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2801 Second Street, Room 181A; Davis, CA 95618-7779
Phone: (530) 750-1223; Fax: (530) 756-1079; calag@ucanr.edu

EDITORIAL

2801 Second Street, Room 184; Davis, CA 95618-7779
(530) 750-1223; calag.ucanr.edu

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COVER: A prescribed fire on private land in El Dorado County, February 2020. The objective of this burn was to reduce fire hazard in the wildland–urban interface on the Georgetown Divide. The area had been high-grade logged 15 years earlier and was pre-commercially thinned two years earlier. *Photo by Rob York.*

Research and review articles

OUTLOOK

Burn permits need to facilitate — not prevent — "good fire" in California

The weather last fall was unusually favorable for private landowners to carry out prescribed burns to reduce wildfire hazard. Burn permits, however, made burning unnecessarily difficult. Safe and effective prescribed burns can benefit from changes in permitting.

Robert A. York, UC Cooperative Extension Specialist, UC Berkeley
Ariel Roughton, Interim Manager, Berkeley Forests
Ryan Tompkins, UC Cooperative Extension Forestry and Natural Resources Advisor
Susan Kocher, UC Cooperative Extension Forestry and Natural Resources Advisor

Online: https://doi.org/10.3733/ca.2020a0014

In California, there is intense focus on expanding the use of prescribed burns — fires that are intentionally set to burn with low intensity and to consume litter and woody debris across the forest floor. Policymakers have recognized the critical importance that prescribed burns have in reducing the impact of large, damaging wildfires (Little Hoover Commission 2018), and $1 billion in state funding over the next 5 years is aimed at reducing the century-long buildup of fuel on forest floors. Yet only a small fraction of what is needed to facilitate these "good fires" is being done.

In 2017–2018, only 33,000 acres of private land were treated by state agencies (Newsom 2019), and much of this work was mechanical (i.e., thinning and chipping), not prescribed burns. By contrast, the California Carbon Plan has the goal of treating 500,000 acres of private land every year. Private landowners, who own roughly half of the mixed-conifer forests in California, can help protect their property and contribute to reducing the broad public impacts of large wildfires by implementing prescribed burns. But a burn permit is often needed, and based on our outreach experience, it is clear that permits are a significant challenge to landowners.

Permits vary

The California Department of Forestry and Fire Protection (Cal Fire) is the primary agency that issues permits for prescribed burns on private land. The permit notifies landowners of their potential liability (see sidebar, page 63) and documents their responsibilities during the burn, which may include ensuring safe weather conditions, having adequate personnel and equipment present, and confirming with local Air Pollution Control Districts that it is an allowable burn day.

Permit duration is variable, with no standards for how long a permit lasts. Permits may or may not be contingent upon Cal Fire resources being present for the burn; and on any given day after the permit is issued, Cal Fire may deny permission for a burn if conditions are thought to be unsafe. A burn plan may or may not be required. If required, there is no recognized burn plan template that landowners can follow.

Susan Kocher

A prescribed burn is contained by creating a break in surface fuel along the burn area perimeter. Prescribed burning is critically important in reducing the impact of large wildfires.

Pile burning (left) is a generally accepted and common method of burning surface fuels. Per unit of fuel burned, it typically causes more air pollution than a prescribed fire (right). As with prescribed burns, pile burning requires expertise and appropriate weather conditions, but the permit process is simple, unlike the permitting for prescribed burns.

Perceived barriers to prescribed burns

Some examples exist of the successful use of prescribed burns on federal lands, but there are very few examples on private lands. Lack of expertise, air quality regulations and liability issues are typically cited as barriers to the expansion of prescribed burns (Miller et al. 2020). A counter-argument suggests that these cited barriers are based on the cultural perceptions of prescribed fire, and not necessarily empirical evidence (Quinn-Davidson 2019).

Miller et al. (2020) estimated recently that 6,663 burns were done in California on all land ownership types between 2013 and 2018. We estimate the vast majority of those burns — as many as 90% of them based on a sampling of available data — were either grassland or pile burns. Pile burning involves concentrating forest fuels by hand or with equipment into a pile and then burning it under appropriate conditions. Pile sizes can vary from 4 feet tall on residential land to over 40 feet tall on industrial and federal land. Pile burning is done by small landowners and large agencies and timber companies, after a relatively quick and simple permit application. The practice is common, even though it requires expertise that is similar to prescribed burning.

Air quality regulations are often not as big a barrier as they are perceived to be. During our landowner workshops, California Air Quality Control Board officials were clear that they are encouraging of prescribed burns, and the agency has a transparent process for approving smoke emissions. Of all of the steps involved with prescribed burns, smoke management is arguably the clearest and most achievable. It is even possible to do a prescribed burn on a no-burn day. Pile burning can be dirtier from an emissions perspective than prescribed burns (Robinson et al. 2011). Piles contain higher amounts of dirt and duff because fuel is raked or pushed into the pile, resulting in less efficient combustion and emission of more particulate matter. Further, ignition of piles usually occurs in the winter when fuel is wet, leading to less efficient combustion than prescribed burns of drier fuel.

A landowner's potential liability is the same for pile and prescription burning. Yet during workshops, we often heard that liability is a primary reason why landowners conduct pile burns but not prescribed burns. Landowners conducting fires in California may be held liable if, *through negligence*, a burn escapes their control and causes damage to another landowner's property. Fire suppression agencies are not able to seek compensation from a landowner for suppression costs unless the fire burns onto someone else's property.

Miller et al. (2020) quantified the rate of "escape" during prescribed burns in California at 1.76%. This surprisingly high rate, however, included pile burning and assumed that any fire that was marginally larger than planned was an escape. The percentage of prescribed burns that resulted in liable damage or monetary reimbursement of agencies because it escaped and caused damage to another's property was very likely far lower than 1.7%.

Counter to conventional wisdom, pile burning may be more risky than prescribed burns; embers are typically cast high into the sky because of the intensity of the fire and the heat that builds up in the pile causes the material to smolder for days or months. Many escapes, especially those that cause damage through negligence, are likely to be from pile burns, not prescribed burns. A thorough evaluation of escape rates from pile burning versus prescription burning would be a helpful step toward understanding actual escape risk and possibly a step toward greater acceptance of prescribed burns.

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Ecological benefits of fall burning

A guiding principle of sustainable silviculture is that forest treatments should mimic, to the extent possible given other factors, the ecosystem's natural disturbance regime. An important element of a disturbance regime is its seasonality. In Sierra Nevada forests, fires historically (prior to European American settlement) tended to occur during summer and fall, depending on annual weather variability and long-term climatic trends (Stephens and Collins 2004; Swetnam and Baisan 2003). Because prescription burning in summer is typically viewed as too risky, fall is the only time when landowners can burn in line with the natural disturbance regime.

Prescribed burns effectively reduce the buildup of fuel with little or no negative ecological side effects (Stephens et al. 2012). Fall is optimal for meeting fuel reduction and ecological restoration objectives.

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Fall burn window depends on weather, permit factors

Burning in the fall (September through November) is preferable for the practical reason that fires can consume fuel thoroughly without damaging trees, and also for ecological reasons (see sidebar). The fall weather window for burning opens when either early fall rain or high humidity increases fuel moisture. The window shuts after heavy storms in late fall make burning impossible. This favorable weather window is interrupted on any given day, however, by dry foehn winds (e.g., Santa Ana winds) that can be particularly hazardous in late fall, as they were in the destructive 2017 and 2018 fall wildfires in Northern California.

During the fall weather window for burning, the status of permitting is highly variable. When the weather window opens, the permit suspensions Cal Fire puts in place during summer (fig. 1) are typically still in effect, meaning that it is extremely difficult or impossible for a landowner to get a permit. Permits eventually become obtainable when the suspension is lifted, but this occurs at varying times during the weather window. A significant influence on the timing of lifting suspensions is the number of wildfires occurring across the state. Because "contingency resources" (i.e., firefighters available to contain a burn escape) are considered when issuing permits, the permit suspensions are much less likely to be lifted during a large wildfire, even if it is in a different part of the state.

Three burn cases in fall 2019

The 2019 fall season had particularly good weather for conducting prescribed burns along the western slopes of the Sierra Nevada. Following a relatively wet and late spring, early fall precipitation and high humidity preceded an extended period of dry and stable weather across much of the region, providing an unusually long weather window for burns, prior to heavy storms in November.

During this period, we conducted three prescribed burns across a south-to-north transect on the west

Winter	Spring	Summer	Fall
• Open burning season. • Permit not required in many counties (but a smoke emission permit may still be required). • Fuel consumption is often limited because of high fuel moisture.	• Permit season begins (often on May 1) at the start of wildfire season. • Season lasts from zero days to several weeks, depending on when permits are suspended. • Burning can be effective, but high soil moisture often limits fuel consumption.	• Permits are suspended across large regions and eventually the entire state as forest fuels dry out. • If appropriate levels of planning and resources are demonstrated, a permit may be issued, but this is rare. • Burning can be effective, but risk is typically perceived as too high.	• Optimal time for effective prescribed burns. • After fuels moisten from rain or high humidity, permits may be issued. • Burn window lasts from zero days to several weeks. • Often permitting does not begin until after storms end the season for effective burns.

