated sites ($\chi^2 = 27.9$, df = 4, $P < 0.001$) (table 1). Surprisingly, the percentage of wetlands with flowing water did not differ significantly between wetter and drier years at both irrigated ($\chi^2 = 6.6$, df = 4, $P = 0.16$) and nonirrigated ($\chi^2 = 5.2$, df = 4, $P = 0.26$) sites. Based on the random-point data collected in 2008, the percent surface area covered by the substrate/hydrology classes in PEM1 wetlands averaged 5% flowing surface water, 13% standing water, 16% firm mud, 20% saturated mud and 46% dry substrate. PEM1 wetlands were generally shallow, averaging 1.00 ± 0.14 inches (2.55 ± 0.35 centimeters) in water depth, with a positive skew (median = 0.20 inches [0.50 centimeter]; range = 0 to 12.4 inches [0 to 31.5 centimeters]).

About 24% of PEM1 wetlands exhibited some evidence of a seasonal water regime between June and August 2008, which was a relatively dry year. Of these wetlands, about half had springs, streams and rainfall as primary water sources, and half had irrigation water as the primary source. These seasonal wetlands created a shifting patchwork of habitats that varied both spatially and temporally.

Plant diversity

The PEM1 wetlands were floristically diverse, both between and within sites. We identified a total of 46 plant species across 20 sites in 2007 (table 2). The average number of plant species identified at each wetland was 10.1 ± 0.8 (range = 4 to 19). The most frequent species were common rush (*Juncus effusus*) and cattails (*Typha latifolia*, *T. angustifolia* or *T. domingensis*, not distinguished in the field), which occurred at 38% and 35% of the points sampled, respectively. Four species, including dallis grass (*Paspalum dilatatum*), common spikerush (*Eleocharis macrostachya*), willowherb (*Epilobium ciliatum*) and rice cutgrass (*Leersia oryzoides*) each occurred at between 5% and 10% of the points sampled, while all other species occurred at less than 5% of the points sampled. All species identified in the Poaceae family were nonnative and invasive, except for rice cutgrass. This does not come as a surprise, given that California's grasslands are dominated by nonnative, invasive species.

A few unexpected species were present, such as large periwinkle (*Vinca major*), an invasive garden species, and wild grape (*Vitis californica*). Himalayan blackberry is a nonnative invasive plant and was observed to overgrow wetlands in some settings. The percentage of obligate wetland plants ranged from 40% to 95%, facultative wetlands or plants from 0% to 60%, and facultative obligate upland plants from 0% to 37% across all sites (USFWS 1988) (table 2). Based on the random-point data collected from 184 PEM1 wetlands in 2008, the percent coverage by broad vegetation classes was, on average, 26% grasses (excluding rice cutgrass), 24% rushes, 12% cattails, 12% sedges (excluding hardstem bulrush), 7% Himalayan blackberry, 6% forbs, 5% hardstem bulrush, 3% willows and 1% rice cutgrass.

Black rail use of PEM1 wetlands

Black rails typically occur in the shallowest zones of wetland edges where water depths are generally less than 1.2 inches (3 centimeters) (Flores and Eddleman 1995). In the northern Sierra foothills, they are resident and occupy PEM1 wetlands year-round (Richmond et al. 2008). They construct well-concealed nests in dense vegetation over moist soil or very shallow water (Eddleman et al. 1994). The breeding season in the foothills is unknown but extends from approximately March through July in other California locations (Eddleman et al. 1994). The black rail's preferred wetland habitats have undergone severe historical declines in California due to habitat destruction for agriculture, salt production and urbanization (Eddleman et al. 1994). Since black rails are listed as threatened by the California Department of Fish and Game, it is important to characterize their precise habitat requirements in this

Since black rails are listed as threatened by the California Department of Fish and Game, it is important to characterize their precise habitat requirements in this newly discovered part of their range.

newly discovered part of their range.

We found black rails at 158 PEM1 wetland sites during our surveys from 2002 to 2008 in the Sierra foothills. Black rails had strong positive associations with larger PEM1 wetlands fed by irrigation water. PEM1 wetlands that had at least one black rail detection (mean area 3.2 ± 0.2 acres [1.3 ± 0.1 hectares]; $n = 158$) were significantly larger (*t*-test on log-transformed data; $P < 0.001$) than wetlands without black rails (mean area 1.2 ± 0.2 acres [0.5 ± 0.1 hectare]; $n = 70$) from 2002 to 2008 (fig. 2). The median size of wetlands with black rails was 1.63 acres (0.66 hectare) compared to 0.43 acre (0.18 hectare) for wetlands without black rails.

No significant differences were detected in elevation between wetlands with and without rails (fig. 2). The occurrence of black rails in PEM1 wetlands was significantly related to water source ($\chi^2 = 29.02$, df = 3, $P < 0.001$) (table 3) and geomorphic setting ($\chi^2 = 9.15$, df = 3, $P < 0.05$) (table 3). These patterns were driven by the high occurrence of

TABLE 2. Plant species and occurance in 20 PEM1 wetlands of the northern Sierra foothills in 2007, and U.S. Fish and Wildlife Service (1988) wetland indicator category

Family	Common name*	Species	Occurrence	Indicator category†
			%	
Juncaceae	Common rush (N)	*Juncus effusus*	18.62	OBL
Typhaceae	Common cattail (N), narrowleaf cattail (N) or southern cattail (N)	*Typha latifolia, T. angustifolia* or *T. domingensis*	16.48	OBL
Poaceae	Dallis grass (I)	*Paspalum dilatatum*	7.92	FAC
Cyperaceae	Common spikerush (N)	*Eleocharis macrostachya*	5.84	OBL
Onagraceae	Willowherb (N)	*Epilobium ciliatum*	5.78	FACW
Poaceae	Rice cutgrass (N)	*Leersia oryzoides*	5.06	OBL
Polygonaceae	Water smartweed (N)	*Polygonum punctatum*	4.54	OBL
Cyperaceae	Sand spikerush (N)	*Eleocharis montevidensis*	4.15	FACW
Juncaceae	Baltic rush (N)	*Juncus balticus*	3.83	OBL
Cyperaceae	Black cyperus (N)	*Cyperus niger*	3.57	FACW
Poaceae	Velvetgrass (I)	*Holcus lanatus*	2.40	FAC
Polygonaceae	Swamp smartweed (N)	*Polygonum hydropiperoides*	2.40	OBL
Brassicaceae	Watercress (N)	*Rorippa nasturtium-aquaticum*	2.34	OBL
Rosaceae	Himalayan blackberry (I)	*Rubus discolor*	2.08	FACW
Cyperaceae	Woolly sedge (N)	*Carex lanuginosa*	1.62	OBL
Cyperaceae	Tall flatsedge (N)	*Cyperus eragrostis*	1.62	FACW
Cyperaceae	False nutsedge (N)	*Cyperus strigosus*	1.17	FACW
Cyperaceae	Hardstem bulrush (N)	*Scirpus acutus*	0.91	OBL
Verbenaceae	Purple top vervain (I)	*Verbena bonariensis*	0.78	FACW
Aristolochiaceae	California pipevine (N)	*Aristolochia californica*	0.65	UPL
Portulacaceae	Miner’s lettuce (N)	*Claytonia perfoliata*	0.65	FAC
Lamiaceae	Pennyroyal (I)	*Mentha pulegium*	0.58	OBL
Poaceae	Rabbitfoot grass (I)	*Polypogon monspeliensis*	0.58	FACW
Asteraceae	Sneezeweed (N)	*Helenium puberulum*	0.52	FACW
Lamiaceae	Sonoma hedgenettle (N)	*Stachys stricta*	0.52	FACW
Vitaceae	California wild grape (N)	*Vitis californica*	0.52	FACW
Cyperaceae	Valley sedge (N)	*Carex barbarae*	0.45	FACW
Polygonaceae	Curly dock (I)	*Rumex crispus*	0.45	FACW
Gentianaceae	Muhlenberg’s centaury (N)	*Centaurium muehlenbergii*	0.39	FAC
Lamiaceae	American water horehound (N)	*Lycopus americanus*	0.32	OBL
Asteraceae	Bull thistle (I)	*Cirsium vulgare*	0.26	FACU
Clusiaceae	Klamath weed (I)	*Hypericum perforatum*	0.26	FAC
Lythraceae	Common loosestrife (N)	*Lythrum californicum*	0.26	OBL
Apocynaceae	Large periwinkle (I)	*Vinca major*	0.26	UPL
Cyperaceae	Field sedge (N)	*Carex praegracilis*	0.19	FACW
Cyperaceae	Yellow flatsedge (I)	*Cyperus flavescens*	0.19	OBL
Clusiaceae	Creeping St. John’s wort (N)	*Hypericum anagalloides*	0.19	OBL
Asclepiadaceae	Narrow leaf milkweed (N)	*Asclepias fascicularis*	0.13	FAC
Juncaceae	Taper tip rush (N)	*Juncus acuminatus*	0.13	OBL
Cyperaceae	Black sand spikerush (I)	*Eleocharis pachycarpa*	0.06	OBL
Onagraceae	Dense flowered boisduvalia (N)	*Epilobium densiflorum*	0.06	OBL
Onagraceae	Largeflower spike primrose (N)	*Epilobium pallidum*	0.06	FACW
Poaceae	Italian rye grass (I)	*Lolium multiflorum*	0.06	FAC
Plantaginaceae	Ribgrass (I)	*Plantago lanceolata*	0.06	FAC
Poaceae	Medusahead (I)	*Taeniatherum caput-medusae*	0.06	UPL

* N = native; I = introduced (Calflora 2010).

† OBL = obligate wetland, plant occurs almost always (estimated probability 99%) under natural conditions in wetlands; FACW = facultative wetland, usually occurs in wetlands (estimated probability 67%–99%), but occasionally found in nonwetlands; FAC = facultative, equally likely to occur in wetlands or nonwetlands (estimated probability 34%–66%); FACU = facultative upland, usually occurs in nonwetlands (estimated probability 67%–99%), but occasionally found in wetlands (estimated probability 1%–33%); UPL = obligate upland, occurs in wetlands in another region, but occurs almost always (estimated probability 99%) under natural conditions in nonwetlands in the regions specified (USFWS 1988).

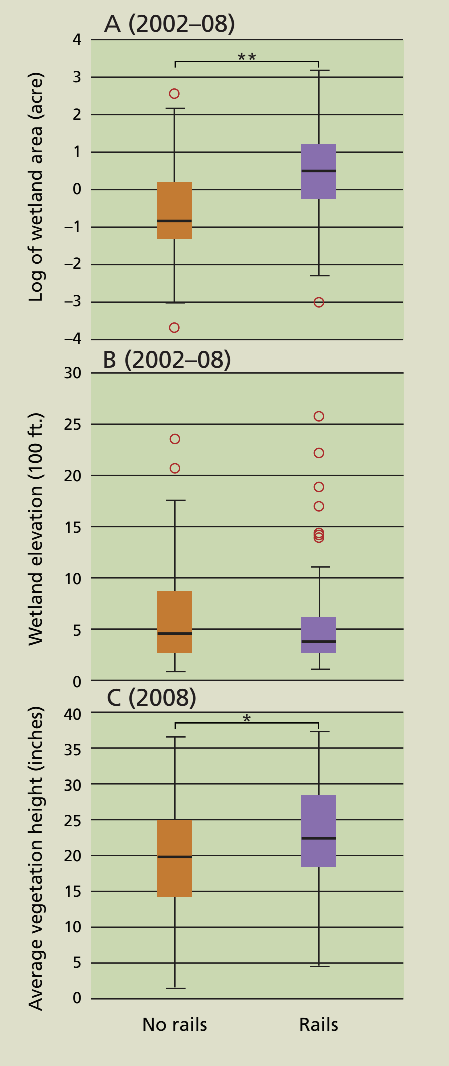


Fig. 2. Differences in area and elevation for wetlands in northern Sierra foothills that had at least one black rail present from 2002 to 2008 vs. wetlands without black rails in 2008, and differences in vegetation height for wetlands with black rails vs. wetlands without black rails. Boxes depict lower and upper quartiles, bold lines depict medians, whiskers extend to the most extreme data point, which is no more than 1.5 times the interquartile range, and outliers are shown as open circles. * Significant difference, *t*-test, $P < 0.01$; ** significant difference, *t*-test, $P < 0.001$.

black rails in wetlands fed primarily by irrigation water and by the low occurrence of rails in wetlands fed primarily by rainfall and in fringe wetlands (table 3). Black rails rarely used livestock watering ponds (stock ponds) with narrow fringes of emergent vegetation and mostly deep (greater than 1 foot) water; however, seepage zones below bermed ponds often provided suitable shallow-water conditions.

Black rails were strongly, positively associated with flowing water and negatively associated with drier PEM1 wetlands and wetlands with evidence of a seasonal water regime. The occurrence of black rails in PEM1 wetlands was significantly related to the wettest hydrology rating ($\chi^2 = 153.30$, df = 6, $P < 0.001$) (table 4). This pattern was primarily driven by the high use of wetlands with flowing water, the low use of wetlands with standing water as the wettest hydrology rating, and the low use of dry wetlands (table 4). Black rail occupancy was significantly negatively associated with wetlands that showed evidence of a seasonal water regime ($\chi^2 = 11.54$, df = 1, $P < 0.001$). While the presence of flowing water was positively associated with black rail occupancy, the average surface area covered by flowing water at wetlands with black rails was only 7%, while standing water covered 16%, saturated mud 27%, firm mud 15% and dry substrate 34%, based on the random -point data collected in 2008. Water depth at PEM1 wetlands with black rails averaged 0.83 ± 0.15 inch (2.12 ± 0.39 centimeters).