FIG. 1. In California, a burn permit is required in most seasons. The permit pattern often does not match well with the best times for effective burns.

slope of the Sierra Nevada mixed-conifer forest. The burns were part of a UC ANR education program for landowners and professionals interested in conducting prescribed burns (see sidebar). They reveal how the permitting process can either encourage or prevent "good fires" on private land.

Burn 1: Oct. 16, northern Sierra Nevada

Local permit suspensions had been lifted on Oct. 3, following fall precipitation, and the permit was issued Oct. 14 for a period of 1 week. Cal Fire staff had visited the site in September to discuss how the burn would be conducted; they did not insist on being present for the burn but offered to send an engine for contingency resources if seasonal staffing allowed. After receiving the permit, forest managers tracked fuel and weather conditions before deciding on the burn day, just 2 days later. A high degree of nimbleness was necessary to organize resources on short notice; forecasted precipitation later in the week would make fuel too wet.

Cal Fire was notified the day before the burn. The burn was conducted successfully by the landowner and met objectives of reducing hazardous fuels without excessive damage to canopy trees. Cal Fire staff visited the site a few days after the burn and offered a permit extension, but the fuels had become too wet.

Burn 2: Nov. 6, southern Sierra Nevada

The region had not experienced significant precipitation, but local permit suspensions had been lifted. Although live fuel moisture was relatively low, stable weather and elevated relative humidity created good prescribed burn conditions. The permit was issued for an entire year after a Cal Fire review of the landowner's plans for burning. Cal Fire was notified the day before the burn, and the burn was completed without Cal Fire being present.

The fire consumed logging slash, which was a particularly important objective for this burn, while minimizing damage to young trees of desired species. The landowner let the fire burn downslope overnight, when humidity was higher, to consume more fuel over a larger area. Although sometimes explicitly not allowed on permits, burning at night can be an effective tactic to conduct prescribed burns when fuel moisture is low.

Burn 3: Nov. 13, central Sierra Nevada

Over 2.8 inches of precipitation had occurred at this site between Sept. 16 and Sept. 30, an above-average amount of early fall rain, yet permit suspensions had not been lifted in central Sierra Nevada counties. A detailed burn plan (developed by fire scientists) was submitted. Cal Fire required that numerous Cal Fire firefighting resources be on site, in addition to the landowner's resources, which were adequate for the

UC ANR trains Sierra Nevada landowners in live burns

Since 2018, UC ANR advisors and specialists have been helping landowners understand prescribed burning and gain practice in live burns during workshops throughout the Sierra Nevada. The Sierra Nevada prescribed fire education program builds on successful workshops held by Lenya-Quinn Davidson, UC ANR fire advisor, throughout the state in 2016 and 2017. Funding has been awarded from Cal Fire for the UC ANR outreach team* to host additional workshops through 2021.

Fifteen workshop days have taken place so far, attended by about 350 people. Participants have included owners of forest, range, farm and recreational lands, as well as staff and volunteers from Fire Safe Councils, Resource Conservation Districts, state and federal agencies, tribes, local government, conservation organizations, farm and forestry associations and consulting companies. Workshops include content on these topics:

- Use of prescribed burns to manage forests and rangelands
- Prescribed burn options, including conducting their own burns, contracting them out or participating in Cal Fire's Vegetation Management Program
- Cal Fire permitting and legal considerations
- Air quality permitting and smoke management
- Fire weather, fire terms and fire behavior
- Burn planning, burn unit preparation
- Tools, safety and personal protective equipment
- Firing techniques, mop up and patrol

Susan Kocher

An educational burn for landowners. Mark Garrett, UCCE Mariposa County; Stacey Frederick, UCB California Fire Science Consortium; Susan Kocher, UCCE Central Sierra; Fadzayi Mashiri, UCCE Mariposa; Rebecca Ozeran, UCCE Fresno; Rob York, UC Berkeley.

All workshops have included an opportunity to participate in live burn training. For more information, visit https://ucanr.edu/sites/forestry/Prescribed_fire/Rx_workshop/.

UC ANR prescribed fire workshops were funded in part by California Climate Investments.

* *Sierra Nevada Prescribed Fire Outreach team*: Rob York, Ariel Roughton, Susie Kocher, Ryan Tompkins, Dan Macon, Scott Oneto, Fadzi Mashiri, Rebecca Ozeran, Lenya Quinn-Davidson, Jeff Stackhouse, Mark Garrett, Sheri Mace.

burn. Because Cal Fire resources were difficult to schedule, the burn had to be planned to occur on a specific day several days in the future. This requirement resulted in a delay of almost 2 weeks after the time when conditions at the burn site were assessed as appropriate, given weather forecasts and the monitoring of fuel and local weather patterns. During this delay, fuels dried out to the point that conditions were on the hot end of the prescription (weather and fuel conditions prescribed in the submitted burn plan).

Four engines, at Cal Fire's expense, each with five firefighters, and two 12-person inmate crews were deployed to help conduct the 17-acre burn. Burn effectiveness was mixed, with undesired torching and killing of some large trees in the canopy. Strong winds occurred shortly following the burn, which required the landowner to devote additional resources for patrolling the area and extinguishing hot spots. Cal Fire was not involved with this postburn activity.

A permit for the burn was never issued to the landowner, so the burn took place with no clarity of responsibilities. The landowner was not given a permit to burn additional acres later in the fall weather window, and then heavy storms shut the burn window. The additional acres were burned in the winter, when a permit was not necessary (fig. 1) but fuel consumption was less effective.

Permits facilitate or constrain

Burn 2 demonstrates the most facilitative permitting approach, with the permit issued for an entire year. Key to the success of this burn and also burn 1 were several factors: the good preburn collaboration between Cal Fire and the landowner; the landowner was allowed to time the burn based on local monitoring of fuels and weather; permit restrictions did not unreasonably constrain needed flexibility (e.g., allowing the night burn); and Cal Fire resources were offered but not required to be present. The permit constraint for burn 1 was the 1-week permit duration; conditions were adequate for only 1 day during the permit window, and the burn was only possible because of the nimbleness of the landowner.

Burn 3 demonstrates some of the permitting constraints that are common for private land burning. During fall 2019 in the central Sierra region — the first opportunity for fall burning since the tragic 2018 wildfire season — the permit window for effective prescribed burns was kept closed. The permit suspension in this region was lifted only well after heavy storms in late November precluded the possibility of any prescription burning. Although strong winds occurred on specific days, just as they inevitably do every year in fall, climatically there was a relatively broad window of opportunity. Some days were too risky to burn, but many more days were in prescription.

Our experience suggests that inconsistency in permitting and narrow or nonexistent time periods for issuing permits are significant barriers to a successful prescribed burn strategy on private land in California. If conditions are appropriate and an adequate burn plan has been developed, then a burn permit should be issued readily. Instead, our experience with burning and conducting outreach throughout the state over the past decade suggests that the closed window at the burn 3 site is a reality that constrains burning on private lands. Landowners who want to protect their property and contribute to solving the wildfire problem currently do not have sufficient opportunities to burn during fall, the optimal time for effective fuel burning.

For more information, explore this UC ANR educational video series, where experts demonstrate the many ways prescribed fire can be used to meet resource management objectives in California's forests, woodlands and grasslands: https://youtube.com/channel/UCiA9f4-WZcFyK9ayh_TkEZQ?view_as=subscriber

Suggestions for permitting changes

To promote discussion at various scales among policy, regulatory and practitioner stakeholder groups, we suggest the following adjustments to the permitting process in order to more effectively facilitate prescribed burns in California:

1. *Let burn permits serve their original purpose* — to give landowners permission to conduct their own burns. Rather than controlling each burn, Cal Fire can focus on offering standby support during burns or assistance with mop-up and patrolling.
2. *Increase permit duration*. Issuing permits for a year provides landowners flexibility in timing burns while still allowing agencies to suspend permits when necessary.
3. *Lift permit suspensions earlier or at more local scales*. Extrapolating fire hazard conditions across large regions or from lower elevations to higher elevations limits prescribed burns unnecessarily. In some cases, prescribed burn prescriptions may be in alignment on north-facing slopes but not on south-facing slopes. Landowners need maximum flexibility to schedule burns, which is only afforded by site-specific decision making.
4. *Track, report and analyze the issuance of permits*. Data on permitting prescribed burns on private lands should be available for objective third-party analyses so that trends can be monitored. If a permit request is denied, a written justification should be given to the landowner, and an appeal process created, so denying permit requests without reason is not the default response to a permit application.
5. *More clearly articulate when permits are required*. Improve permit descriptions for landowners — most, for example, are unaware that winter burning can be done without a permit in many mountain counties of Northern California (fig. 1).

While funding and policy priorities are building important foundations for facilitating more prescribed burns on private land, considerable adjustments to permitting are likely needed before "good fire" can make a difference in reducing wildfire risks in California. CA

The UC National Laboratory collaborative project Smart Practices and Architecture for Prescribed Fires in California (SPARx-CAL) supported this work.

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OUTLOOK

COVID-19 and California farm labor

COVID-19 may accelerate trends in California agriculture toward mechanization and the use of guest-worker programs.

Philip Martin, Professor Emeritus, Department of Agricultural and Resource Economics, UC Davis

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The stay-at-home orders issued in March to slow the spread of COVID-19 exempted essential farmworkers.

This article addresses three major questions: will there be enough farmworkers in California for the remainder of 2020, how can farmworkers be kept safe at work and home, and how will COVID-19 influence key long-term trends linked to farm labor, including rising wages and the growth of mechanization, migrant guest worker programs and imports of fresh produce?

Following the issuance of the stay-at-home orders in March 2020, most farm employers took immediate steps to avoid the introduction and spread of COVID-19. California's Division of Occupational Safety and Health (Cal/OSHA) required employers to update their Injury and Illness Prevention Programs to specify who is responsible for training employees about the virus, investigating illnesses and keeping records. Farm employers began to discourage sick employees from reporting to work, installed more handwashing facilities and implemented physical distancing while working and during breaks.

Many farmworkers already wear hairnets and gloves to enhance food safety, and some employers provided additional personal protective equipment. Transportation providers often made several trips with their buses and vans to allow riders to spread out (Cimini 2020; Hecteman 2020). However, farmworker advocates want employers to do more to protect their employees.

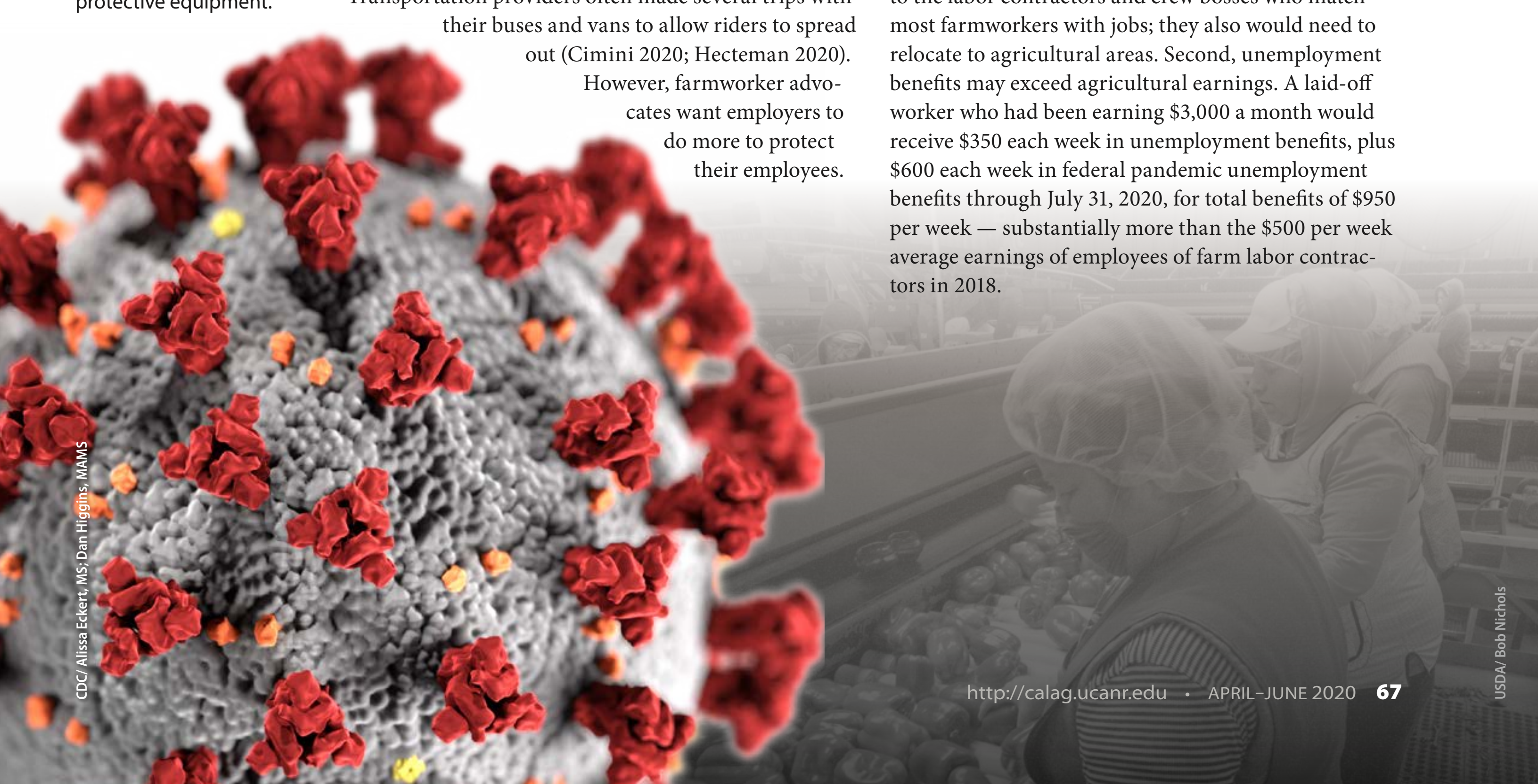
Peak-season farm employment

Will there be enough farmworkers this summer, when California farm employment would ordinarily peak at almost 500,000?

As of early May, nearly two months into the COVID-19 closures, there have been more reports of farmers having to destroy commodities due to market disruptions than complaints of too few farmworkers.

Several factors will influence the availability of farmworkers in summer 2020, including the number of experienced farmworkers who get sick and cannot work. Many experienced farmworkers are not legally authorized to work in the United States and thus are ineligible for safety net benefits such as unemployment insurance, so they are likely to stay in or return to seasonal farm jobs. However, some workers may fall ill or stay home to care for sick family members or children whose schools and child care facilities are closed, reducing the availability of seasonal workers.

There is no absolute shortage of workers — more than 3 million Californians filed for unemployment benefits between mid-March and mid-April 2020 — but few unemployed nonfarm workers are likely to fill seasonal farm jobs. First, many are in cities and lack links to the labor contractors and crew bosses who match most farmworkers with jobs; they also would need to relocate to agricultural areas. Second, unemployment benefits may exceed agricultural earnings. A laid-off worker who had been earning $3,000 a month would receive $350 each week in unemployment benefits, plus $600 each week in federal pandemic unemployment benefits through July 31, 2020, for total benefits of $950 per week — substantially more than the $500 per week average earnings of employees of farm labor contractors in 2018.



Many farmworkers already wear hairnets and gloves to enhance food safety, and in response to the COVID-19 pandemic, some employers have provided additional personal protective equipment.

CDC/ Alissa Eckert, MS; Dan Higgins, MAMS

USDA/ Bob Nichols

All farmworkers, including those who are working in the United States illegally, are eligible for two weeks of paid sick leave of up to $511 a day or $5,110 in total if they were employed at least 30 days and are subject to quarantine orders due to COVID-19, or have been advised to self-quarantine by a health care provider or are experiencing COVID-19 symptoms. Farmworkers are eligible for two-thirds of their regular pay, up to $200 a day or $2,000 total, if they cannot work in order to care for someone with COVID-19 or a child whose child care facility or school is closed. Pending state legislation (AB 2915) would expand state-mandated paid sick leave, provide supplemental hazard pay to farmworkers and offer subsidies to those who care for the children of farmworkers. Some employers worry that the availability of these benefits will reduce the availability of seasonal workers.

Farmworker safety

In April 2020, meatpacking plants emerged as major COVID-19 hotspots, perhaps because they often have thousands of workers in close proximity in refrigerated environments that allow the virus to persist. After state and local governments closed several major plants, President Trump invoked the Defense Production Act to require them to reopen, albeit with improved protections for workers.

Farmworkers also work in close proximity, especially if they are following a conveyor belt in strawberry or lettuce fields to harvest commodities and place them on the belt. Rearranging crews so that some are in front and others behind the machine, or reducing crew sizes to allow physical distancing, can reduce the spread of the virus and productivity.

Limiting the spread of the virus in farmworker communities is another concern. Many farmworkers live in crowded housing; infections from a farm workplace could spread rapidly. Such workplace-originated COVID-19 clusters have not been found in California agriculture to date, but the meatpacking example demonstrates that the virus can spread quickly and reduce workforce availability. Public health officials and NGOs are supplementing employer efforts to educate farmworkers about COVID-19 and how to avoid being infected and transmitting the disease.

Farm labor's changing role

Longer term, COVID-19 is likely to join a list of factors — including the minimum wage rising toward $15 an hour, and overtime pay after eight hours a day or 40 hours a week — that are raising labor costs and accelerating three major trends: labor-saving mechanization, more H-2A guest workers and more imports of labor-intensive commodities.

COVID-19 could spur renewed efforts to mechanize hand tasks in the medium term. Machines are being developed to harvest commodities that range from apples to melons, and growers are changing the layout of orchards and fields to facilitate mechanization. The "tipping point" when machines are cheaper than hand labor varies by commodity, but rising labor costs and declining machinery costs are accelerating the mechanization of canning peaches and raisin grapes.

The virus may further expand the H-2A guest worker program that allows farmers who anticipate labor shortages to be certified to hire guest workers after they try and fail to recruit individuals who are working in the United States (either legally or illegally), and satisfy two other major conditions: provide free housing for guest workers and pay them the Adverse Effect Wage Rate of $14.77 in 2020.

Because of the cost of housing and transportation in the metro counties with most labor-intensive commodities, H-2A labor can cost farm employers as much as $24 per hour, substantially more than the $15 to $17 per hour cost of U.S. farmworkers. Nonetheless, H-2A workers have proven to be highly productive and California farm employers have been hiring them at increasing rates; the number of jobs certified to be filled with H-2A workers rose from 6,000 in FY15 to over 23,000 in FY19.