Black rails occupied wetlands dominated by a variety of vegetation types and were positively associated with dense cover. Sites with black rails had a significantly lower percentage of sample points composed of grasses, excluding rice cutgrass (0.20 ± 0.02), compared to sites without black rails (0.30 ± 0.02) (permutation test, $t = 2.40$, $P < 0.05$) and a significantly higher percentage of sample points composed of rushes (0.32 ± 0.03) compared to sites without black rails (0.19 ± 0.02) in 2008 (permutation test, $t = 3.45$, $P < 0.001$). Used and unused sites did not differ significantly for the other seven vegetation classes (table 4).

Vegetation cover was significantly higher at PEM1 wetlands with black rails than at wetlands without black rails for stem hits in the following height strata: 8 to 12 inches, 12 to 20 inches, and 20 to 39 inches (fig. 3). Sites with black rails did not have greater vegetation density near the ground in the 0 to 4 inches and 4 to 8 inches height strata. However, our methodology may have lacked the resolution to capture finer-scale differences, as we only recorded whether at least one stem touched the pole in a given height category (e.g., a point with 20 stems in the 0 to 4-inch interval was considered as dense as a point with one stem hit in the same stratum). Vegetation height at wetlands with black rails (22.6 ± 0.8 inches [57.5 ± 2.1 centimeters], $n = 68$) averaged

PEM1 wetlands obtain water from a variety of sources in the northern Sierra foothills including: (A) irrigation canals, (B) natural springs, (C) wetlands fed only by rainfall and (D) streams; irrigation canals are the most common source.

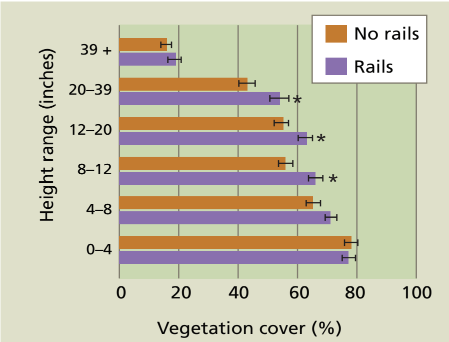


Fig. 3. Differences in vegetation cover, measured as the average percentage of random sample points with vegetation present, at six different height strata in wetlands of the northern Sierra foothills with and without black rails in 2008. Error bars represent standard errors. * Significant difference, permutation test, $P < 0.05$.

TABLE 3. PEM1 wetlands with each primary water source and geomorphic setting category, with at least one black rail detected from 2002–2008, and without black rails detected

Habitat characteristics	With black rails (*n* = 158)	Without black rails (*n* = 70)
	. . . . %	. . . .
Primary water source		
Irrigation canal	78	47
Rainfall	1	11
Spring	18	31
Stream	4	10
Geomorphic setting		
Depressional	22	16
Fluvial	19	19
Fringe	9	24
Slope	50	41

TABLE 4. PEM1 wetlands with each wettest hydrology rating category and average percentage of sample points within a wetland for each vegetation group, with and without black rails detected in 2008

Habitat characteristics	With black rails (*n* = 68)	Without black rails (*n* = 115)
	. . . . %	. . . .
Wettest hydrology rating		
Flowing water	86	60
Standing water	13	25
Saturated mud	1	2
Firm mud	0	4
Dry wetland	0	9
Vegetation group		
Cattails	13	12
Cutgrass	1	2
Forbs	5	6
Hardstem bulrush	5	5
Himalayan blackberry	7	7
Other grasses	20	30
Other sedges	11	13
Rushes	32	19
Salix	3	3

PEM1 wetlands were situated in four geomorphological settings in the northern Sierra foothills: (A) slope, (B) depressional, (C) fringe and (D) fluvial.

3.1 inches (7.9 centimeters) taller than at wetlands with no black rails (19.5 ± 0.8 inches [49.6 ± 2.0 centimeters], $n = 115$) in 2008 (*t*-test, $P < 0.01$) (fig. 2).

Management recommendations

Habitat loss and degradation are the primary threats to black rails (Eddleman et al. 1994), so a comprehensive black rail management strategy should focus on both site-level and landscape-level factors related to habitat. Notable site-level factors affecting occupancy by black rails include water regime, water depth, vegetation density and wetland size.

Water regime. Water regime is a critical habitat factor; black rails were most often found in wetlands with perennial standing or flowing water (permanently or semipermanently flooded), although they were occasionally found in drier wetlands with seasonally flooded, intermittently exposed or saturated water regimes (Cowardin et al. 1979). Previous studies have highlighted the importance of stable water levels for inland populations (Repking and Ohmart 1977). In the Sierra foothills, irrigation water and perennial springs and streams provide consistent permanent or semipermanent water sources during the driest part of the year, from mid-April until mid-October. Wetlands that are fed primarily by rainfall or seasonal springs or streams are more likely to dry out as the summer progresses. Non-irrigation-fed wetlands had a lower proportion of flowing water present in both wetter and drier summers than irrigation-fed wetlands (table 1). The presence of flowing water in the summer is associated with black rail occupancy (table 4) and may be viewed as an indicator of wetland permanence. We recommend that PEM1 wetlands with permanently or semipermanently flooded water regimes be prioritized for conservation.

Black rails use wetland zones with shallower water than other North American rails (Eddleman et al. 1988), generally less than 1.2 inches (3 centimeters) (Flores and Eddleman 1995). Wetlands in the Sacramento Valley that are managed for waterfowl or rice typically lack sufficient shallow water zones, and previous surveys indicated that black rails were uncommon in these habitats (Richmond et al. 2008). Persistent shallow water conditions can be more easily maintained on gentle slopes rather than in depressions, since continual downslope drainage prevents water from pooling too deeply. The combination of abundant semipermanent water sources (irrigation canals and springs) and the gently sloped landscape of the northern Sierra foothills creates an ideal setting for such shallow wetlands to form. A management strategy that maintains wetland complexes with variable water levels, including shallow (less than 1.2 inches) water zones, is recommended. The creation of more extensive shallow water zones at the margins of managed wetlands on the Sacramento Valley floor should be explored.

Vegetation. Black rails depend on dense vegetative cover, so disturbances to wetland vegetation arising from deliberate clearing, burning or overgrazing by wildlife or livestock are potential threats. Previous research in Arizona found that plant species composition was not as important for black rail habitat selection as appropriate vegetation structure (high stem densities and canopy coverage) and substrate characteristics (Flores and Eddleman 1995). The manual removal or burning of emergent vegetation for improved pond access or to facilitate recreation activities (fishing, swimming, boating) could render a wetland unsuitable for black rails. While light-to-moderate grazing appears to be compatible with occupancy by black rails and can benefit wetlands by stimulating increased herbaceous plant productivity and improving water quality (Allen-Diaz et al. 2004; Jackson et al. 2006), our anecdotal observations suggest that black rail occupancy declines when overgrazing substantially reduces wetland vegetation cover. We recommend that landowners control livestock access to ponds and wetlands and avoid wetland vegetation removal or overgrazing, especially during the black rail breeding season (approximately March to July). Fortunately, wetland vegetation appears to rebound quickly, and a cleared or heavily grazed site can regain dense vegetation within a single growing season. Additional research is needed to determine the minimum vegetation cover that black rails require for successful breeding.

Wetland area. A critical question is the minimum wetland area required to support a breeding pair. We found that wetlands with at least one black rail detection were significantly larger than wetlands with no detections (median area 1.6 versus 0.43 acres, respectively), and 97% of wetlands with at least one black rail detection were 0.25 acre or larger. However, we detected black rails occupying wetlands as small as 0.040 acre (0.016 hectare), although only temporarily. Since local rail population size should increase with wetland area, conservation priority should increase with wetland size. Nevertheless, very small wetlands (less than 0.25 acre) may also act as "stepping stones" that could facilitate dispersal across the landscape (Gibbs 1993; Loehle 2007), even if they may be too small to support breeding pairs. Based on current knowledge, we recommend that existing PEM1 wetlands with suitable water regimes and shallow water zones, especially those 0.25 acre or larger, be prioritized for conservation.

An artificial wetland created using irrigation water provides habitat for black rails at Spenceville Wildlife Area.

Landscape factors. Maintaining and improving site-level habitat quality is necessary for black rail management, but a comprehensive strategy must also take into consideration landscape-level factors such as isolation, canal maintenance and land-use change. Given the sparse and patchy distribution of PEM1 wetland habitats across the foothills, isolation of habitat patches is a potential concern. The loss of wetlands can affect metapopulation dynamics by reducing the number or density of dispersing individuals, while simultaneously increasing dispersal distances between wetlands (Gibbs 1993). Little is known about black rail dispersal aside from a radiotelemetry study in Arizona where three black rails were recorded moving an average of 0.89 ± 0.06 mile [1.43 ± 0.09 kilometers], range = 0.75 to 1.00 mile between breeding seasons (Flores and Eddleman 1991).

We have noted black rails colonizing newly created wetland sites in the foothills within one year. However, we have also found evidence that the rate of patch colonization decreases and the rate of local patch extinction increases as sites become more isolated (unpublished data). A regional management

Slicks Canyon, location of the first northern Sierra foothills black rail detection, is in the UC Sierra Foothill Research and Extension Center.

strategy for black rails should prevent the isolation of wetlands and promote the creation of new habitat to improve connectivity. In general, sites that are currently well connected should be prioritized for protection and new sites, if created, should be located close (less than 0.6 mile [1 kilometer]) to other occupied sites to maximize potential dispersal opportunities. Wildlife managers have successfully created several artificial wetlands — now used by black rails — by maintaining semipermanent flows of irrigation water on sloped land at Spenceville and Daugherty Hill wildlife areas. The speed with which suitable habitat can be created and then colonized by rails suggests that mitigation for wetland habitat loss from, for example, canal lining projects, may be effective. The lining of irrigation canals to improve water efficiency can adversely affect black rail habitat (Evens et al. 1991); a balanced approach to such projects should simultaneously address water efficiency and wildlife habitat needs, perhaps through a rotating short-term water-leasing program (Peck et al. 2004).

The ongoing replacement of ranching with residential land uses in the Sierra foothills (Smethurst 1999) is probably the greatest long-term threat to black rails because most of their habitat is maintained by irrigation water used for cattle ranching. PEM1 wetlands not only provide habitat for black rails, but also support wildlife species by improving tailwater quality from irrigated pastures thereby reducing loads of total suspended sediments, nitrate and *Escherichia coli* (Knox et al. 2008). Long-term protection of wetlands can be achieved through conservation easements and voluntary programs such as the Wetlands Reserve Program and Conservation Reserve Program run by the U.S. Department of Agriculture's Natural Resources Conservation Service, which provide landowners with opportunities to protect, restore and enhance wetlands in exchange for technical and financial support. The Central Valley Joint Venture is another important organization that brings together conservation organizations, public agencies and private landowners to conserve bird habitat in California's Central Valley. We recommend that detailed management guidelines for black rails be integrated into existing conservation programs. Finally, impacts to black rails and other wetland-dependent species should be considered in the environmental review process for development projects that eliminate ranching lands or reduce irrigation water flows.

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References

Aigner PA, Tecklin J, Koehler CE. 1995. Probable breeding population of the black rail in Yuba County, California. West Bird 26:157–60.

Allen-Diaz B, Jackson RB, Bartolome JW, et al. 2004. Long-term grazing study in spring-fed wetlands reveals management tradeoffs. Cal Ag 58:144–8.

Calflora. 2010. Information on California plants for education, research and conservation. The Calflora Database, Berkeley, California (accessed Feb. 16, 2010).

[CDFG] California Department of Fish and Game. 2008. State and federally listed endangered and threatened animals of California. Sacramento, CA. www.dfg.ca.gov/biogeodata/cnddb/plants_and_animals.asp.

Conway CJ, Sulzman C. 2007. Status and habitat use of the California black rail in the southwestern USA. Wetland 27:987–8.

Cowardin LM, Carter V, Golet FC, LaRoe ET. 1979. Classification of wetlands and deepwater habitats of the United States. US Fish and Wildlife Service, Washington, DC. Northern Prairie Wildlife Research Center Home Page, Jamestown, ND.

Eddleman WR, Flores RE, Legare M. 1994. Black rail (*Laterallus jamaicensis*). In: Poole A. (ed.). The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, NY. http://bna.birds.cornell.edu/bna/species/123. doi:10.2173/bna.123.

Eddleman WR, Knopf FL, Meanley B, et al. 1988. Conservation of North American rallids. Wilson Bull 100:458–75.

Evens JG, Page GW, Laymon SA, Stallcup RW. 1991. Distribution, relative abundance and status of the California black rail in western North America. Condor 93:952–66.

Flores RE, Eddleman WR.1991. Ecology of the California black rail in southwestern Arizona. Final Report. US Bureau of Reclamation, Yuma Project Office and Arizona Dept. of Game and Fish, Yuma, AZ.

Flores RE, Eddleman WR. 1995. California black rail use of habitat in southwestern Arizona. J Wildl Manag 59:357–63.

Gibbs JP. 1993. Importance of small wetlands for the persistence of local populations of wetland-associated animals. Wetland 13:25–31.

Jackson RD, Allen-Diaz B, Oates LG, Tate KW. 2006. Spring-water nitrate increased with removal of livestock grazing in a California oak savanna. Ecosystem 9:254–67.

Knox AK, Dahlgren RA, Tate KW, Atwill ER. 2008. Efficacy of natural wetlands to retain nutrient, sediment and microbial pollutants. J Env Qual 37:1837–46.

Lewis D, Singer MJ, Dahlgren RA, Tate KW. 2000. Hydrology in a California oak woodland watershed: A 17-year study. J Hydrol 240:106–17.

Loehle C. 2007. Effect of ephemeral stepping stones on metapopulations on fragmented landscapes. Ecol Complex 4:42–7.