The final effect of COVID-19 could come via trade. California's agricultural exports are roughly $20 billion annually. Rising wages or reduced availability of farmworkers could further shift the state's crop mix towards highly mechanized export-oriented crops like nuts and encourage the mechanization of hand harvested commodities. The United States currently imports half of its fresh fruit and a third of its fresh vegetables from Mexico, where farm labor costs are 10% of costs, mostly in California. Continued improvements in growing practices in Mexico are extending seasons and elevating quality, driving increased exports; for example, over half of the fresh tomatoes consumed in the United States today are imported from Mexico.

COVID-19 introduces new uncertainties for everyone. For California agriculture, COVID-19's major short-term challenge is to keep farmworkers and their families healthy, while in the longer term COVID-19 promises to accelerate trends that include faster mechanization, more guest workers and rising imports. CA

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CONVERSATION

How is coronavirus affecting agriculture in California?

An interview with UC Cooperative Extension experts about the effect of the coronavirus pandemic on food production.

Online: https://doi.org/10.3733/ca.2020a0018

Richard Smith, UCCE Farm Advisor, Monterey County

Phoebe Gordon, UCCE Farm Advisor, Madera County

Maurice Pitesky, UCCE Assistant Specialist, UC Davis

The coronavirus pandemic has affected every Californian and seems likely to continue doing so for some time. But how is COVID-19 affecting the systems that put food on California's tables — and the world's? For insights into the pandemic's effect on food production, we spoke with UC Cooperative Extension (UCCE) experts in three parts of the state: Richard Smith, UCCE Farm Advisor in Monterey County who specializes in vegetable crop production; Phoebe Gordon, UCCE Farm Advisor in Madera County who specializes in orchard crops; and Maurice Pitesky, UCCE Assistant Specialist at UC Davis who specializes in poultry health and food safety.

How is the coronavirus affecting growers and processors and the overall food system in your area of focus now?

Smith: The vegetable industry here has a couple of components — the retail market to markets such as Walmart, Costco, Safeway and so on, and food service, which is the market selling to restaurants, hotels, schools and institutions. The food service market basically greatly contracted, and growers heavily into food service have been greatly affected. Some may be trying to modify their operations so they can sell to retail, but there are a lot of obstacles — packaging, for example.

Another aspect is labor, and that's a big, evolving issue. I think growers are trying to adjust as best they can. In the field, I see they are spreading people out for social distancing. But workers might live in more dense living quarters, and that's not in the growers' control, and they also do a lot of carpooling. In California processing, so far we don't have the kinds of issues that the meatpacking plants back east have — just mindboggling problems, with thousands of people ill and plants shut down for weeks.

Gordon: For field work, [the level of disruption caused by coronavirus] really depends on what you're doing. If you're looking at irrigation, it tends to be one person, so that's very easily done alone. With pesticides, only a few people are involved so that you won't need to use so much personal protective equipment, which has been hard to source in some cases. But for planting, and for training young orchards, I'm sure they're trying to keep people apart. But it may be hard to do some tasks with just one person, or with people spaced apart, like hand-planting trees. I think things might be tougher when it gets to harvest, especially for something like figs. The picking can be spaced out, but some growers field-pack figs, and then everyone works under one big canopy.

Pitesky: There are two big areas where coronavirus seems to be having an effect. First, we're getting a lot more interest in backyard poultry. That creates some interesting challenges. Some people might eventually realize they don't want the birds and abandon them. And if poor husbandry and biosecurity practices are used, diseases like virulent Newcastle disease can spread from backyards into commercial operations.

The second problem is the challenges in poultry plants and meatpacking plants in general. If processing lines are slowed due to lack of healthy employees or social distancing, everything upstream bottlenecks, which results in less product available commercially and even euthanasia of flocks. Broiler production nationally is down about 15% right now, reflecting those realities. From a worker safety perspective, meat processing plants are designed to reduce foodborne pathogens and facilitate efficient production. However, the aerosols generated from saws, HVAC systems and cool refrigerator temperatures, which are conducive to optimizing food safety, facilitate the transmission of respiratory pathogens like the coronavirus.

Malcolm Hobbs

Workers harvesting grapes in California. On some farms, growers are spreading workers out for social distancing.

How do you expect things to change in the next few months?

Smith: For growers, there's a lot of uncertainty. Growers who have been at this for a while have their buyers and they know how much to plant each week. But with coronavirus, how do you plant for two months from now? One thing we do know is that people need to eat. But there's also been disruption in the marketing chain. You hear about the problems facing stockers at the grocery, but people in the distribution centers can also get sick. The good thing in California is we seem to be very organized in our response — but people are going to be people. They want to get out of their houses and that does not bode well for containment of the virus. How that will affect agriculture? We don't know.

Gordon: Labor could be a problem. It has been hard to get labor in general, particularly skilled labor. Pruning takes skill, operating machinery takes skill. If farmworkers start getting sick, it's going to make labor issues even harder. But in my area, most things dry and store well. Even figs, you can let them drop from the tree and sell them dried. But in fig and almond harvest, workers tend to work somewhat close depending on the task, and the harvest happens over a short time. The longer you leave nuts on the ground, or the longer you leave them on trees, the greater the chances they'll get infested with insects. So growers face the possibility of crop losses due to labor shortages. If you only have a certain number of people trained to use a shaker, and they get sick, what are you going to do? You can train someone else to use a shaker, but an unskilled person can damage trees to the point where they'll die.

Pitesky: Paid sick leave is going to be a huge issue for processing plants. The working culture in most places is that you work sick, in part because of the lack of paid sick leave. We need to view paid sick leave as a public health shield instead of an employee perk. Infrared temperature guns are needed for screening. Finally, testing for virus and antibodies is a big issue. The presence of antibodies due to natural exposure is not definitively shown to prevent disease or reinfection, but if companies can identify workers who have antibodies after natural exposure, these workers may be extremely useful in order to maintain our meat supply. An additional complication is that undocumented workers may be unlikely to know about or utilize resources with respect to testing or antibody testing.

We're a huge exporter of poultry meat — we're the world's largest exporter of broilers, for example — but the export market may soften. Therefore, any slackening in the export market could be redirected domestically to account for any shortages. It's different on the egg side due to shelf-life issues. You can turn eggs into egg powder, for example. But we don't have a ton of capacity in that area to shift production, and the economics of egg powder are not good for farmers.

Broilers on a farm in Texas. If processing lines are slowed due to a lack of healthy employees or social distancing, everything upstream bottlenecks, which results in less product available commercially and even euthanasia of flocks.

Almonds ready for harvest. The longer nuts are left on the ground or on trees, the greater the chances they'll get infested with insects.

What are some ways in which this crisis could result in permanent changes to the food system?

Smith: Good question. I don't know that much will change in the field. There might be changes in distribution, and consumer preferences and so forth.

Gordon: One possibility is that growers may try to become less reliant on human labor where they can, which has already been happening in ag in general. One reason California orchard crops are dominated by nut crops is that nut crops are already pretty mechanized, while the cost of picking fruit is very high because labor is so expensive.

Pitesky: One possibility is to have more and more automation in poultry. There's a lot already, but there is potential for more, and the realities of what is happening in the meat industry with the spread of COVID will speed this type of innovation. For example, when you walk into some milk plants, it's hard to find people in those places. It's moving in that direction in swine and beef. CA

RESEARCH BRIEF

Recent blue oak mortality on Sierra Nevada foothill rangelands may be linked to drought, climate change

UC Cooperative Extension and landowners join forces to probe possible causes of mysterious blue oak mortality in the Sierra foothills.

by Dan Macon, Tracy Schohr, Doug Schmidt and Matteo Garbelotto

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In the course of their everyday activities, like fencing, checking livestock health and assessing forage growth, ranchers are often among the first to observe changes in the landscape.

This research brief describes how rancher observations of blue oak tree mortality in the Sierra Nevada foothills prompted an investigation by UC Cooperative Extension scientists and the rapid identification of likely causes for the tree loss.

During the first week of June 2019, two foothill cattle producers contacted author Macon about an unusual number of dead and dying blue oaks on their annual rangelands in Placer and Nevada counties. Other reports of blue oak mortality emerged in the foothill region, including Butte County, where ranchers and landowners reached out to author Schohr. Reports indicated that diseased or dead oaks of different size classes were intermixed with what appeared to be healthy trees.

Macon conducted a field visit after the calls and observed the following conditions:

- Some trees that had been observed with normal leaf out in the spring appeared to be entirely dead and devoid of leaves by early summer.
- Several trees appeared to be dying from the top down or on individual branches. Many of the leaves on these trees also appeared to be scorched.
- These trees did not appear to have any lesions on their trunks — no wounds or noticeable fungal growth.

A dying blue oak (foreground) in Butte County with healthy blue oaks in the background.

Tracy Schohr

Macon contacted author Garbelotto, who has studied a variety of tree diseases. Garbelotto suggested collecting samples from foothill oaks for analysis. In early August, author Schmidt, who works with Garbelotto in the UC Berkeley Forest Pathology and Mycology Lab (www.matteolab.org), joined Macon to collect samples. Samples collected included leaves with evidence of scorching, soil samples from the base of symptomatic trees and wood samples from the trunks at eight sites in Placer and Yuba counties. Wood was collected at breast height, at the root collar and/or where obvious symptoms such as discoloration and decay were present. No obvious insect activity was detected at any of the sites.