Peck DE, McLeod DM, Hewlett JP, Lovvorn JR. 2004. Irrigation-dependent wetlands versus instream flow enhancement: Economics of water transfers from agriculture to wildlife uses. Wetlands 34:842–55.

R Development Core Team 2008. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.

Repking CF, Ohmart RD. 1977. Distribution and density of black rail populations along the lower Colorado River. Condor 79:486–9.

Richmond OM, Tecklin J, Beissinger SR. 2008. Distribution of California black rails in the Sierra Nevada foothills. J Field Ornithol 79:381–90.

Smethurst D. 1999. Land degradation and the decline of ranching in the Sierra Nevada foothills, California. Land Degrad Dev 10:161–75.

[USFWS] US Fish and Wildlife Service. 1988. National list of vascular plant species that occur in wetlands. Biological Report 88 (26.9).

REVIEW ARTICLE

Integrated data-collection system tracks beef cattle from conception to carcass

by Alison L. Van Eenennaam, Kristina L. Weber, Krista Cooprider *and* Daniel J. Drake

Data on the performance of individual beef cattle from birth to processing can be used to improve herd management and genetic characteristics such as fertility, weaning weight and tenderness. Likewise, tracing the origins and whereabouts of cattle that may have been exposed to infectious disease agents is necessary to protect the health of the national beef herd. Such information is rarely available, in part because cattle often change ownership during the beef production process. A system developed to support the lifetime tracking of individual cattle in the UC Davis beef herd seamlessly transfers information between the UC Sierra Foothill Research and Extension Center, UC Davis campus feedlot and a commercial beef-cattle processing plant, and provides a repository for performance data collected at all production stages. The system provides real-time data sharing, as well as integrated analysis and management evaluation options, and will be a valuable resource for beef-cattle research. UC livestock farm advisors are now implementing a similar system with cooperating commercial ranches.

A model cattle-identification system tracks animals from birth at the UC Sierra Foothill Research and Extension Center, to feedlot and harvest. Researchers are using the system to better understand cattle genetics, beef qualities and other characteristics.

The beef-cattle supply chain consists of several distinct sectors. An animal may change ownership several times during its life, and each transfer presents a major obstacle for the dissemination of individual animal records from one sector to the next. Often animal health data and other important information are never shared among members of the supply chain.

The cycle typically starts in the cow-calf sector, where the animals are bred, born and raised. Once animals reach a certain age or weight, or their feed resources become limiting, they are sold, sometimes to a stocker operation for additional weight gain before they are sold again to a feedlot. At the feedlot, animals are "finished" — often fed on a grain-based diet until they reach market weight, at which time they are harvested. Carcasses are then transferred to the packer where they are divided into wholesale cuts, then into retail cuts.

In the absence of an integrated identification system, tracing a single steak back to its carcass, let alone back to the cow-calf operation where the animal originated, becomes extremely complicated. Although steak may be the end-product, it is not the end of the chain. That position is reserved for the consumer, and it is ultimately the consumer's eating experience that should be the driving force for selection and management decisions throughout the supply chain. However, because most cow-calf producers do not retain ownership of animals after they leave the ranch, they receive no information on (1) animal performance at the feedlot, (2) carcass quality attributes or (3) consumer satisfaction with products derived from the animals they bred and raised. Consequently, they receive no price premiums or discounts.

Industry fragmentation is also a major obstacle hindering the effective traceback of animal disease outbreaks. Animal diseases pose a major threat to livestock production in the United States, and the intentional or unintentional introduction of infectious disease agents could have a catastrophic impact on cattle producers. A 2006 study estimated that the combined consumer and producer losses from a foot-and-mouth disease outbreak in the United States would exceed $266 billion (Zhao et al. 2006).

Although approaches to enable traceback for investigation and response to disease incidents have been discussed nationwide, implementation has been slow. The U.S. Department of Agriculture (USDA) National Animal Identification System (NAIS) has met with considerable resistance for a variety of reasons, including uncertainty about proposed equipment and sys-

Round electronic ear tags, *inset*, were placed in the left ears of SFREC cattle and used as the key integrating identification number for cattle records. Visual ear tags, electronic wands and various electronic devices were also used to collect data.

Remote-access antennae (yellow ovals) were used to transmit data from cattle chutes to computers in the SFREC office.

tems, and the absence of any direct benefit to the producers who must pay for its implementation. Currently, participation in NAIS is voluntary and limited. However, other beef-producing countries — including Australia, the European Union, Japan, Brazil, Argentina and Canada — have already adopted such systems, usually in conjunction with government subsidies to encourage participation, and they are enjoying the benefits of source- and age-verified marketing opportunities. The end result is that U.S. beef producers are falling behind in technology adoption, and their responsiveness to biosecurity issues is limited. At the same time, the public may perceive that the beef industry is unresponsive to animal health and food safety issues.

To address these problems, a collaborative research team developed a fully integrated, electronic, individual-animal tracking-system prototype for the UC Davis Department of Animal Science cow-calf herd, which is used for research and education and is located at the UC Sierra Foothill Research and Extension Center (SFREC). Vertical integration of the system provides opportunities for researchers to analyze commercial beef-cattle production from conception to carcass. The overall objective of this project was to demonstrate that a functional, integrated data and trace-back system could be useful for cattle management, while simultaneously providing biosecurity features. The project team included staff at SFREC, the UC Davis campus feedlot, employees of a commercial processing plant, UC farm advisors, and researchers from the UC Davis Department of Animal Science and School of Veterinary Medicine.

System design

Conceptually, the data management system now in place for the UC Davis cow-calf herd comprises several distinct operations (fig. 1). Since 2007, various sectors (users) have been collecting data with commercially available software designed for their specific needs.

SFREC. Data collected at SFREC includes calving date, birth weight, mother-of-calf identification, weaning weight and health records. All (approximately 250) calves are fitted with individually numbered ear tags at birth. The SFREC herd manager enters all records into Cow Sense herd management software (Midwest MicroSystems, Lincoln, NE). Subsequently, a computer running Cow Sense is used to collect data on location at the handling chute each time cattle are brought through. That information is then remotely transferred to the main office at SFREC where it can be updated before being linked through the Internet to the UC Davis central computer and stored in a Microsoft Access database.

Feedlot. Data is available in real time when calves are shipped to the UC Davis feedlot. This information is valuable to feedlot operators when assigning calves to specific dietary, production or other experimental groups. Calves are weighed upon feedlot entry and exit, and at 30-day intervals to determine the average daily rate of gain. Feedlot data is collected using the Measurement and Analysis Research System (MARS) (Midwest

Herd veterinarian Bruce Hoar works with graduate student Krista Cooprider.

Herd manager Dan Myers enters cattle information into a hand-held device.

MicroSystems), a computer program that allows for repeated measurements of multiple variables.

Harvest. Cattle are harvested based on weight and visual estimates of finish, and shipped in groups of approximately 20 head. Carcass data is collected from a commercial harvest facility in Los Banos, Calif., by a USDA grader using a hand-held scanner (PSION Workabout Pro) similar to those used by overnight delivery services (fig. 1).

Database connections. Data is delivered to the UC Davis server via software called Beef STAR (Midwest MicroSystems), with databases from the three sectors connected using Microsoft Access. Data also flows back to the herd management software, Cow Sense, to provide the SFREC herd manager with information on calf performance in the feedlot and at harvest. This feedback allows for the development of on-ranch genetic evaluations for feedlot performance and carcass traits, not typically an option for commercial cow-calf producers.

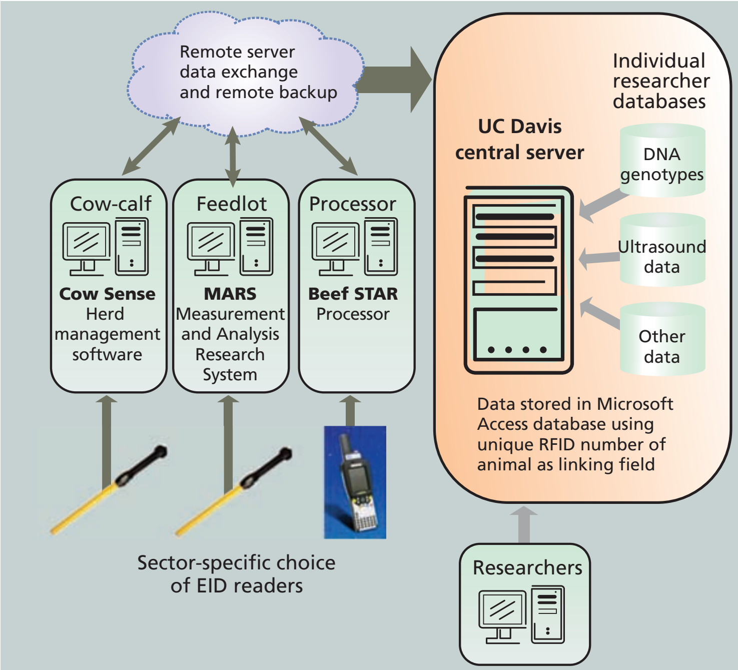
UC researchers also have linked ancillary databases of detailed research data to the central database. Alison Van Eenennaam developed a DNA database that contains SNP (single nucleotide polymorphism) genotypes for each bull, cow and calf at SFREC. Other UC researchers are beginning to tie into the system, including Bruce Hoar of the UC Davis School of Veterinary Medicine, who is the attending veterinarian for the UC cow-calf herd at SFREC. This collective information enhances the value of data from each individual researcher, and both the content and number of animals in the database will continue to grow over time.

Unique identification numbers

Data is collected from each calf crop from conception to carcass over a period spanning 2 to 3 years. At any point in time, three crops consisting of 100 to 250 calves are either being gestated, calved and grown at SFREC, or finished at the feedlot. It is easy for animal numbering systems to become confusing. Two animals with the same number (e.g., no. 1) might exist concurrently as a weanling at SFREC and a steer being fattened at the feedlot. The key to keeping accurate records is assigning a unique identification number to each animal. This is done using a radio-frequency-identification (RFID) ear tag transmitting an embedded 15-digit number, which is assigned to each animal in the cow-calf herd at SFREC. The small, round button tags are placed in the left ear and read by hand-held or chute-side electronic readers as the animal moves through the production process. The tags provide rapid and error-free recording and tracking of individual animals. The identification number links information about each animal, whether it concerns assigning the calf to DNA-based parentage determinations, weaning weight, feedlot gain or the eventual quality grade of its carcass or size of the rib-eye steak it produced.

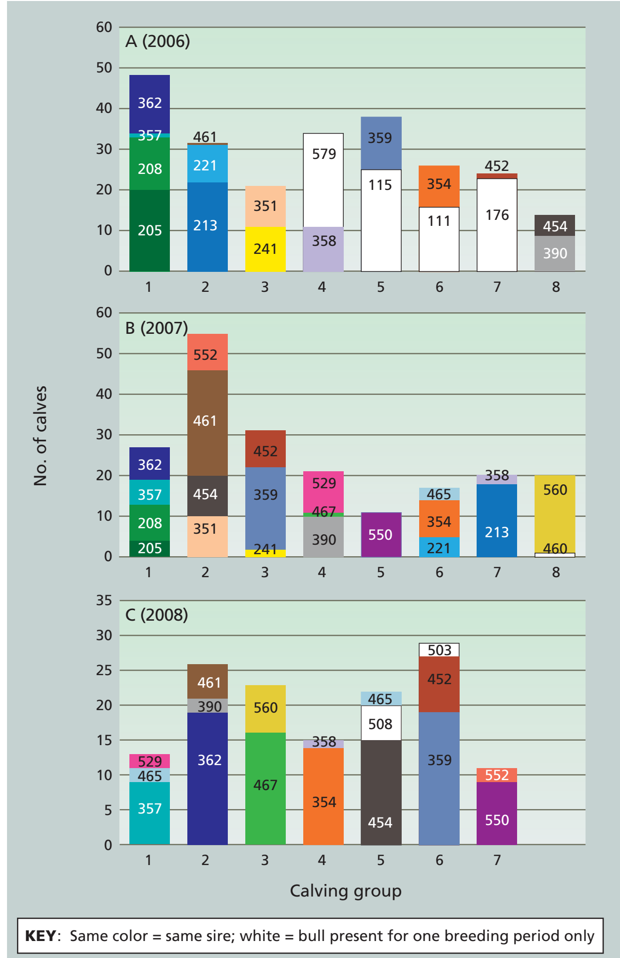
At harvest, when carcass data is collected, reliable identification takes on additional importance. The detection of a contagious animal disease could potentially trigger an urgent need to determine the source and recent movements of the animal relating to a particular carcass. In the event of such a traceback, linkage to all previous production records from birth to harvest would be critical for a timely response. Knowledge of each animal's whereabouts and origin would facilitate a targeted health response, as opposed to a mass recall and potential depopulation of unaffected herds. This would increase response effectiveness and decrease the costs associated with an animal disease outbreak.

Some of the problems that we encountered during the development of this integrated data-collection system included implementing electronic identification technology in a practical manner for the field collection of data, database sharing structure, data integrity and security, the education of collaborators and staff working on the project, and the timeliness of data availability for real-time use. The system was designed to be dual purpose: first, to accomplish traceback in the case of a disease outbreak, and second, to develop valuable information for cattle management, thereby rewarding data collection by all parties.