Wood tissue from a blue oak in Placer County with staining associated with developing Botryosphaeria canker.

Samples underwent a series of laboratory tests, including:

- testing soil and fine roots for the presence of pathogens in the genus *Phytophthora*, the cause of sudden oak death;
- plating wood chips on a variety of culture media and on carrot disks to identify a broad range of pathogens, including *Fusaria*, *Raffaelea* and *Ceratocystis* spp., that are known to cause oak wilt diseases;
- performing DNA analysis (www.wooddecay.org) on wood samples designed to identify serious tree pathogens, including species of *Armillaria, Ganoderma, Hericium, Heterobasidion, Inonotus/ Phellinus, Laetiporus, Perenniporia, Pleurotus, Schizophyllum, Stereum* and *Trametes*, among others (Nicolotti 2009); and
- testing scorched leaves and associated twigs (tests were performed by Dr. Rodrigo Almeida, UC Berkeley) for the presence of the bacterium *Xylella fastidiosa*, known to cause disease in oaks and other tree species.

All tests were negative, except for direct culturing of wood chips at breast height resulting in the growth of *Botryosphaeria* (synonym *Diplodia*) spp., specifically *Botryosphaeria corticola* and *B. dothidea*. These two species are native to California, and have been known to cause a lethal canker disease in some California oak species. Susceptibility to *Diplodia* is known to be genetically regulated in oak species, meaning that some families are more susceptible than others. Susceptibility can be greatly enhanced by predisposing factors, such as drought and infection by other primary pathogens, often root infection by *Phytophthora* species.

Based on the testing results, the working hypotheses is that recent drought events and overall climate change is causing an increased and widespread susceptibility of blue oaks to Botryosphaeria oak canker caused by *Diplodia corticola* and other *Diplodia* spieces. An alternative hypothesis is that a yet unknown pathogen may be increasing the susceptibility of blue oak to Botryosphaeria oak canker disease.

Additionally, the interaction between genetic driven susceptibility and limiting ecological conditions may explain the rather haphazard distribution of diseased trees, which do not appear to be clustered next to each other or to be prevalent in specific and similar topographic conditions (e.g., more abundant in draws, riparian habitats, ridges, etc.).

Interestingly, blue oak is not yet an official host for these two pathogens in the U.S. Department of Agriculture fungus-host database (https://nt.ars-grin.gov/fungaldatabases/fungushost/FungusHost.cfm). Hence, the observed infections may be the result either of a recent host jump or of an emergence of diseases once rare in this host.

In both cases, one of the possible outcomes of the observed mortality is a decrease in size and genetic diversity of populations of blue oaks in the Sierra Nevada foothills, with cascading effects on biodiversity and on the quality of pastures in associated rangelands.

In the spring of 2020, the UC Berkeley Forest Pathology Laboratory will be working with local UC Cooperative Extension agents at the county level to officially confirm the status of blue oaks as hosts of *D. corticola* and *D. dothidea* through controlled inoculation experiments.

D. Macon is UC Cooperative Extension (UCCE) Livestock and Natural Resources Advisor in Placer, Nevada, Sutter and Yuba counties; T. Schohr is UCCE Livestock and Natural Resources Advisor in Butte, Plumas and Sierra counties; D. Schmidt is Research Associate and Lab Manager, and M. Garbelotto is UCCE Specialist and Adjunct Associate Professor in the UC Berkeley Forest Pathology Laboratory.

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RESEARCH ARTICLE

Boons or boondoggles: An assessment of the Salton Sea water importation options

Importing ocean water from the Sea of Cortés to the Salton Sea would be substantially more expensive than leasing agricultural water from the Imperial Valley and transferring it to the Salton Sea.

by Lucia Levers, S. Drew Story and Kurt Schwabe

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The second-lowest point in the United States, an ancient seabed, was flooded at the turn of the 20th century by Colorado River water being brought into California, forming the Salton Sea. Named La Palma de la Mano de Dios (the Palm of the Hand of God) by pre-statehood Mexicans (Cross and Signius Larson 1935), the sink has since continuously remained submerged. The Salton Sea exists today due to agricultural drainage water, the vast majority of which flows from the farmlands of the Imperial Valley — the fingers of la Mano. During the 20th century, California and northern México lost almost all of their wetlands, leaving the Salton Sea an incongruous combination of a drainage water sink and critical habitat for millions of migratory birds and several endemic, endangered and sensitive species.

Critical habitat or not, as a terminal lake, the Sea has significantly deteriorated due to the declining quality and quantity of its inflows. Nearly 85% of the inflows are from agricultural drainage, which brings with it fertilizers, pesticides and salts that have caused a salinity level intolerable to most fish (Schwabe et al. 2008). In 2003, a federal-state-local agreement — the Quantification Settlement Agreement — formalized an agriculture-to-urban water transfer of Colorado River water from the Imperial Irrigation District (IID) to the San Diego County Water Authority (SDCWA). The agreement also mandated that the Imperial Irrigation District send additional water to the Salton Sea — through 2017 — from its several million acre-feet of Colorado River water entitlement to counter the decreases in Salton Sea inflow that would arise from this transfer.

Abstract

Several ways to address the looming ecological disaster that is the Salton Sea have been proposed — including water importation. Here we considered two options: importing ocean water from the Sea of Cortés and leasing water from agricultural users in the Imperial Valley. We estimated the monetary costs for importing Sea of Cortés water to the Salton Sea and compared that with the costs of transferring water from agricultural users to the Salton Sea. We found that leasing water from agriculture would be substantially cheaper than ocean water imports. Additionally, all the infrastructure for leasing water from growers exists, which means water transfers could begin immediately. That is important given the present and increasing environmental and human health damages that are occurring at the Salton Sea.

A heron in flight above foraging gulls. Due to the Salton Sea's decreasing volume and increasing salinity levels, all but one fish species has died off and the diversity of waterbirds has been in decline. Transferring water from agricultural users to the Salton Sea is a potential solution for preventing future habitat loss.

Barbara Barry

This "mitigation" water was an attempt to buy time to develop solutions for the Salton Sea and avert damages caused by decreased volume and increased salinization. However, solutions were delayed, the Sea's volume fell and its salinity concentrations rose from 2003 through 2017. Since the cessation of mitigation water at the end of 2017, the decline in the quality and quantity of the inflows to the Sea has accelerated, furthering concerns over environmental and human health damages and culminating in a recent unanimous emergency declaration by the county's supervisory board (Wilson 2019a).

One category of damages is habitat loss — all but one fish species has died off in the Salton Sea's main body. This sole fish species, a hybrid tilapia, serves as the primary food source for migratory bird populations (Bradley and Yanega 2017). Unfortunately, winter 2019 fish surveys revealed few remaining tilapia and, consequently, extremely low bird counts (Wilson 2019b). If the current salinity trends continue, only brine shrimp and brine flies will survive. These creatures tolerate quite high salinity, but their upper limit of tolerance will be surpassed in roughly 15 years (Bradley 2018). At that point, algal and microbial populations will grow exponentially, leaving the Sea biologically active but incapable of supporting its endangered, threatened and migratory species (Bradley 2018; Cohen and Hyun 2006).

Human health damages are another significant concern. As the Sea recedes, the former sea bottom — that is, the playa — is exposed. The playa is a source of airborne particulates, a precursor/exacerbator of asthma and other lung conditions, which is particularly concerning to the lower-income communities surrounding the Salton Sea, of whom a substantial portion have Latinx and/or Native American heritage (Abrams 2017; Johnson 2019a, 2019b; Marshall 2017).

Combining the environmental and health costs with decreased property and recreational values, total damages are estimated to be upward of $70 billion over 30 years, which does not include damages to the people in México who live within the Salton Sea airshed (Cohen 2014; Schwabe and Baerenklau 2007).

A tilapia carcass. Hybrid tilapia are the main fish in the Salton Sea. While salt tolerant, even they are reaching their salinity limit, with numbers declining precipitously in recent years.

"Fixing" the Sea will require reversing the habitat loss and playa exposure trends, which means addressing the quantity and quality of water in the Salton Sea, and understanding that quality is influenced by inflow volume. A central and controversial issue is where the water is going to come from to maintain the Sea. One proposal that the state is considering — the Cortés-to-Salton option — consists of importing ocean water from the Sea of Cortés (also known as the Gulf of California). An alternative option, which builds upon the over 30-year history of agriculture-to-urban transfers in the region as well as the Quantification Settlement Agreement's mitigation water transfer precedent, is an agriculture-to-environment water transfer, described in Levers et al. (2019).

Higher inflows from either of these options would decrease playa exposure and the associated human health impacts. The Salton Sea is a terminal lake, which means that eventually the rise in salinity will result in a dead sea. As such, a permanent solution to reverse environmental, health and recreational damages will require some machinations beyond simply bringing in more water. However, inflows could also be used with habitat and dust suppression projects, even just in the short term, reversing past and preventing future habitat loss and playa exposure.

We evaluated the costs associated with two options for increasing inflows: ocean water imports, and agriculture-to-environment voluntary, albeit compensated, water transfers. While an understanding of the respective and relative costs of each option is important in informing policy — the goal of this paper — cost is only one of the factors to consider. Three other factors are the legal and political issues surrounding each option, their respective benefits, and their potential environmental damages.