▲ **Fig. 1. Overall design of the system. The three sources of cattle performance data (producers, feedlot, processors) use activity-specific software to input records, which are conveyed to a central database. Appropriate data is available to cooperators in real time and across sectors for decision making.**

▶ **Fig. 2. Sire prolificacy data for 3 years (2006–2008) with sires present in multiple years. Each calving group had two to four bulls, and the number of cows per pasture varied from year to year. The first digit of each bull's identification number is the last digit of the bull's year of birth (i.e., bull 362 was born in 2003). Large variations in prolificacy year-to-year and among sires were observed, and prolificacy of a sire in the first year was not always predictive of subsequent prolificacy when sire-breeding groups changed.**



Breeding performance

We were able to apply data obtained though the integrated data-collection system in a study of cattle paternity and breeding success. Commercial beef-cattle herds using multiple-sire breeding pastures often have no way of identifying which bull fathered a calf, or which bull produced the best (or worst) cohort of calves. Inherited DNA markers can be used to assign paternity. Bulls pass on only one of the two copies of each gene or "marker allele" that they carry. Paternity identification involves examining each calf's genotype at multiple locations in the genome and excluding as potential sires those bulls that do not share common alleles with the calf (Van Eenennaam, Weaber, et al. 2007). DNA was extracted from tissue collected from all bulls housed at SFREC before they were turned out with the cow herd for the 2006, 2007 and 2008 breeding seasons, and DNA was collected from all calves delivered during those 3 years. All DNA samples were genotyped using a 99 SNP panel (Igenity, Duluth, GA), and the results were used to match potential sires to their offspring.

Sire performance in terms of the number of offspring produced was highly variable from year to year (fig. 2). For example, bull 357 was a sire all three years, but in the first year he sired only one calf, during the second year he improved slightly to sire six calves, and in the third year he sired nine calves, for 16 calves total. In contrast, while in 2006 bull 115 was only present for the first year, he sired 25 calves. At first glance, it would appear that bull 115 far outperformed bull 357; however, consideration must be given to the size of the breeding groups (or how many cows were available to be bred) and how many competing sires were in the group. Bull 357 was in a four-sire breeding group for the first two years (with two older, and thus likely more dominant, bulls), and a three-sire breeding group (with two older bulls) in the third year. This means he had to compete with older bulls in every breeding season. In contrast, bull 115 had only one young sire as competition the year that he was an active sire in this evaluation.

We have examined sire prolificacy (breeding success) on a number of commercial cow-calf herds over the past few years, and have consistently seen this variability in calf output (Van Eenennaam, Weaber, et al. 2007). Other studies have reported similar variability in calf output among herd sires, and further, found that prolificacy is moderately repeatable if the composition of bull mating groups remains similar (DeNise 1999; Holroyd et al. 2002). This information is important from the standpoint of genetic improvement because prolific bulls will have a greater impact on herd genetics. Reconciling DNA information on sires and calves is the only way to assign parentage in multiple-sire breeding pastures.

On-ranch genetic evaluations

Another area in which comprehensive animal tracking is invaluable is in improving cattle performance through selective breeding. Breeders can make

Graduate student Gustavo Cruz records ultrasonograms at the feedlot as part of research activities with the UC cattle herd.

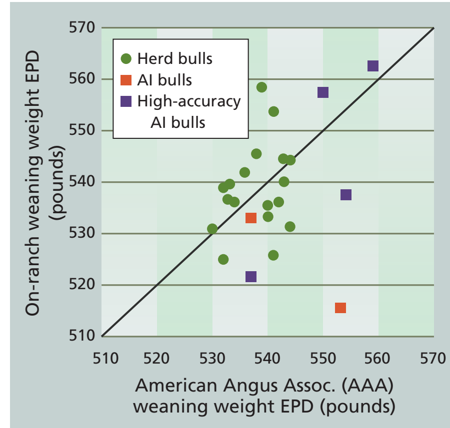


Fig. 3. Breed association expected progeny difference (EPD) for weaning weight, with calculated on-ranch weaning weight EPDs adjusted to represent potential observed weaning weights for both natural service (herd) and artificial insemination (AI) bulls.

genetic progress by determining the genetic potential of animals as parents. In the beef-cattle industry, an estimate of genetic potential or breeding value is called an expected progeny difference (EPD) (see box).

It is particularly important to obtain accurate estimates of the genetic potential of bulls, as bulls will produce more offspring than cows during their lives. Genetic evaluations of young natural-service bulls are often based on the average genetic potential of the parents and observations of the bull itself, and these estimates cannot be further improved in the absence of progeny data. DNA markers cannot only resolve the paternity of offspring produced in multiple-sire breeding pastures, they can also be used to better estimate the genetic worth of natural-service bulls through on-ranch progeny testing (Pollak 2005).

To illustrate these concepts, we compared on-ranch and breed-association EPDs for a set of 21 natural-service bulls and six artificial-insemination bulls whose semen was used at SFREC (fig. 3). To show how bull EPDs influence offspring performance in the absence of other effects and to contrast on-ranch and breed association EPDs, we projected possible offspring averages by resetting the EPD baseline to the SFREC herd average for weaning weight (540 pounds). If breed association EPDs were consistent with on-ranch progeny performance, all EPDs would be expected to fall on a diagonal line. However, this was not always the case. Some bulls with similar breed-association EPDs had significantly disparate on-ranch genetic evaluations, showing how on-ranch EPDs can help to distill actual genetic potential from the considerable variation associated with the low-accuracy EPDs typical of yearling bulls.

Because the EPDs of heavily used artificial-insemination bulls already include progeny-test information, on-ranch evaluations do not offer an opportunity to greatly improve EPD accuracy. However, on-ranch evaluations can identify artificial-insemination sires whose offspring may be particularly well-suited to a given ranch environment. Using the integrated identification and tracking system, we tracked steer progeny of two high-accuracy artificial-insemination bulls from birth to harvest (fig. 4) (see box). Actual differences in performance average for birth weight, weaning weight and carcass weight were consistent with expected differences based on high-accuracy breed association EPDs for the same sires. In addition, this growth trend was consistent for two time points between weaning and harvest that are not typically included in breed-association genetic evaluations.

The use of integrated systems to develop high-accuracy EPDs for natural-service bulls could provide a powerful selection tool for commercial producers interested in improving their herds for feedlot and carcass traits. This will only occur if the market rewards producers for considering these traits in their selection criteria. The adoption of integrated identification systems depends on whether marketing systems provide monetary incentives for this information. Many cow-calf producers sell their calves at weaning and derive their income solely from the number and weight of calves sold. Therefore they never receive feedback regarding feedlot performance or information on how

Measuring bull performance

Expected progeny difference (EPD) is the difference between the average performance of a bull's progeny and the average of those sired by another bull. Breed associations develop the most commonly available EPDs based on their extensive nationwide databases of pedigree and performance information. In the absence of other information, the genetic merit of an animal can be predicted based on the average breeding value of its parents. This generates a low-accuracy "pedigree estimate" that is typically associated with young animals prior to the collection of any information on their own performance. With only ancestor information, full siblings will have the same EPD. Their true value will vary, however, as a result of the random inheritance of parental genes. Incorporating progeny performance information increases the accuracy of EPDs. This can be seen in beef-sire semen catalogs, where very-high-accuracy EPDs are associated with bulls with many progeny as a result of their use in artificial-insemination programs.

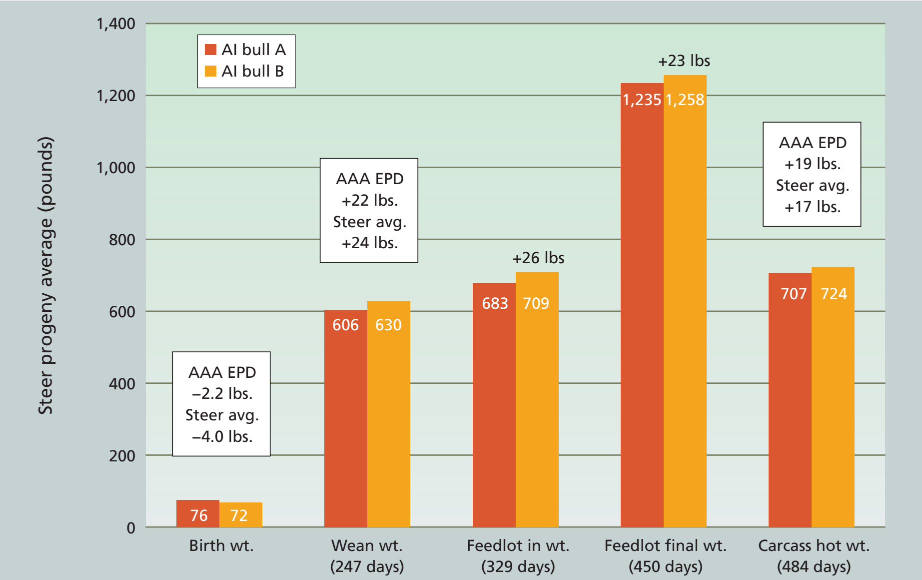


Fig. 4. American Angus Association (AAA) birth, weaning and carcass weight EPDs were similar to observed average values for steer progeny of two high-accuracy artificial insemination (AI) sires. Sire B's calves outperformed those of sire A from weaning through processing.

well those animals suited consumer preferences for tender, juicy meat. The fact that there is no financial incentive for cow-calf producers to consider many of these "downstream" traits in selection decisions effectively precludes genetic improvement for a number of important traits.

Tenderness evaluation

Increased tenderness has been associated with both consumer willingness to purchase and the price they are prepared to pay for beef (Platter et al. 2005). It is difficult to select for increased tenderness, a trait that can only be measured after the animal has left the herd. Traits that are difficult to measure, or are measured late in life, are well-suited to a DNA-based approach to estimate genetic merit (Allan and Smith 2008). Researchers are using molecular biology and quantitative genetics to identify regions of DNA that influence meat tenderness. DNA-marker tests developed to detect subtle sequence differences show whether a segment of an animal's DNA is positively or negatively associated with tenderness (Casas et al. 2006; Schenkel et al. 2006).

The two most prevalent marker tests for tenderness explain about 20% to 25% of the genetic variation for tenderness, and 12% to 18% of the overall variation in this trait (Van Eenennaam, Li, et al. 2007). These tests can be used for marker-assisted selection, which is the process of using the results of DNA-marker tests in a genetic-improvement program to assist in the selection of individuals to become the parents of the next generation.

As a field demonstration of the effect of these markers on meat tenderness, 40 genotyped steers from the 2008 calf crop at SFREC were selected and divided into two groups: one with the most tender genotypes, and the other with the least tender genotypes. Following harvest, meat samples will be collected from each carcass to take tenderness measurements. The Warner-Bratzler shear force (WBSF) protocol is the industry-accepted method of standardizing tenderness evaluations (Dikeman et al. 2005). It has three main components: (1) uniform handling and cooking of steaks, (2) core sampling steaks and (3) measuring the amount of force — equivalent to chewing — required to tear the core samples.

While tenderness is undoubtedly an important trait to consumers, it is less clear how selection for tenderness can provide an economic return to the cow-calf producer, who makes decisions based on factors for which they are paid — typically the number of calves sold and the price received for those calves. In the absence of a more integrated beef supply chain, it is likely that market failure will prevent tenderness from being an important consideration in breeding decisions on most commercial cow-calf ranches. However, some producers, such as Northern California's Prather Ranch, have developed vertically integrated niche markets for their beef, and are incorporating information from DNA tests for meat tenderness in their breeding decisions.

Whole-genome selection

Traditional genetic improvement of beef cattle relies on developing breeding values or EPDs for animals based on their performance and that of their relatives. Over the past 50 years, the selection of animals with the best breeding values has doubled the amount of milk that the average dairy cow produces in

Assistant feedlot supervisor James Moller operates the hydraulic squeeze chute at UC Davis.

The system was designed to be dual purpose: first, to accomplish traceback in the case of a disease outbreak, and second, to develop valuable information for cattle management, thereby rewarding data collection by all parties.

Farm advisor Dan Drake (right) and processing plant personnel examine the carcass of a UC steer. An electronic hand-held device loaded with appropriate software was used to capture the animal's electronic identification tag number, associate it with carcass attributes, and deliver that information to a database on the UC Davis server, where it was linked with earlier cow-calf and feedlot data.

a year, and halved the amount of feed needed to produce a pound of pork. However, selection has not been as successful for traits that are difficult to measure, such as disease resistance, or traits that are not evident until late in an animal's life, such as fertility or longevity.

Technology breakthroughs developed during the sequencing of the human genome brought DNA-sequencing costs down, which made it economically feasible to sequence the genomes of other species. The bovine genome has recently been sequenced (Elsik et al. 2009), which has led to the discovery of many thousands of naturally occurring DNA-sequence variations in the form of SNPs between individuals (Bovine HapMap Consortium 2009). Researchers are now working to determine which variations are associated with desirable characteristics, such as disease resistance, in both humans and livestock species.

Information on variation in DNA sequences between animals may improve the accuracy of breeding values, that is, give breeders more confidence that they are selecting the best animals. Because DNA is available from birth, it may be possible to predict the genetic potential of animals at a very young age, in the absence of progeny testing, and keep only the best animals for breeding purposes. This may pave the way for producers to select animals to become parents of the next generation based on breeding values calculated from DNA-marker data alone, a process called "genomic selection" (Meuwissen et al. 2001). This approach may open the way to develop genetic predictions on difficult-to-measure traits, such as disease resistance and feed efficiency, that are not routinely included in beef-cattle genetic evaluations. It may also allow for the selection of traits that have never been previously considered in genetic evaluations, such as the compositional makeup and nutritional value of meat for human consumption.

Genomic technologies also offer new opportunities to develop management systems to optimize an animal's DNA genotype to best fit the production environment. For example, the genotype of some beef and dairy cattle may be better suited to grass-based production systems. It may also be possible to select animals that are able to grow to a given size using less feed, or that are more resistant to certain diseases. These technologies have great potential to enable the production of safer, more nutritious animal products. They may also allow for the selection of animals with a decreased environmental footprint and improved animal welfare due to lower levels of disease.

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References

Allan MF, Smith TPL. 2008. Present and future applications of DNA technologies to improve beef production. Meat Sci 80:79–85.

Bovine HapMap Consortium. 2009. Genome-wide survey of SNP variation uncovers the genetic structure of cattle breeds. Science 324:528–32.

Casas E, White SN, Wheeler TL, et al. 2006. Effects of calpastatin and {micro}-calpain markers in beef cattle on tenderness traits. J Anim Sci 84:520–5.

DeNise S. 1999. Using parentage analysis in commercial beef operations. In: Proc 31st Ann Res Symp Beef Improv Fed. Roanoke, VA. p 183–90.

Dikeman ME, Pollak EJ, Zhang Z, et al. 2005. Phenotypic ranges and relationships among carcass and meat palatability traits for fourteen cattle breeds, and heritabilities and expected progeny differences for Warner-Bratzler shear force in three beef cattle breeds. J Anim Sci 83:2461–7.

Elsik CG, Tellam RL, Worley KC. 2009. The genome sequence of taurine cattle: A window to ruminant biology and evolution. Science 324:522–8.

Holroyd RG, Doogan VJ, De Faveri J, et al. 2002. Bull selection and use in northern Australia. 4. Calf output and predictors of fertility of bulls in multiple-sire herds. Anim Reprod Sci 71:67–79.

Meuwissen TH, Hayes BJ, Goddard ME. 2001. Prediction of total genetic value using genome-wide dense marker maps. Genetics 157:1819–29.

Platter WJ, Tatum JD, Belk KE, et al. 2005. Effects of marbling and shear force on consumers' willingness to pay for beef strip loin steaks. J Anim Sci 83:890–9.

Pollak EJ. 2005. Application and impact of new genetic technologies on beef cattle breeding: A "real world" perspective. Aust J Exp Agr 45:739–48.

Schenkel FS, Miller SP, Jiang Z, et al. 2006. Association of a single nucleotide polymorphism in the calpastatin gene with carcass and meat quality traits of beef cattle. J Anim Sci 84:291–9.

Van Eenennaam AL, Li J, Thallman RM, et al. 2007. Validation of commercial DNA tests for quantitative beef quality traits. J Anim Sci 85:891–900.

Van Eenennaam AL, Weaber RL, Drake DJ, et al. 2007. DNA-based paternity analysis and genetic evaluation in a large, commercial cattle ranch setting. J Anim Sci 85:3159–69.

Zhao Z, Wahl TI, Marsh TL. 2006. Invasive species management: Foot-and-mouth disease in the U.S. beef industry. Agr Resource Econ Rev 35:98–115.

RESEARCH ARTICLE

Fecal pats help to predict nutrient intake by cattle during summer on California's annual rangelands

by Angela D. Jinks, James W. Oltjen, Peter H. Robinson *and* Chris C. Calvert

For a study of nutrient intake by cattle, forage was harvested by hand to minimize shatter losses.

Near-infrared spectroscopy (NIRS) of fecal samples has been used to predict the crude protein and digestible organic matter of forages consumed by grazing animals. However, for NIRS predictions to be accurate, the equation used must be based on samples from the target population. The Texas A&M Grazinglands Animal Nutrition Laboratory has developed a NIRS program based on forages in Texas, the Midwest and Canada's lower prairie provinces. California producers have been using these equations even though they had never been evaluated for California conditions. We conducted beef-cattle digestibility trials on two California rangeland summer forages to produce forage-fecal pairs for testing the existing NIRS ones and developing new equations as necessary. The predictions from the original equations were significantly different from the true values determined in the digestibility trials. The addition of data from this research has improved the predictive capability for both crude protein and digestible organic matter in California.

IN comparison to much of the rest of the United States, California receives most of its rainfall in late fall and winter. Fall rains and warm temperatures initiate forage germination and growth, which slows as temperatures cool. Growth accelerates with warmer spring temperatures, but when the rainy season ends in late spring the annual grasses characterizing much of the state's rangelands mature and senesce (dry and die). Because this annual grassland system is different from most other rangelands in the United States, it is difficult to apply information from other areas to California.

In addition, due to the variability of rangeland systems, it is difficult to estimate what nutrients grazing animals are consuming and whether their diets are deficient. The dry season is of special interest to livestock producers and scientists because inherent in the drying process is an increase in fiber content. Because fiber is digested more slowly, it remains in the rumen longer; this increased rumen fill decreases forage intake and the energy available to the animal. Also, increased plant shatter and bleaching further concentrate fiber in the remaining forage and decrease the plant's nutrive value as it dries. Of particular concern for many cattle producers is the loss of crude protein (CP), which is important for growth, lactation and gestation in cattle (Church 1991). To maintain acceptable levels of production, producers often must supplement cattle diets with forages, grains and/or minerals in various forms. Even during times when the feed's energy content is sufficient, energy intake is generally limited by rumen fill due to high fiber levels (Conrad 1966; Ellis 1978).

Cattle producers must determine when, how and how much to supplement to meet the changing nutrient demands of their cattle. Traditional methods of determining when to supplement include tracking cow weight or body condition score, hand-sampling available forage, visual appraisal of rangelands and, in some cases, routine supplementation in certain seasons or at specific stages of cattle production.

Although crude protein (a source of nitrogen) is important, it is also expensive. If producers do not provide enough nitrogen or provide it at the wrong time, animal production and profitability decrease. On the other hand, providing too much nitrogen (protein) is wasteful because excess nitrogen is excreted in the feces, where it may contribute to water and air pollution.

Predicting forage quality

The Grazinglands Animal Nutrition Laboratory (GAN Lab) at Texas A&M University in College Station developed equations for predicting the crude protein and digestible organic matter (DOM) of forages consumed by grazing animals using near-infrared spectros-

▶ **In the trial, steers wore harnesses to capture 100% of their fecal output, which was then analyzed for crude protein, fiber content and other constituents. *Inset*, fecal pat analysis was used to develop California-specific forage information.**

copy (NIRS) to analyze fecal matter (http://cnrit.tamu.edu/ganlab). NIRS technology projects light in the near-infrared region onto a sample. As the light hits chemical bonds within the sample, the bonds bend and twist, reflecting a predictable and repeatable pattern of light. The pattern becomes a fingerprint that can be used to determine the presence and amount of matching bonds in an unknown sample. However, in order for equations to provide accurate predictions, they must be built from known forage-fecal pairs from the same population as the samples to be predicted.

NIRS has been gaining the attention of scientists in a variety of fields since the late 1970s. Although the technology can be used to predict the chemical composition of many different substrates, including forages, fecal spectroscopy is unique because it predicts the nutrient composition of forage that was actually consumed by grazing cattle (Leite and Stuth 1995; Lyons and Stuth 1992).

Two predictive equations were developed by the GAN Lab using data sets from rangelands in Texas, the Midwest and the southern portion of western Canadian prairie provinces. They are commonly called the "warm-season equation" and the "cool-season equation." The cool-season equation is used for pastures that include introduced small-grain-type forages such as rye, wheat and brome grasses. This equation is best suited for intensively managed pastures such as monocultures. The inaccurately named warm-season equation is used for ranges where native forages are found, such as more extensive rangeland systems. Some cool-season grasses are also included in this group. The cool-season equation is rarely used to predict the nutrient composition of California forages and therefore was not analyzed in this study.

Cattle producers in California began using the GAN Lab equations in the late 1990s, despite the fact that they were not developed using forages from California's unique production system and had never been validated for use in California. California cattle producers using the GAN Lab system have reported mixed results in terms of perceived predictive accuracy based on cattle performance.

The purpose of this trial was to determine whether the Texas A&M fecal NIRS system accurately predicts forage nutrient composition for California's annual rangelands and, if necessary, to revise the regression equations to improve their ability to predict forage quality under California conditions.

Evaluating NIRS accuracy

Forage harvests. In order to evaluate the existing equations, rangeland forage was harvested from two California sites beginning in June 2002 to provide forage for *in vivo* digestibility trials. The first site was the UC Sierra Foothill Research and Extension Center (SFREC), located about 15 miles east of Marysville and 60 miles northeast of Sacramento. Forage was harvested from mostly flat-to-rolling ground with an eastern exposure. The site, dominated by annual grasses, is typical of the land grazed by many cattle in California. It has a hot and dry climate due to being on the eastern side of the Sacramento Valley in the Sierra foothills. Average rainfall is 28 inches per year, with rain events generally in late fall through spring. The main species at SFREC in late May and early June 2003 were wild oat (*Avena fatua*), rose clover (*Trifolium hirtum*), medusahead (*Elymus caput-medusae*) and soft chess (*Bromus hordeaceus*) (table 1).

The second site was on privately owned land 5 miles west of Petaluma, about 30 miles north of the Golden Gate Bridge. Forage was harvested from a relatively steep slope with a western aspect. The surrounding region is heavily influenced by coastal weather patterns, as it is

TABLE 1. Comparison of forage types between Petaluma and SFREC sites, 2003

		Forage cover	
Common name	**Scientific name**	**Petaluma, May 14**	**SFREC, May 30**
		%	
Italian ryegrass	*Lolium multiflorum* L.	49	5
Barbados oat (wild oat)	*Avena barbata*	9	
California burclover	*Medicago polymorpha*	*	
California brodiaea	*Brodiaea californica*		*
Common chickweed	*Stellaria media*	*	
Filaree	*Erodium cicutarium*	*	*
Foxtail	*Hordeum murinum* L. ssp. *Leporinum*	11	
Medusahead	*Elymus caput-medusae* L.		19
Perennial ryegrass	*Lolium perenne* L.	6	
Ripgut brome	*Bromus diandrus*	14	*
Rose clover	*Trifolium hirtum*		25
Soft brome, soft chess	*Bromus hordeaceus* L.		14
Smooth cat's-ear	*Hypochaeris glabra* L.		*
Subterranean clover	*Trifolium subterraneum*	5	
Wild oat	*Avena fatua* L.		34

* Traces.

approximately 15 miles from the Pacific Ocean and 15 miles from San Pablo Bay. Fog is common throughout the entire year. After forages stop growing, this moisture contributes to a decline in forage quality compared to farther inland. The area receives about 25 inches of rain per year, primarily in late fall to spring. The main species at this site in late May and early June 2003 were Italian ryegrass (*Lolium multiflorum*), ripgut brome (*Bromus diandrus*), foxtail (*Hordeum leporinum*) and wild oat (*Avena fatua*). Total production was 2,105 pounds dry matter per acre on April 14, 2003, at Petaluma, and 4,105 pounds dry matter per acre on May 30, 2003, at SFREC.

To minimize shatter loss, the forage at both sites was handled by hand from cutting through hauling. To minimize species variation among forage harvests, the total area to be harvested was divided, with a portion of each section included in each harvest. Harvest occurred at 6-week intervals at each site and continued at each site until one harvest following the first germinating rain, defined as 0.5 to 1 inch of rainfall within 1 week (George et al. 2001; George et al. 1985; Bentley and Talbot 1951). The first harvest at SFREC was on June 11, 2002, and the first rain event of 1.6 inches occurred on Nov. 7, with an additional 4.7 inches falling on Nov. 12. The last harvest at SFREC was on Nov. 26, 2002, 2 weeks following germination. The first harvest at Petaluma was on July 1, 2002, and the first week with rainfall total over 0.5 inches began Oct. 26. The last harvest at Petaluma was on Nov. 4, 2002. Significant "green-up" was observed by the time of final harvest. Five harvests at SFREC and four harvests at Petaluma were collected.

Cattle feeding. The harvested range forage was chopped before feeding to increase voluntary intake by the cattle and to minimize sorting (choosing to eat only the most palatable particles). Chopped feed also mirrors samples clipped in the field, which were used to create the forage-fecal pairs. After the initial adjustment period, during which the steers lost weight, nearly all of the feed was consumed at each feeding. An average of five crossbred Angus steers were fed chopped forage every 8 hours to meet predicted maintenance energy requirements. Immediately prior to forage feeding, soybean meal was offered to bring total nitrogen in the diet to 3% of dry matter (DM). Water was freely available.

Steers were used because total fecal collection using fecal harnesses was necessary to determine the digestibility of the forage. The anatomy of female cattle results in urine contamination of the fecal matter, which would increase nitrogen levels measured in the feces above true levels. The steers were housed in individual pens at the UC Davis feedlot.

If producers do not provide enough supplemental protein or provide it at the wrong time, animal production and profitability decrease.

Fecal and forage analysis. Steers were fed for a 14-day adjustment period, followed by a 5-day total fecal collection period using fecal harnesses. The steers were then switched to feed from the next collection site for 14 days to allow rumen microbe adjustment before another 5-day total fecal collection period. Fecal samples were composited, preserved in triplicate and frozen. One of the three samples was sent by 2-day mail to the Texas A&M GAN Lab for NIRS analysis, and the second sample was further dried and ground for nutrient analysis and sent to the Dairy One Forage Laboratory (Ithaca, N.Y.) where it was analyzed for crude protein, acid detergent fiber (ADF), neutral detergent fiber (NDF) and ash. Species information (cattle) was submitted with the samples. We froze the third sample in case a second test was required to verify a result.

Data analysis. Forage and soybean samples, as well as significant feed refusals, if they occurred, were collected, weighed and composited in the same manner as the fecal samples, then dried, ground and analyzed for CP, ADF, NDF and ash by the Dairy One Forage Laboratory.

Forage CP was determined by standard laboratory nutrient analysis. DOM, which measures the amount of organic matter in the feed that is retained by the animal, was used instead of digestibility because digestibility is influenced by the mineral component of the feed, which varies. However, DOM can be related to digestibility using a correction for the ash content. Once calculated, digestibility can be related to total digestible nutrients and net energy using National Research Council equations. The following equation was used:

$$\text{Forage DOM} = \text{DM forage intake x forage OM} - (\text{fecal DM output x fecal OM} - \text{fecal OM soybean meal})/(\text{DM forage intake})$$

where fecal OM soybean meal = DM soybean meal intake x (1 − ash) 0.85 and soybean meal is assumed to be 85% digestible (NRC 2000). (DM is dry matter; OM is organic matter.)