Legal and political issues ultimately determine proposal feasibility and possible implementation. Both options — ocean water imports and agriculture-to-environment water transfers — will face significant political and legal challenges. In terms of the respective benefits of the two options, our analysis focuses on comparing the costs of different options to bring water to the Sea, a question raised in the Salton Sea 10-Year Plan (CNRA 2017a). As such, the benefits of these solutions to the state's charge of importing water to the Salton Sea are likely to be very similar. In terms of environmental damages, while ocean water importation may offer an opportunity to further address regional water security in the Southwest, it also opens up the possibility of significant environmental impacts to the Sea of Cortés. Clearly, there is a different array of benefits associated with such a broader system, but such an analysis goes beyond the more targeted scope of this paper.

Ocean water imports

The idea to build a pipeline system to import ocean water to the Salton Sea has been around since at least the 1970s (Goldsmith 1971; Goolsby 2015). The two alternatives for uptake locations are the Pacific Ocean near San Diego and the Sea of Cortés in México. The U.S. coastline is closer than the Sea of Cortés, approximately 100 miles compared to 160 miles, respectively, from the Salton Sea. However, the elevation of the Peninsular Ranges, west of the Salton Sea, would complicate the journey of water pumped from the Pacific. So, the Mexican route has been singled out as easier — that is, cheaper —even though it would necessitate an international pipeline (Cohen 2015).

Any pipeline importing untreated ocean water into the Salton Sea would fundamentally impact its habitat, keeping water levels high but concentrating salts. Some proposals suggest incorporating expensive desalinization and/or purification systems to deal with salinity concerns (CNRA 2018a, 2018b). A return pipeline could be built to export salts to the Sea of Cortés, but a pipeline bringing water from the Salton Sea to the Sea of Cortés would also transport agricultural pollutants, of particular concern as parts of the Sea of Cortés are on the UNESCO World Heritage List, including the Islas de Golfo de California Biosphere Reserve at the northern edge of the Sea of Cortés. The Sea of Cortés is critical habitat for diverse endemic and endangered species, including the most critically endangered marine mammal in the world, the vaquita (United Nations 2019). Despite the pitfalls, the sheer volume of water available makes the Cortés-to-Salton option tempting for many.

In 2017, the California Natural Resources Agency requested proposals for ocean water importation (CNRA 2017b). They received 11 responses in 2018. A concern with the proposals was the lack of detailed cost information (Metz 2018). While three proposals provided some cost information during a public workshop (CNRA 2018b), the proposals have not been independently assessed for accuracy or feasibility. However, they consistently suggest initial investment costs in the billions of dollars and annual maintenance costs in the millions. Given the lack of detailed cost information, we used cost estimates commissioned by the Salton Sea Authority in 2002 indexed to 2018 dollars (Tetra Tech 2013).

Agriculture water transfers

The alternative to ocean water importation is an agriculture water use transfer program. Such programs have existed in the region for more than 30 years, including an agreement between the Imperial Irrigation District (IID) and the Metropolitan Water District (MWD) to transfer approximately 100 thousand acre-feet (TAF) of agriculture water to urban uses (the earliest example was in 1988); an agreement between the Metropolitan Water District and the Palo Verde Irrigation District for approximately another 100 TAF of agriculture water; and the transfers outlined in the Quantification Settlement Agreement between the Imperial Irrigation District and the San Diego County Water Authority (SDCWA), culminating in 200 TAF of agriculture water being transferred to the San Diego County Water Authority (IID, SDCWA 2003; U.S. Bureau of Reclamation 2018). The transferred water is "generated" by reducing both conveyance losses through lining canals and field-level water application through land fallowing and improving irrigation system efficiency. The transfers have mostly consisted of agriculture-to-urban transfers, with some agriculture-to-agriculture transfers.

This water transfer history, including that of the Quantification Settlement Agreement, motivated the schemes described by Levers et al. (2019) to transfer water from Imperial Valley agricultural users to the Salton Sea. Levers et al. (2019) proposed three possible programs to allow more Colorado River water to flow to the Sea: growers would be paid for fallowing fields, implementing less water-intensive irrigation methods, or direct leasing. Direct leasing left the "how" of reducing their water use to the growers (e.g., through fallowing, irrigation improvements or simply deficit irrigation). Using a biophysical model coupled with an economic model, Levers et al. (2019) estimated Salton Sea inflows — transferred inflows, drainage flows and tailwater runoff — and the opportunity costs to growers (i.e., foregone profits) under the different programs.

Levers et al. (2019) found that the direct lease program was the lowest-cost method for purchasing water, but as it caused the greatest reduction in drainage and tailwater of the three programs, it was not the most efficient in generating total Sea inflows. Land fallowing was found to generate the highest total inflows to the Salton Sea at the lowest cost. Irrigation efficiency improvements were not only the most expensive option but also the most limiting in generating total overall flows since, from a hydrological perspective, water savings were achieved through reduced evaporation only. Overall, their results suggested that a substantial amount of water could be purchased from agricultural users for a relatively low cost, particularly through fallowing and direct leasing.

Costs: Ocean water imports

To estimate costs and inflows for the Cortés-to-Salton option, we used engineering and cost estimates provided to the Salton Sea Authority by Tetra Tech (Tetra Tech 2013). These costs include capital cost estimates to build the pipeline(s) to import the water, taking into account pipe diameter, pipeline length, intake structures and energy for pumping. We assumed a round-trip length of 357 miles (Tetra Tech 2013), which would put the pipeline intakes (and outputs) well south of the particularly ecologically sensitive area at the northern edge

A lone nest, likely belonging to a cormorant pair. Double-crested cormorants used to nest by the thousands at the Salton Sea, but no longer.

Barbara Barry

of the Sea of Cortés. The route to the Sea of Cortés does not involve a mountain range, but the Salton Sea is 250 feet below sea level and the route rises 270 feet above sea level before dropping down to the ocean, so significant pumping would be necessary.

We estimated the costs for importing 250 TAF per year and 500 TAF per year. We chose these values because they are physically feasible and within the range needed to increase the Salton Sea's water level to midcentury levels. Exporting water back to the Sea of Cortés would more than double the costs. We calculated construction and yearly maintenance and energy costs. Initial costs would be between $3.3 billion (for import only of 250 TAF) and $13.3 billion (for import and export of 500 TAF); annual operations, maintenance, energy and repair costs would be between $6 and $42 million, respectively (table 1).

These cost estimates are of similar magnitudes to the estimates in the three Cortés-to-Salton proposals submitted to the California Natural Resources Agency that included cost information. It was difficult to compare the three proposals as their potential services differed: two included a desalinization component, and one included an export pipeline (CNRA 2018a).

TABLE 1. Cortés-to-Salton costs and Salton Sea inflows*

To import this much water (TAF) …	250	500
Construction cost ($ million)†		
Import only	$3,331	$6,662
Import and export	$6,662	$13,324
OMER costs ($ million)‡		
Import only	$6	$12
Import and export	$21	$42
Salton Sea yearly inflows (TAF)	1,097	1,347

* Construction and OMER‡ costs adapted from Tetra Tech (2013), with dollar values converted from 2002 to 2018 dollars (values in Tetra Tech [2013] were reported in 2002 dollars). Importation of 250 TAF requires one 12-foot-diameter pipe; 500 TAF requires two 12-foot-diameter pipes. Inflows include drainage and tailwater, assumed as a baseline of 847 KAF (Levers et al. 2019).

† Construction cost at $9.3 million per mile per pipeline, for 357 miles. Per Tetra Tech (2013), a pipeline of this size could import 230 TAF/export 225 TAF, less than the 250 TAF used here. Additionally, construction cost does not include ancillary capital costs such as for increased energy generation capacity or intake structures. As such, the estimates above may be an underestimate.

‡ Annual operations, maintenance, energy and repair costs.

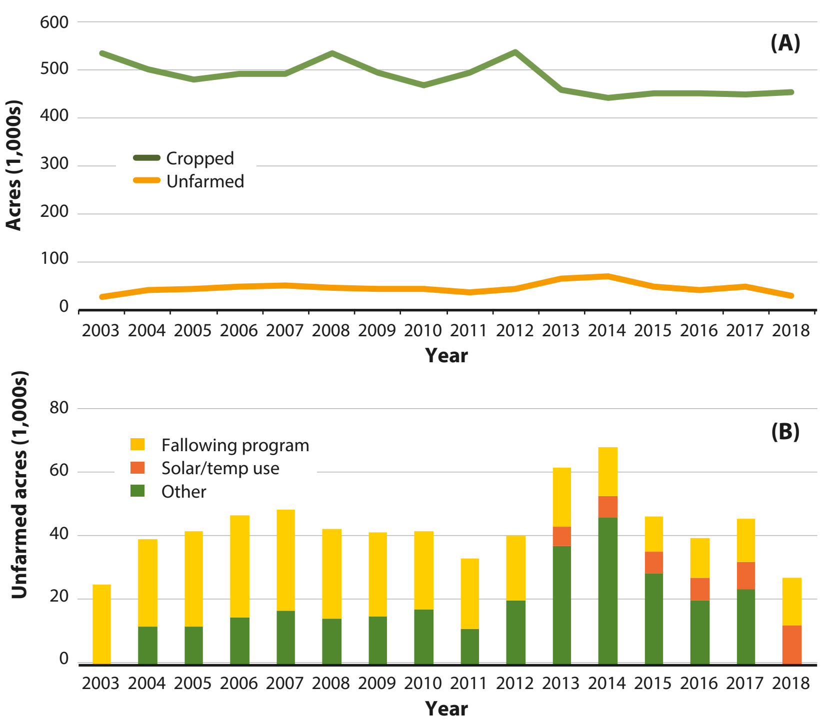

FIG. 1. Reported cropped acreage and unfarmed acreage (A) in the Imperial Irrigation District 2003–2018, and (B) the unfarmed acreage in the district's fallowing program, in solar production or temporary conversion, or other use. Adapted from IID 2005, 2008, 2012, 2016, 2019b.