Warm-season data was analyzed using the Proc GLM (General Linear Models) statistical procedure in SAS (SAS Institute, Cary, N.C.) to determine the effect of equation (original vs. improved), time (date of harvest) and location (SFREC vs. Petaluma) on predictive capability. Interactions were also analyzed.

Improved equations for forage CP and DOM were constructed using forage-fecal pairs whose predicted constituents fell within 1.5 standard deviations of the expected value based on similar spectra from the same population of samples. The equations used forage-fecal pair data from the day composites obtained in the digestibility trial, because they match what occurs when a cattle producer takes a sample on one day from several fecal pats.

Predictive capability

As expected, forage digestibility declined as the summer progressed. Although less-variable low CP values were observed (table 2), all were less than the minimum requirement of about 7% for dry beef cows in the middle third of pregnancy (NRC 2000).

Crude protein. The addition of dry season forage-fecal pairs to the existing GAN Lab equation improved the predictive capability for CP (table 3). All single factors were highly significant, and location-by-equation and location-by-time interactions were observed ($P < 0.01$). Because there was a location-by-

TABLE 2. Laboratory crude protein (CP) and *in vivo* digestible organic matter (DOM) values for range forage from two locations harvested at different times, 2002

Date	Laboratory CP	*In vivo* DOM
	. . . . %	
Petaluma		
July 1	5.2	53.96 ± 0.27
Aug. 12	5.2	54.03 ± 1.04
Sept. 23	5.8	50.36 ± 1.82
Nov. 4	6.0	50.55 ± 1.89
SFREC		
June 11	4.3	56.17 ± 1.32
July 23	4.1	53.01 ± 1.83
Sept. 3	4.5	52.95 ± 2.13
Oct. 15	4.8	52.59 ± 3.52
Nov. 26	5.1	50.89 ± 0.53

TABLE 3. Means of digestible organic matter (DOM) and crude protein (CP) predictions by original and improved equations for spectra from fecal samples from two locations harvested at different times, 2002

Date	Predicted CP ± SE		Predicted DOM ± SE	
	Original equation	Improved equation	Original equation	Improved equation
	. . . . %		. . . . %	
Petaluma				
July 1	8.28 ± 0.33	6.62 ± 0.25	59.46 ± 0.26	58.49 ± 0.34
Aug. 12	7.12 ± 0.05	4.54 ± 0.28	56.54 ± 0.48	54.20 ± 0.15
Sept. 23	7.28 ± 0.29	5.23 ± 0.35	56.74 ± 0.17	49.99 ± 0.18
Nov. 4	7.60 ± 0.25	5.78 ± 0.40	56.60 ± 0.29	49.19 ± 0.43
SFREC				
June 11	7.89 ± 0.42	4.50 ± 0.19	57.33 ± 0.21	55.19 ± 0.42
July 23	7.71 ± 0.37	4.03 ± 0.14	58.28 ± 0.20	56.09 ± 0.48
Sept. 3	9.22 ± 0.29	4.58 ± 0.34	58.00 ± 0.05	54.14 ± 0.14
Oct. 15	9.94 ± 0.17	4.94 ± 0.11	58.64 ± 0.13	54.91 ± 0.19
Nov. 26	9.28 ± 0.16	5.83 ± 0.43	56.71 ± 0.22	53.63 ± 0.31

equation interaction, data was analyzed by location.

Data from the Petaluma site (fig. 1A) showed that both time and equation used were significant ($P < 0.01$). Analysis of the least-square means (prediction − laboratory value) demonstrated that predictive capability for CP was improved by more than 2% from the original equation ($P < 0.01$) (table 4).

At the SFREC site (fig. 1B), equation, time and an equation-by-time interaction were important sources of variation, but equation had the most significant effect on predictive capability. The ability to predict forage CP from SFREC fecal samples improved by more than 4% with the new equation (table 4).

There was also a strong location-by-equation interaction ($P < 0.0001$). Both the original equation and the improved equation predicted CP for Petaluma samples better than for SFREC samples. Under the new equation, predictive ability for the Petaluma samples was numerically more accurate (0.21%) than for SFREC samples. On average, CP was overpredicted. The ability of the equations to better predict Petaluma samples may be due to the higher percentage of perennials at the Petaluma site. Another explanation is that there was greater species variability at the SFREC site, indicating that the system may not have been exposed to all of the different species or that a single laboratory value may not be sufficient to reflect variation at the SFREC site (table 1).

Digestible organic matter. Predictions of DOM were more accurate using the new equation than with the original equation. In the statistical model including all data, only equation was highly significant ($P < 0.0001$). Similar to the original equation, the new equation predicted Petaluma samples (fig. 2A) more accurately than SFREC samples (fig. 2B) by more than 0.92%. The ability of the GAN Lab NIRS equation to better predict Petaluma samples may be a plant-species effect, meaning that the plants found at the Petaluma site are more similar to those fed to create forage-fecal pairs in other trials whose data was also used to construct the equation. In addition, the Petaluma site had slightly more perennials and biennials than the SFREC site.

DOM was consistently overpredicted with both the original and improved equations. The improved equation overpredicted DOM of samples from Petaluma by nearly 0.74%, and samples from the SFREC site by more than 1.67%. The consistent overprediction of DOM indicates a systematic error, either in the GAN Lab NIRS system or in the digestibility trial. However, because this overprediction was seen in the original equation as well as for CP, it is likely that the error lies within the GAN Lab system.

When DOM and CP are compared, the new equation is more accurate for DOM than CP. This difference in predictive accuracy is likely due to greater variation in measures of DOM due to animal and daily variation.

Additional digestibility trials on a wider variety of California rangelands will help to identify nutritional variations in different vegetative communities throughout the state.

Implications for California

The addition of California rangeland forage-fecal pairs made a significant improvement to the existing GAN Lab

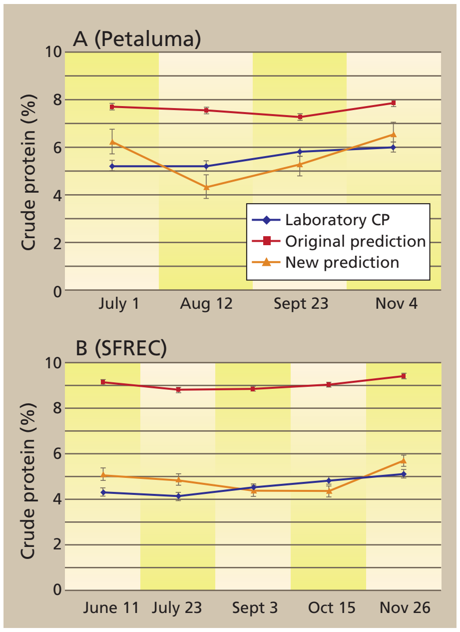

Fig. 1. Predictions of crude protein (CP), 2002.

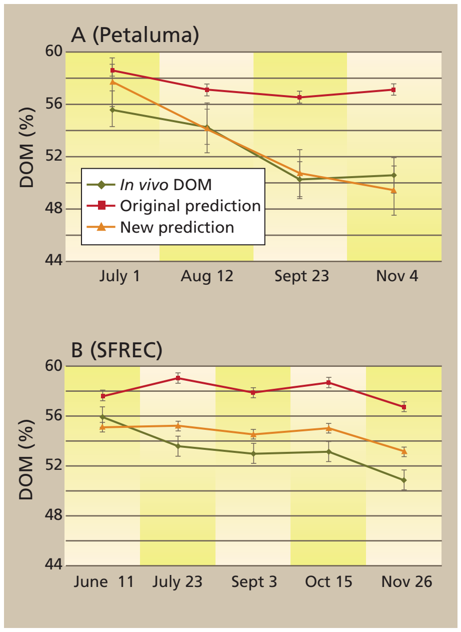

Fig 2. Predictions of digestible organic matter (DOM), 2002.

NIRS system. Further improvements are necessary and could be made with additional digestibility trials on a wider variety of California rangelands. To increase the usefulness of the system, these trials should include forages from the entire year, rather than only the dry season, and should include a number of additional sites to represent the variation in vegetative communities that occurs throughout the state.

Predictive capability was different between the sites. In general, the original equation overpredicted the CP content of the rangeland forages. At the coastal site near Petaluma, the difference between the true CP content and predicted content was 2.02% and −0.01% for the original and new equations, respectively. In comparison to laboratory values, the original and improved equation overpredicted CP at the SFREC site by 4.25% and 0.22%, respectively. At the Petaluma site, the original equation overpredicted DOM by 5.14% while the new equation overpredicted the true value by 0.74%. Differences between true DOM and predicted DOM were 4.67% and 1.67% for the original and new equations at SFREC. This study showed that the addition of forage-fecal pair data produced on California rangelands improves the capability of the GAN Lab system to predict California samples. These data must be added for the system to more accurately predict California samples.

These data were added at the Texas A&M GAN Lab to improve California and annual range predictions. In addition, results from this study were presented to UC Cooperative Extension advisors throughout the state to improve their ability to use and interpret results more accurately. This study did not investigate the accuracy of the GAN Lab predictions on irrigated pastures, and did not create forage-fecal pairs to improve the equation during the green season. The accuracy of the system on irrigated pasture or during the green season on California's annual rangeland is unknown. However, these data were also used in a UC Cooperative Extension irrigated pasture study in Northern California that is expected to be published in 2010 (Larry Forero, personal communication).

TABLE 4. Least square means of prediction bias for digestible organic matter (DOM) and crude protein (CP) by original and improved equations for spectra from fecal samples from two locations harvested at different dates, 2002

	CP			DOM		
Date	Original	Improved	*P* value*	Original	Improved	*P* value
	.... %			.... %		
Petaluma						
July 1	3.08	1.42	0.0003	5.50	4.53	0.6400
Aug. 12	1.92	–0.66	< 0.0001	2.52	0.18	0.2625
Sept. 23	1.48	–0.58	< 0.0001	6.38	–0.37	0.0024
Nov. 4	1.60	–0.22	< 0.0001	6.14	–1.36	0.0009
SFREC						
June 11	3.59	0.20	< 0.0001	1.17	–0.98	0.4815
July 23	3.61	–0.07	< 0.0001	5.27	3.08	0.4706
Sept. 3	4.72	0.08	< 0.0001	5.04	1.19	0.2086
Oct. 15	5.14	0.14	< 0.0001	6.04	2.31	0.2231
Nov. 26	4.18	0.73	< 0.0001	5.82	2.74	0.3125

* Probability value average errors for the two equations are not different.

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References

Bentley JT, Talbot MW. 1951. Efficient use of annual plants on cattle ranges in the California foothills. USDA Circ 870. Washington, DC. 52 p.

Church DC. 1991. *Livestock Feeds and Feeding* (3rd ed.). Englewood Cliffs, NJ: Prentice Hall. 546 p.

Conrad HR. 1966. Symposium on factors influencing the voluntary intake of herbage by ruminants: Physiological and physical factors limiting feed intake. J Anim Sci 25:227–35.

Ellis WC. 1978. Determinants of grazed forage intake and digestibility. J Dairy Sci 61:1828.

George M, Bartolome J, McDougald N, et al. 2001. *Annual Range Forage Production*. UC ANR Pub 8018. 9 p.

George M, Clawson J, Menke J, Bartolome J. 1985. Annual grassland forage productivity. Rangeland 7:17–9.

Leite ER, Stuth JW. 1995. Fecal NIRS equations to assess diet quality of free-ranging goats. Small Ruminant Res 15:223–30.

Lyons RK, Stuth JW. 1992. Fecal NIRS equations for predicting diet quality of free-ranging cattle. J Range Manage 45(3):238–44.

[NRC] National Research Council. 2000. *Nutrient Requirements of Beef Cattle* (7th ed.). Washington, DC: Nat Acad Pr. 248 p.

Progesterone inserts may help to improve breeding readiness in beef heifers

by Pedro H. Favetto, Bruce R. Hoar, Dan M. Myers *and* Justin Tindall

The accurate determination of pubertal status in yearling beef heifers, possibly combined with the use of exogenous progesterone, allows females to produce the maximum number of calves over their lifetimes. This study aimed to determine the reliability of a reproductive tract scoring (RTS) system that combines manual palpation with ultrasound as a measure of pubertal status, and whether the treatment of heifers with progesterone-containing vaginal inserts — followed by breeding on the second estrus after removal of the insert — could result in increased conception rates compared to untreated heifers. Over 2 years, we found that RTS predicted pubertal status reasonably accurately. Progesterone-treated heifers were more likely to exhibit estrus than control heifers, but their overall breeding efficiency was not affected by progesterone treatment. Inadequate nutrition associated with increased pasture stocking density during both breeding seasons likely had a negative effect on the results of our study.

Researchers investigated methods to identify the pubertal status of beef heifers, in order to maximize calf production. Graeme Ernest-Hoar watches a cow being "worked" at the UC Sierra Foothill Extension Center.

The primary economic goal of cow-calf operators is to produce as many calves per year as possible from sexually mature females. Yearling heifers should be enrolled in a breeding program to calve as 2-year-olds, maximizing the number of calves produced in their lifetimes (Wood-Follis et al. 2004; Byerley, Staigmiller, et al. 1987). Consequently, they must be sufficiently mature to be bred at 14 to 15 months of age. The ability to accurately determine sexual maturity as a predictor of future reproductive efficiency is important so that producers can retain the heifers most likely to become pregnant at a young age in the herd.

Reproductive tract scoring (RTS) is performed by transrectal palpation that may be combined with ultrasonography of the uterine horns and ovarian structures (Rosenkrans and Hardin 2003). Heifers are categorized into five different groups based on uterine size and tone, and ovarian findings (Rosenkrans and Hardin 2003; Dahlen et al. 2003). The method considered most accurate measures progesterone levels in two separate blood samples taken 10 days apart, in order to determine whether the heifer is prepubertal or pubertal.

As females reach puberty, serum concentrations of sex hormones are modified due to normal fluctuations in the estrous cycle. After the first ovulation (pubertal estrus), progesterone levels are higher than any values previously observed (Gonzalez-Padilla, Wiltbank, et al. 1975). After the onset of pubertal estrus, progesterone follows a cyclic pattern; it is lowest on days 0 to 2, increases to a maximum between days 12 and 15, and decreases rapidly 3 to 4 days before the next estrus (Donaldson et al. 1970).

The use of progesterone to influence the onset of puberty has been widely studied (Smidt and Majerciak 1971; Gonzalez-Padilla, Niswender, et al. 1975; Wood-Follis et al. 2004; Jaeger et al. 1992; Lucy et al. 2001; Colazo et al. 2003). Progesterone-based protocols have been tested for their effectiveness in inducing puberty and synchronizing estrus. The oral administration of a progestin, melengestrol acetate (MGA), for 14 days followed by an injection of 25 milligrams (mg) of prostaglandin $F_{2\alpha}$ ($PGF_{2\alpha}$) 17 to 19 days after MGA withdrawal (Wood-Follis et al. 2004; Jaeger et al. 1992) was effective in inducing puberty. This confirmed that exogenous progesterone can successfully induce cyclicity in prepubertal heifers, and that the onset of puberty induced by progestin can be followed

Nutrition is clearly an important factor for the success of any reproductive management tool.

by the ability to maintain continued cyclic activity (Jaeger et al. 1992). Another progesterone-based product, an intravaginal insert known as a controlled internal drug-releasing (CIDR) device, contains 1.38 grams of progesterone in elastic rubber molded over a nylon spine in a "Y" shape. Unlike the standard protocol using MGA, CIDR inserts are in place for 7 to 10 days, reducing the treatment time and avoiding delays in the onset of the breeding season.

CIDRs can reduce the time to puberty in beef heifers and effectively synchronize estrus in cattle (Lucy et al. 2001; Colazo et al. 2003; Chenault et al. 2003). In these studies, after the CIDR implant was removed on the 7th day of treatment, a fixed-time artificial insemination was performed at the resulting estrus (Lucy et al. 2001). Consequently, prepubertal heifers that responded favorably to the treatment were artificially inseminated at the pubertal estrus. Unfortunately, this may result in lower pregnancy rates, because there is evidence of suboptimal fertility at pubertal estrus in beef heifers and other female mammals (Byerley, Staigmiller, et al. 1987). Previous studies have found that pregnancy rates were higher in heifers bred on the third estrus compared to those bred on the pubertal estrus (Byerley, Staigmiller, et al. 1987). This difference in pregnancy rates may be explained by a change in the progesterone-to-estrogen ratio between the first and third estrous cycles, resolving the early unfavorable uterine environment caused by higher progesterone and lower estrogen concentrations in the pubertal estrus (Byerley, Berardinelli, et al. 1987).

Given that the first estrus following the prepubertal stage may lead to the ovulation of subfertile ova, we conducted a further evaluation of CIDR inserts in order to collect important data on breeding efficiency (breeding age, interval to conception and pregnancy rate) in heifers treated with CIDR and bred on the second estrus following the onset of puberty. The goals of this study were to determine (1) the accuracy of RTS as a measure of pubertal status and (2) whether the treatment of heifers with CIDR inserts, followed by breeding on the second estrus following removal of the insert, could result in increased conception rates compared to untreated heifers under the same management conditions.

Progesterone inserts were administered by veterinarian Pedro Favetto to test whether puberty could be induced earlier in heifers.

Study animals

Our 2-year study was performed using animals belonging to the UC Sierra Foothill Research and Extension Center (SFREC). We studied 201 (84 in year 1 and 117 in year 2) Black Angus and Hereford crossbred yearling heifers that were to be bred as part of routine management at SFREC. The UC Animal Care and Use Committee approved all protocols and procedures.

Heifers were initially transrectally palpated and examined with ultrasound by a single researcher to evaluate their reproductive status (pregnancy status and RTS) (Rosenkrans and Hardin 2003; Dahlen et al. 2003). Ultrasonography was used to measure ovarian structures and uterine horn diameter to more accurately determine the RTS (table 1) (Dahlen et al. 2003). A blood sample was collected to measure serum progesterone concentration, and a second blood sample was collected 10 days later. Additional data included body condition score, body weight, age and nutritional history of the group.

TABLE 1. Reproductive tract score (RTS), based on rectal palpation combined with ultrasound, assigned to heifers according to uterine horn size and ovarian structures on a scale of 1 to 5

RTS	Uterine horn diameter	Ovarian structures
	mm	
1	< 5	No palpable follicles
2	5–10	8 mm follicles
3	10–15	8–10 mm follicles
4	15–20	> 10 mm follicles
5	> 20	> 10 mm follicles, corpus luteum present

Source: Rosenkrans and Hardin 2003.

Charles Raguse

Reproductive tract scoring (RTS) and progesterone inserts may improve the breeding efficiency of heifers, but nutrition is an important limiting factor.

The RTS values, based on palpation and ultrasound measurements, were analyzed and used to assign the heifers to either prepubertal or pubertal groups. Heifers were blocked by pubertal status (RTS ≤ 3, prepubertal; RTS ≥ 4, pubertal), then randomly allocated into either a CIDR-treated or control group using a random-number generator.

To determine progesterone concentrations in the blood, we used a rapid, solid-phase microtitre plate enzyme immunoassay (EIA) (Munro and Stabenfeldt 1984). Briefly, the EIA uses progesterone 3-O-carboxymethyloxime-horseradish peroxidase as the labeled analyte, and antiserum (raised in rabbits) to a progesterone 11a-hemisuccinyl-bovine serum albumin (BSA) immunogen. The EIA was able to detect a lower threshold of 0.07 nanogram per milliliter (ng/ml) of progesterone. If either of the blood samples showed a progesterone concentration greater than 1 ng/ml, the animal was considered pubertal. If both samples were below 1 ng/ml, then the animal was considered prepubertal (Dow et al. 1982; Gonzalez-Padilla, Wiltbank, et al. 1975; Donaldson et al. 1970; Rosenkrans and Hardin 2003; Wehrman et al. 1996). The progesterone information was not used to assign the animals to treatment groups, but rather to analyze pubertal status and other data obtained throughout the study.

CIDR implants

CIDR implants were placed in the treatment group when the second blood sample was taken. This was considered day 0 (zero) of the clinical trial. Eight days later, the treatment group received an intramuscular dose of 25 mg $PGF2_{\alpha}$.

The CIDR implants were removed the next day (day 9), and both groups were observed for estrus behavior for 1 hour, twice daily, for 7 days. In year 1, a simple synchronization protocol was started on day 17 in both the CIDR and control groups. It consisted of two injections of $PGF2_{\alpha}$ (25 mg) 12 days apart, followed by a single injection of gonadotrophin-releasing hormone (GnRH) (12 micrograms [μg]) 48 hours after the last $PGF2_{\alpha}$. In year 2, the protocol was modified in an attempt to shorten the breeding season. A single dose of $PGF2_{\alpha}$ was injected on day 17, followed by a single injection of GnRH 48 hours later. In both years, all heifers were artificially inseminated 20 hours after the GnRH injection by two experienced inseminators using frozen semen from a single bull. Three weeks after artificial insemination, the heifers were gathered in a single group and bulls were turned in for 2 months. All bulls had previously passed a breeding soundness examination. The bull-to-heifer ratio was approximately 1-to-20. At 30 days and 140 days after artificial insemination, all study animals were examined using ultrasound to detect pregnancy.

Statistical analysis

The sensitivity, specificity and overall "correct classification of palpation combined with ultrasound" was compared to "serum progesterone assay." In this trial, sensitivity was defined as the proportion of heifers classified as pubertal by RTS — given that they were truly pubertal as determined by progesterone assay — while specificity was defined as the proportion of heifers classified as prepubertal by RTS — given that they were truly prepubertal. Overall correct classification was calculated as the sum of those correctly called pubertal and those correctly called prepubertal divided by the total number of heifers.

The final total proportion pregnant in each group in each year was compared using a Pearson's chi-square test. The ages and weights measured throughout the study were compared between the CIDR and control groups as well as between prepubertal and postpubertal heifers, using a one-way analysis of variance with a Bonferonni correction for multiple comparisons. A Kaplan-Meier survival analysis was performed, comparing time to pregnancy for both groups (CIDR and control). All the statistical analyses performed on the data were evaluated at a 5% significance level using a commercially available software program (SPSS Statistics 17.0, Chicago, Ill.). Results were calculated separately by year of study, and were also compared between years.

Heifer classification, pregnancy

There were no significant differences between the CIDR and control animals within a given year in age at artificial insemination, initial weight and weight at insemination, but animals in year 2 were younger at artificial insemination than in year 1 (the project was initiated earlier in year 2), and weighed significantly less than the control heifers in year 1 (and numerically, but not significantly, less than CIDR heifers) (table 2).

In year 1, 38% of the heifers were prepubertal and 62% pubertal (table 3), based on serum progesterone levels at the beginning of the study, while in year 2 these values were 79.5% prepubertal and 20.5% pubertal. There were significantly more prepubertal heifers in year 2 than in year 1 ($P < 0.001$), primarily associated with their younger age. The sensitivity of RTS for determining pubertal status increased from 76.9% to 83.3% from year 1 to year 2, while specificity increased from 40.6% to 68.8%. The overall proportion of heifers correctly classified increased from 63.1% in year 1 to 71.8% in year 2.

During the 7 days following removal of the CIDR inserts, estrous behavior was observed in 21% (9/42) and 24% (14/58) of the CIDR-treated heifers, and 7% (3/42) and 15% (9/59) of the control heifers in year 1 and year 2, respectively. The observed differences were not statistically significant ($P = 0.12$ and $P = 0.26$, respectively).

Overall conception at first breeding was 23.8% and 17.9% (20/84 and 21/117) for year 1 and year 2, respectively (table 4). The combination of those pregnant from artificial insemination and natural service, after both groups were exposed to the bulls, was 75.0% and 70.1% (63/84 and 82/117) for the two study years. Pregnancy rates did not differ between CIDR and control groups in either year, either at first breeding ($P = 0.61$ and $P = 0.44$, respectively) or at the end of breeding season ($P = 0.21$ and $P = 0.89$, respectively).

TABLE 2. Mean values for age, initial weight and weight at artificial insemination (AI) of 201 beef heifers in a CIDR-treatment or control breeding group at UC Sierra Foothill Research and Extension Center

	Year 1		Year 2	
	CIDR (*n* = 42)	Control (*n* = 42)	CIDR (*n* = 58)	Control (*n* = 59)
Age at AI (months)	13.8a* (13.6; 14.0)†	14.0a (13.7; 14.3)	13.2b (13.1; 13.4)	13.2b (13.0; 13.3)
Initial weight (kg)‡	279.1ab (271.8; 286.4)	282.8a (275.8; 289.8)	268.7b (262.0; 275.2)	269.2b (262.4; 276.1)
Weight at AI (kg)§	274.5 (267.8; 281.2)	276.8 (269.1; 284.5)	284.5 (276.5; 292.4)	283.5 (276.3; 290.7)
Weight gain between enrollment and AI (kg)	−4.6a (−7.4; −1.9)	−6.0a (−8.7; −2.3)	15.8b (12.2; 19.4)	14.3b (10.6; 18.0)

* Values having different letters within rows are significantly different using one-way ANOVA ($P < 0.05$).
† Numbers in parentheses correspond to the lower and upper limit of 95% confidence interval.
‡ At first evaluation, 10 days prior to CIDR placement.
§ 32 days post-CIDR placement at the time of artificial insemination.

TABLE 3. Agreement between serum progesterone levels and palpation combined with ultrasound (reproductive tract score [RTS]) as methods of determining pubertal status of beef heifers

	Status predicted by progesterone levels		
Status predicted by RTS	Pubertal	Prepubertal	All
	n (%)		
Year 1			
Pubertal	40	19	59 (70.2)
Prepubertal	12	13	25 (29.8)
All	52 (61.9)	32 (38.1)*	84†
Year 2			
Pubertal	20	29	49 (41.9)
Prepubertal	4	64	68 (58.1)
All	24 (20.5)	93 (79.5)*	117‡

* There were significantly more prepubertal heifers in year 2 than in year 1 ($P < 0.001$).
† Year 1 sensitivity = 76.9%, specificity = 40.6%, overall correct classification = 63.1%.
‡ Year 2 sensitivity = 83.3%, specificity = 68.8%, overall correct classification = 71.8%.