Costs: Agriculture water transfers

For the agriculture-to-environment option, we focused on the fallowing and direct leasing options from Levers et al. (2019), using their model to estimate the costs to generate equivalent volumes of water imports. A central element of the Levers et al. (2019) study was the use of voluntary, albeit compensated, programs in the Imperial Irrigation District that growers could participate in depending on their crop profitability. Since the model did not account for heterogeneity within a crop type, at particular price points an entire crop might opt into the program. This made it difficult to generate a specific volume of water. Additionally, and following guidelines from the California Department of Water Resources, Levers et al. limited fallowing to 20% of baseline acreage for each crop due to concerns over third-party effects from reduced agricultural production that might arise from transfers.

In the Imperial Irrigation District, 20% of the acreage of the two crops most likely to be fallowed due to their low profit margins, alfalfa and sudangrass, is about 45,000 acres. For comparison, cropped area in the Imperial Irrigation District from 2003 to 2018 ranged from 440,000 to 540,000 acres (fig. 1). Unfarmed, but farmable, area was 25,000 to 70,000 acres — a good portion of that due to the Quantification Settlement Agreement–induced fallowing program, which ended in 2017 (IID 2019a). Unfarmed acreage in 2018 was the lowest it had been since 2003, over 40,000 acres lower than its highest level, in 2014.

Since the 20% limit on fallowing acreage affects the amount of water that can be generated from fallowing, and consequently the comparisons that are possible with the ocean water imports option, we increased the limit on fallowed alfalfa acreage to 50% of baseline acreage. The 50% limit increased the potential to fallow over 110,000 acres, which, if implemented, would likely lead to greater third-party (e.g., regional employment and income) effects. The degree to which more fallowing leads to more significant third-party effects depends on multiple factors, including the level of unemployment in the region, the strength of the linkages between the crop that is fallowed and upstream and downstream businesses, and how much of the compensation payment stays within the region. We did not evaluate these effects.

We estimated annualized costs and total inflows (leased plus drainage and tailwater inflows) for a variety of scenarios. Table 2 gives purchased water volumes ranging from 200 TAF to 850 TAF. These scenarios result in total inflows ranging from about 870 to about 1,450 TAF. The annualized costs (mainly the opportunity cost to growers) range from $6 to $69 million, depending on the desired volume of purchased water. As the conveyance system is already in place, there are no initial construction costs.

It is important to remember that growers are compensated completely for lost agricultural profits from enrolling acreage in the leasing programs. Because of the relative profitability of vegetable (also called garden) crops versus field crops, the least-cost solution consists of fallowing acreages of alfalfa and sudangrass rather than vegetable acreage. Given that the reduction in production represents only a small fraction of U.S. total alfalfa and sudangrass production (Levers et al. 2019), there are likely no market or price effects.

Options evaluation

As shown in table 3, to achieve over a million acre-feet of inflows annually into the Sea — slightly lower than the long-term historic average — the Cortés-to-Salton option would cost between $3.3 and $6.7 billion initially plus $6 to $21 million per year. The costs to import a similar quantity of water if purchased from agricultural users would be around $28 million per year. For 1.3 million acre-feet, the Cortés-to-Salton option would run between $6.7 to $13.3 billion initially plus $12 to $42 million per year; for the agriculture-to-environment option, the cost would be approximately $62 million annually.

TABLE 2. Agriculture-to-environment costs and Salton Sea inflows

To purchase this much water (TAF) …	≥ 200	≥ 350	≥ 400	≥ 650	≥ 750	≥ 850
using this scheme	Direct*	Fallowing*	Direct*	Direct*	Fallowing†	Fallowing‡
and this water price ($/acre-foot)	$30	$79	$88	$89	$79	$79
Total annual cost ($ million)§	6	28	37	59	62	69
Lost agricultural profit	2.4	1	16	22	2	2
Extra water profit	3.6	27	21	37	61	67
Total inflows (TAF)	867	1,089	943	1,130	1,382	1,447
Purchased	201	357	422	660	786	877
Drainage	284	375	175	166	312	303
Tailwater	383	356	345	305	283	268

* Fallowing limited to 20%, as in Levers et al. (2019).
† Fallowing of alfalfa limited to 50%; other crops to 20%.
‡ Fallowing of alfalfa and sudangrass limited to 50%; other crops to 20%. Rounding results in lost agricultural profit and water profit appearing to not sum to total cost.
§ Total costs are comprised of the lost profits from agricultural production that must be replaced for growers to break even and the added profit of the growers who would have opted into the program at a lower price.

TABLE 3. Comparison of the Cortés-to-Salton and agriculture-to-environment options

To achieve this total inflow (TAF) …	1,000			1,300		
with this option…	Cortés-to-Salton		Agriculture-to-environment*	Cortés-to-Salton		Agriculture-to-environment†
	Import	Import and export		Import	Import and export	
Costs ($ million)						
Construction	3,331	6,662	0	6,662	13,324	0
OMER costs‡	6	21	28	12	42	62
Land costs	Unknown	Unknown	0	Unknown	Unknown	0
Annualized costs§	223	454	28	446	908	62
Inflows (TAF)	1,097	1,097	1,089	1,347	1,347	1,382
Purchased	250	250	357	500	500	786
Drainage/tailwater	847	847	731	847	847	595

* Fallowing limited to 20%, as in Levers et al. (2019).
† Fallowing of alfalfa limited to 50%; other crops to 20%.
‡ Annual operations, maintenance, energy and repair costs.
§ Sum of amortized construction cost (interest rate is 5%, lifespan is 30 years) and OMER costs.

A gull carcass. Several species of gulls use the Salton Sea, including the California gull (the state bird of Utah) and the yellow-footed gull, whose only frequented U.S. location is the Sea.

It is difficult to compare these sets of costs as they are not fully annualized. However, if we make a few assumptions for interest rate and pipeline lifespan, we estimate the annualized costs for the pipeline to range from $223 to $908 million (table 3), which does not include any land costs. Again, the comparative costs for the agriculture-to-environment option are between $28 and $62 million, respectively.

Of course, there is uncertainty with these values. The values estimated for the agriculture-to-environment option assume midlevel crop prices representative of prices over the past decade. Lower crop prices would lower the lease price and program costs, while higher crop prices would increase both. However, the cost differences between the Cortés-to-Salton and agriculture-to-environment options are significant. To import 1 million acre-feet (with no exportation), the initial costs of the Cortés-to-Salton option is over 100 times the annual cost of the agriculture-to-environment option — this would double if water exports were implemented.

In addition to uncertainty, it also is important to emphasize that we did not estimate the transaction costs associated with either the Cortés-to-Salton option or the agriculture-to-environment option. For either one, a formal agreement would have to be enacted — something akin to the Quantification Settlement Agreement for the agriculture-to-environment option and an international agreement for the Cortés-to-Salton option. Such agreements, along with their implementation, may incur significant transaction costs. To the extent the transaction costs between these options would be significantly different, their inclusion might influence the conclusions of our research.

Since good economic decisions are not made on costs alone, public benefits and nonmarket values need also to be considered. Ocean water importation may offer more benefits in the area of water scarcity and, depending on treatment, water quality. Many of the proposals included desalinization efforts and water supply augmentation opportunities that are intended to benefit the region through reducing overall water scarcity. As the Salton Sea is a terminal lake, any long-run solution needs to address salinization. Ocean water importation without treatment may exacerbate the rate of salinization of the Sea (as ocean water is more saline than drainage/tailwater), and it may impact the biota given the Sea is not a marine environment, potentially causing more environmental damages. Additionally, potential environmental damages to the fragile Sea of Cortés are not minute and would need to be considered. While expensive desalinization would not address damages to the Sea of Cortés, it could help address these other issues and — as highlighted in many of the ocean importation proposals — offer the region another water supply source to address regional water scarcity that will only worsen under climate change and population growth.

As the Salton Sea does not exist in a vacuum, consideration of proposals to address regional water scarcity should include a broader and geographically wider set of stakeholders, how the costs might be apportioned across a larger set of potential beneficiaries, and comparisons with other possible regional solutions, including possibly ocean water importation from Californian waters. Any adjustments to water use in the increasingly populated Southwest warrant a more comprehensive discussion.

In terms of expediency, the damages associated with ecosystem deterioration and declining public health require both a long-term sustainable solution but also immediate attention. So even if the calculus surrounding ocean water importation from a regional perspective suggested benefits exceed costs, an analysis that has yet to be performed in a rigorous fashion, such a solution would be a decade in the making. Concerns about delay have been expressed by biologists, public health experts and public officials. In 2018, the then Assistant Secretary for Salton Sea Policy, Bruce Wilcox, said of the ocean importation option (Metz 2018): “We don’t want to delay building habitat and air quality that’s needed at the Salton Sea to spend two years evaluating something that may work but also may not.”