TABLE 4. Conception at first breeding compared with overall pregnancy for CIDR-treated and untreated beef heifers, retrospectively classified as pubertal and prepubertal by progesterone levels

	Control*			CIDR*		
	Prepubertal (*n* = 13)	Pubertal (*n* = 29)	Total (*n* = 42)	Prepubertal (*n* = 19)	Pubertal (*n* = 23)	Total (*n* = 42)
	n (%)					
Year 1 (*n* = 84)						
Pregnant to AI†	2 (15.4)	9 (31.0)	11 (26.2)	5 (26.3)	4 (17.4)	9 (21.4)
Pregnant to AI and natural service	11 (84.6)	23 (79.3)	34 (81.0)	11 (57.9)	18 (78.3)	29 (69.1)
Not pregnant at end of breeding season	2 (15.4)	6 (20.7)	8 (19.0)	8 (42.1)	5 (21.7)	13 (30.9)
	Prepubertal (*n* = 48)	Pubertal (*n* = 11)	Total (*n* = 59)	Prepubertal (*n* = 45)	Pubertal (*n* = 13)	Total (*n* = 58)
	n (%)					
Year 2 (*n* = 117)						
Pregnant by AI	6 (12.5)	3 (27.3)	9 (15.3)	9 (20.0)	3 (23.1)	12 (20.7)
Pregnant by AI and natural service	32 (66.7)	9 (81.8)	41 (69.5)	29 (64.4)	12 (92.3)	41 (70.7)
Not pregnant at end of breeding season	16 (33.3)	2 (18.2)	18 (30.5)	16 (35.6)	1 (7.7)	17 (29.3)

* No significant differences in pregnancy proportion from AI or overall were observed between CIDR and control groups in either year.
† Artificial insemination.

TABLE 5. Mean age and weight comparison of heifers bred by artificial insemination (AI), bull or not pregnant by AI or bull breeding

	AI pregnancies			Pregnancies w/bull			Not pregnant		
	Age	Initial weight	Weight at AI	Age	Initial weight	Weight at AI	Age	Initial weight	Weight at AI
	months	*kg*	*kg*	*months*	*kg*	*kg*	*months*	*kg*	*kg*
Year 1									
CIDR	14.1	279.1	266.4	13.9	281.1	275.5	13.6	276.6	274.0
Control	14.6	295.0	290.0	14.0	286.0	281.3	13.7	271.5	261.3
Total	14.3	287.1	278.2	13.9	283.6	278.4	13.6	274.1	267.6
Year 2									
CIDR	13.4	276.7	289.3	13.2	272.1	282.0	13.2	256.4	267.5
Control	13.1	277.6	286.8	13.2	276.2	290.8	13.1	252.6	268.9
Total	13.3	277.1	288.2	13.2	274.3	286.6	13.1	254.4	268.2

TABLE 6. Age and weight comparison of heifers classified as prepubertal and pubertal based on progesterone levels

	Year 1		Year 2	
	Prepubertal (n = 32)	Pubertal (n = 52)	Prepubertal (n = 93)	Pubertal (n = 24)
Age at AI (months)	13.4a* (13.2; 13.6)†	14.2b (13.9; 14.4)	13.2a (13.1; 13.3)	13.3a (13.1; 13.5)
Initial weight (kg)	273.9ab (267.2; 280.7)	285.4ab (278.6; 292.1)	266.3a (260.9; 271.7)	279.0ab (270.4; 287.6)
Weight at AI (kg)	269.6a (262.9; 276.4)	279.3a (272.4; 286.2)	280.6a (274.6; 286.7)	296.5b (286.7; 306.4)
Weight gain between enrollment and AI (kg)	−4.3a (−7.3; −1.2)	−6.1a (−7.9; −3.7)	14.3b (12.2; 17.7)	17.5b (10.8; 24.3)

* Values having different letters within rows are significantly different using one-way ANOVA (P < 0.05).
† Numbers in parentheses correspond to the lower and upper limit of 95% confidence interval.

The average age at artificial insemination, average initial weight and average weight at artificial insemination were compared based on final pregnancy status, and the differences among nonpregnant heifers, heifers pregnant by the bull and heifers pregnant by artificial insemination were not significant (table 5). However, an upward trend was observed in age and weight when nonpregnant heifers were compared to heifers pregnant by the bull. A further increase was observed when heifers pregnant by the bull were compared to heifers pregnant by artificial insemination in the control group. This was consistent in both year 1 and year 2, but less obvious in year 2.

Heifers found to be prepubertal by progesterone levels in year 1 were younger at artificial insemination (P < 0.001), weighed less initially (P = 0.025) and tended to weigh less at artificial insemination (P = 0.062) than pubertal heifers. In year 2, prepubertal heifers tended to be younger (P = 0.16), weigh less initially (P = 0.029) and weigh less at artificial insemination (P = 0.014) than pubertal heifers (table 6). This is consistent with much of the work done by others on the association between weight, age and puberty.

Survival analysis showed no significant difference in the median days to pregnancy between treatments and between years of the study. The overall median number of days to pregnancy was 60.

Screening tests

This study was designed to evaluate whether the treatment of prepubertal beef heifers with CIDR inserts could achieve the early expression of puberty and maintain cyclicity, thereby improving breeding efficiency by reducing the age at breeding and interval to conception, and increasing the pregnancy rate. However, while more heifers treated with CIDR inserts demonstrated estrous behavior, we found no effect on the proportion that became pregnant.

The proportion of heifers correctly classified as either pubertal or prepubertal improved between year 1 and year 2, likely due to the palpator's increased experience. We found that the ability to detect pubertal heifers accurately (sensitivity) was greater than the ability to detect prepubertal animals (specificity). These results are in general agreement with those of a previous study (Rosenkrans and Hardin 2003). Low specificity (high "false positive" rate) may be due to mistakenly identifying a developing corpus luteum (progesterone-secreting endocrine tissue that forms on the ovary immediately after ovulation) present and palpable between day 1 and day 4 of the estrous cycle but not secreting large quantities of progesterone for a mature corpus luteum. Low sensitivity (high "false negative" rate) may be due to luteal tissue being deeply embedded in ovarian stroma, making accurate identification difficult.

For these reasons, we conclude that RTS should not be used as the sole criterion for determining whether a heifer is to be retained within the breeding herd, but rather should be used as a screening test. This could be an important adjunct to current UC recommendations, which suggest using age and weight in selecting replacement heifers. With a sensitivity ranging from 76.9% to 83.3%, 17% to 23% of heifers that are truly pubertal will be called prepubertal and be at risk of being culled. Conversely, with specificity ranging from 40.6% to 68.8%, 31% to 59% of heifers that are prepubertal will be called pubertal.

Nutritional deficiency suspected

In this study, a greater number of CIDR-implanted heifers showed estrous behavior a week after treatment than nontreated heifers. This difference was statistically significant when data from the two years was combined, but not when examined separately. The estrous response to treatment was lower than expected (Wood-Follis et al. 2004; Lucy et al. 2001). There were no significant differences between the CIDR and

Reproductive tract scoring should not be used as the sole criterion for determining whether a heifer is to be retained within the breeding herd, but rather should be used as a screening test.

control groups in overall pregnancy, pregnancy at first breeding or time to conception. Our findings were not in agreement with those presented by other researchers (Lucy et al. 2001), who found that the 3-day artificial-insemination pregnancy rates for beef heifers were 8%, 14% and 39% for controls, animals treated with $PGF_{2\alpha}$, and animals treated with CIDR plus $PGF_{2\alpha}$, respectively.

We believe that the discrepancy in our results is attributable to a nutrition deficiency combined with young age during the trial period. Given that the age of puberty onset is influenced by a heifer's nutritional status and genetic background (Schillo et al. 1992; Dow et al. 1982), these variables must be considered when analyzing the results of a heifer-breeding program. The average breeding age of the heifers in our study was lower than normally accepted in beef operations (Stull et al. 2007). Dow et al. (1982) observed that beef heifers of continental crosses attained puberty between 11.5 and 19.5 months. In year 1, our study heifers were 13.9 months of age at breeding, and in year 2 they were significantly younger (13.2 months). The young age of animals in this study undoubtedly affected the onset of puberty.

A lack of appropriate weight gain was a major problem during the study period in both years. From first evaluation to first breeding, the study animals either lost considerable weight (year 1) or gained only slightly (year 2). Heifers should maintain continuous growth to facilitate breeding, reach a normal adult frame size and reduce the risk of problems at parturition. Dry conditions during both years (due to late rainfall that delayed germination and high summer temperatures) probably contributed to the poor weight gain. In addition, stocking density was increased during these two years. For this trial, a greater number of heifers than normal was retained for breeding, but due to specific management procedures they were pastured on the same field as in previous years. While nutritional problems affected our study, the results provide further evidence that good nutrition is a key element in all areas of animal husbandry and is critical for every breeding protocol (Schillo et al. 1992; Donaldson et al. 1970; Patterson et al. 1992).

Based on the results of this trial, we conclude that RTS can provide important information related to the pubertal status of heifers, but should not be used as the sole criterion for selecting replacement females. Also, CIDR inserts only marginally improve the breeding efficiency of prepubertal beef heifers when nutrition is limiting. Nutrition is clearly an important factor for the success of any reproductive management tool. Adequate nutrition and optimal breeding efficiency enable producers to reduce the economic costs associated with increased feeding to maintain nonpregnant females, the loss of nonpregnant breeding animals due to culling, and the need to provide replacement breeding females.

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References

Byerley DJ, Berardinelli JG, Staigmiller RB, et al. 1987. Progesterone concentrations in beef heifers bred at puberty or third estrus. J Anim Sci 65:1571–5.

Byerley DJ, Staigmiller RB, Berardinelli JG, et al. 1987. Pregnancy rates of beef heifers bred either on pubertal or third estrus. J Anim Sci 65:645–50.

Chenault JR, Boucher JF, Dame KJ, et al. 2003. Intravaginal progesterone insert to synchronize return to estrus of previously inseminated dairy cows. J Dairy Sci 86:2039–49.

Colazo MG, Kastelic JP, Mapletoft RJ. 2003. Effects of estradiol cypionate (ECP) on ovarian follicular dynamics, synchrony of ovulation, and fertility in CIDR-based, fixed-time AI programs in beef heifers. Theriogenology 60:855–65.

Dahlen CR, Lamb GC, Zehnder CM, et al. 2003. Fixed-time insemination in peripubertal, lightweight replacement beef heifers after estrus synchronization with $PGF_{2\alpha}$ and GnRH. Theriogenology 59:1827–37.

Donaldson LE, Bassett JM, Thorburn GD. 1970. Peripheral plasma progesterone concentration of cows during puberty, oestrous cycles, pregnancy and lactation, and the effects of under-nutrition or exogenous oxytocin on progesterone concentration. J Endocrinol 48:599–614.

Dow Jr JS, Moore JD, Bailey CM, et al. 1982. Onset of puberty in heifers of diverse beef breeds and crosses. J Anim Sci 55:1041–7.

Gonzalez-Padilla E, Niswender GD, Wiltbank JN. 1975. Puberty in beef heifers. II. Effect of injections of progesterone and estradiol-17ß on serum LH, FSH and ovarian activity. J Anim Sci 40:1105–9.

Gonzalez-Padilla E, Wiltbank JN, Niswender GD. 1975. Puberty in beef heifers. I. The interrelationship between pituitary, hypothalamic and ovarian hormones. J Anim Sci 40:1091–104.

Jaeger JR, Whittier JC, Corah LR, et al. 1992. Reproductive response of yearling beef heifers to a melengestrol acetate-prostaglandin$_{2\alpha}$ estrus synchronization system. J Anim Sci 70:2622–7.

Lucy MC, Billings HJ, Butler WR, et al. 2001. Efficacy of an intravaginal progesterone insert and an injection of $PGF_{2\alpha}$ for synchronizing estrus and shortening the interval to pregnancy in postpartum beef cows, peripubertal beef heifers, and dairy heifers. J Anim Sci 79:982–95.

Munro C, Stabenfeldt G. 1984. Development of a microtitre plate enzyme immunoassay for the determination of progesterone. J Endocrinol 101:41–9.

Patterson DJ, Perry RC, Kiracofe GH, et al. 1992. Management considerations in heifer development and puberty. J Anim Sci 70:4018–35.

Rosenkrans KS, Hardin DK. 2003. Repeatability and accuracy of reproductive tract scoring to determine pubertal status in beef heifers. Theriogenology 59:1087–92.

Schillo KK, Hall JB, Hileman SM. 1992. Effects of nutrition and season on the onset of puberty in the beef heifer. J Anim Sci 70:3994–4005.

Smidt D, Majerciak P. 1971. [Results of experiments to influence the onset of puberty in animals (author's transl.)]. J Neurovisc Relat Suppl 10:98–106.

Stull C, Barry S, Jensen W. 2007. Beef Care Practices. UC ANR Publication 8257. http://ucanr.org/freepubs/docs/8257.pdf (accessed Nov. 24, 2009).

Wehrman ME, Kojima FN, Sanchez T, et al. 1996. Incidence of precocious puberty in developing beef heifers. J Anim Sci 74:2462–7.

Wood-Follis SL, Kojima FN, Lucy MC, et al. 2004. Estrus synchronization in beef heifers with progestin-based protocols. I. Differences in response based on pubertal status at the initiation of treatment. Theriogenology 62:1518–28.

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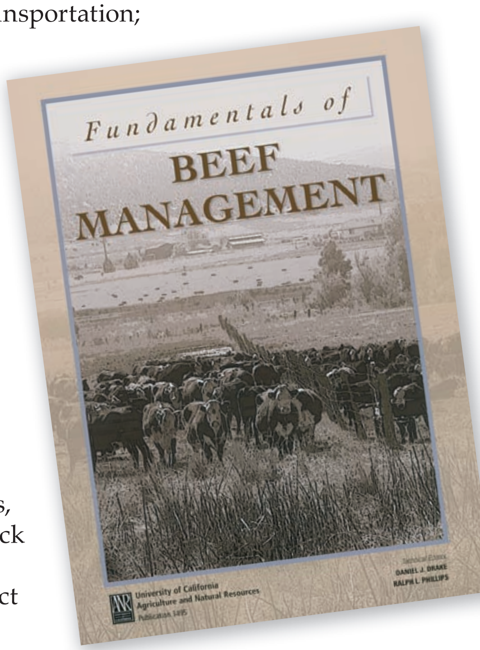

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COMINGUP


In south Salinas, a landscaped driveway faces a field.
Photo courtesy of Sonya Varea Hammond

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