While Assistant Secretary Wilcox was not dismissing the water importation option, he was likely highlighting the timeline concerns. A successful ocean water importation project would take many years of construction — and that would start only after an international agreement was in effect. While an international agreement would not be necessary for the agriculture-to-environment option, another multilevel agreement like the Quantification Settlement Agreement surely would be required, a challenging task given the current system of water rights in California, past and ongoing agreements surrounding the use of Colorado River water and a nearly two-decades-long drought impacting the Colorado River. Furthermore, considering that nearly all previous water transfers in the region have consisted of agriculture-to-urban transfers, which is not surprising given the high prices surrounding urban water use, it is likely that an agreement to use agricultural water for an environmental purpose would be contentious.

Boons or boondoggles

The goal of this paper has been to highlight the cost differences between two possible solutions to bring water to the Salton Sea. Both likely involve significant legal and regulatory issues, a discussion that goes beyond the purpose of this article. The Cortés-to-Salton solution is expensive, both in terms of its development costs as well as the ecosystem and public health damages — damages that may be irreversible — that will continue to occur over the ensuing years until completion. The degree to which the agriculture-to-environment solution could serve as an effective long-run solution requires a more systematic analysis of the public costs and benefits of both it and alternative solutions and involvement with a wider range of stakeholders. Yet, an agriculture-to-environment water transfer may be an attractive short-run option given the cost, the fact that all the physical infrastructure to implement it is in place, and its flexibility, which allows it to be used in conjunction with smaller-scale Salton Sea dust suppression and habitat projects.

So in considering the question whether ocean water importation is a boon or boondoggle, the answer is somewhat indeterminate and depends on the purpose of the importation. If importation is primarily couched as a means to save the Salton Sea, such a scheme certainly seems to warrant the "boondoggle" moniker. Yet if ocean importation is seen as a possible long-run solution to regional water scarcity in the Southwest with the Salton Sea being a potential beneficiary, it is not so easy to assign either label — boon or boondoggle — without further analyses that consider a larger set of stakeholders and factors over a much broader region and timeline.

If importation is primarily couched as a means to save the Salton Sea, such a scheme certainly seems to warrant the "boondoggle" moniker.

L. Levers is Research Associate, Water Resources Center, University of Minnesota, Twin Cities; S.D. Story is Congressional Science and Engineering Fellow, American Association for the Advancement of Science, Washington, D.C.; and K. Schwabe is Professor and Associate Dean, School of Public Policy, UC Riverside, and Adjunct Professor, Center for Global Food and Resources, Adelaide University, South Australia.

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RESEARCH ARTICLE

Traditional market-animal projects positively influence 4-H enrollment

Linear modeling techniques suggest that beef, sheep and swine projects all contribute to increased county 4-H enrollment, though the degree of increase varies.

by Josh Davy, Larry Forero, Nathan Caeton, Ashton Hubbard and Allison Gross

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Abstract

The 4-H Youth Development Program (4-H) teaches life skills. An understanding of the factors that drive participation in the California 4-H program can help the organization target its efforts to increase enrollment and benefit more California youth as they move toward adulthood. 4-H has long been associated with market-animal projects, but the effect of these projects on enrollment is not known. In this study, 7 years' worth of enrollment data from 27 Northern California counties was evaluated with linear modeling techniques to determine the impact of market-animal projects (beef, sheep and swine) on program participation. The analysis demonstrated that market-animal projects produce significant, positive effects on enrollment. Each beef project contributed nearly four new members to county enrollment; a single sheep project yielded just over two new members; and two new swine projects produced a single new enrollment. Region and population density influenced membership but year within the study period did not. These results demonstrate the multiplicative effect of beef and sheep projects on county 4-H enrollment.

The positive impact on youth development of the 4-H Youth Development Program (4-H) is well documented (Ladewig and Thomas 1987). Participation in the program can help discourage risky and unhealthy behavior (Jelicic et al. 2007; Schwartz et al. 2010). Alumni of the program have indicated that 4-H positively affected their leadership and communication skills and made them more responsible (Radhakrishna and Doamekpor 2009). Published research indicates that, in Shasta and Trinity counties, more than 90% of members developed the life skills of sharing, communicating, planning and organizing, goal-setting, keeping records, taking responsibility and self-motivation (Forero et al. 2009). Research suggests that the program can lead young people to maintain a positive image of agriculture (Croom and Flowers 2001) and can influence their college enrollment decisions (Rayfield et al. 2013; Torres and Wildman 2001). Once program alumni begin college, the civic and leadership skills they gained in the program can transfer to leadership roles in college (Park and Dyer 2005) — and, later, to leadership roles in their adult careers (Cano and Bankston 1992; Hoover et al. 2007).

According to the researchers, traditional 4-H livestock projects play a critical role in encouraging youth to participate in the 4-H Youth Development Program.

Elena Zhukova

Some research hints that member interest in animals could be linked to increased 4-H enrollment (Esters and Bowen 2004) and that skills learned in market-animal projects help youth both at school and at home as they become more dependable and confident (Rusk et al. 2003). Additionally, 4-H alumni have indicated that involvement in livestock projects had a positive impact on the development of life skills (Ward 1996).

Though animal projects are highly visible and beneficial, it is not clear how such projects influence enrollment. Attempts to understand such dynamics can prove confounding because enrollment can potentially be affected by factors like fluctuations in the number of eligible youth, local population density or the geographic regions where youth reside.

Because animal projects are among the most recognized components of 4-H, this study examined the importance of beef, sheep and swine projects in relation to total 4-H enrollment. Previous research into 4-H recruitment and retention has drawn on survey information to produce data that describes drivers of 4-H interest — or, specifically, describes what participants like or dislike about the program (Gliem and Gliem 2000; Wingenbach et al. 1999). Much of this work, however, produces subjective results that, instead of contributing to enrollment and retention, prepare program managers to deliver the program in meeting settings.

While improving program delivery is important, the main hypothesis presented here is that encouraging market-animal projects in Northern California could increase overall 4-H enrollment at greater than a 1:1 rate (i.e., adding one market-animal project could increase enrollment by more than one youth participant). This research accounts for variables, beyond market-animal projects, that might reasonably be thought to influence total enrollment. These variables include year, region and population density. Taking these variables into account, a secondary hypothesis is that total enrollment varies naturally from year to year (trends in time), that differences in location (space) influence total enrollment and that population density (people per square mile) affects the pool of potential members and resulting enrollment. The secondary hypothesis seems very practical — but since this type of modeling has not previously been conducted with 4-H enrollment data, no known research-based reference can prove its validity.

County enrollment data over 7 years was used to determine how participation in beef, swine and sheep projects affected enrollment in Northern California. This was accomplished with a six-factor (with interactions) general linear model that included the three livestock species, year, region and population density to determine if, for each factor, a significant causal relationship with total enrollment existed. The novelty of this approach is that it allows the influences of all the factors to be simultaneously considered, resulting in a specific interpretation of each individual factor's contribution to enrollment, independent of the contributions of the others. Because of this, the model can determine how many new 4-H memberships are produced by a new market-animal project — regardless of year, location or population density.

Methods

Animal project data collection

This research focused on 27 Northern California counties — rural, suburban and urban. The 27 counties display considerable diversity in population and geography and together they constitute a sample of ample size for investigating the importance of market-animal projects in 4-H enrollment. Data from the 4-H Online enrollment system was accessed to determine each county's annual level of participation in species-specific livestock projects and its total annual enrollment.

The 4-H program's oldest mode of delivery is the community club, an organized group of at least five young people drawn from at least three different families and led by at least two adult volunteers. Potential members who wish to join the community club program choose a club at the time they enroll in 4-H. They typically choose a club located in the area where they reside. Once they have enrolled, they choose to participate in one or more projects — such as livestock, archery or photography — that the club offers. Members are free to participate in as many projects as they like, but they must choose to participate in at least one. Members are required to attend both community club meetings and project meetings. Typically, projects facilitate in-depth learning about a particular subject while community club meetings provide opportunities for leadership and community service. Extension staff, using 4-H Online, collect and retain county data about projects and use it to prepare an annual, federally required report known as an ES-237 Activity Count.

In this research, when data derived from 4-H Online was used to determine the number of species-specific livestock projects conducted in each county, noncategorized projects (e.g., "sheep") and categorized projects (e.g., "market sheep") were — to account for categorization errors that may have occurred when individual families enrolled in 4-H at the local level

To determine how participation in beef, swine and sheep projects affected 4-H enrollment in Northern California, the authors used a six-factor general linear model that included the three livestock species, year, region and population.

— both included in the totals. The same approach was taken for each of the three livestock categories. Duplicate records were removed from the gross total membership reported for each year to arrive at the net totals. To make the research as current as possible, while still covering a period long enough to allow for accurate identification of trends, data was collected over an annual enrollment period of 7 years, from 2008 to 2015.

Region

In an effort to limit degrees of freedom in the model's categorical variables, counties were categorized as belonging to five distinct Northern California regions (fig. 1), which were coded as one through five. The regions are: (1) northern coastal counties, (2) northern mountain counties, (3) northern valley counties, (4) southern valley and coastal counties and (5) southeastern foothill/mountain counties.

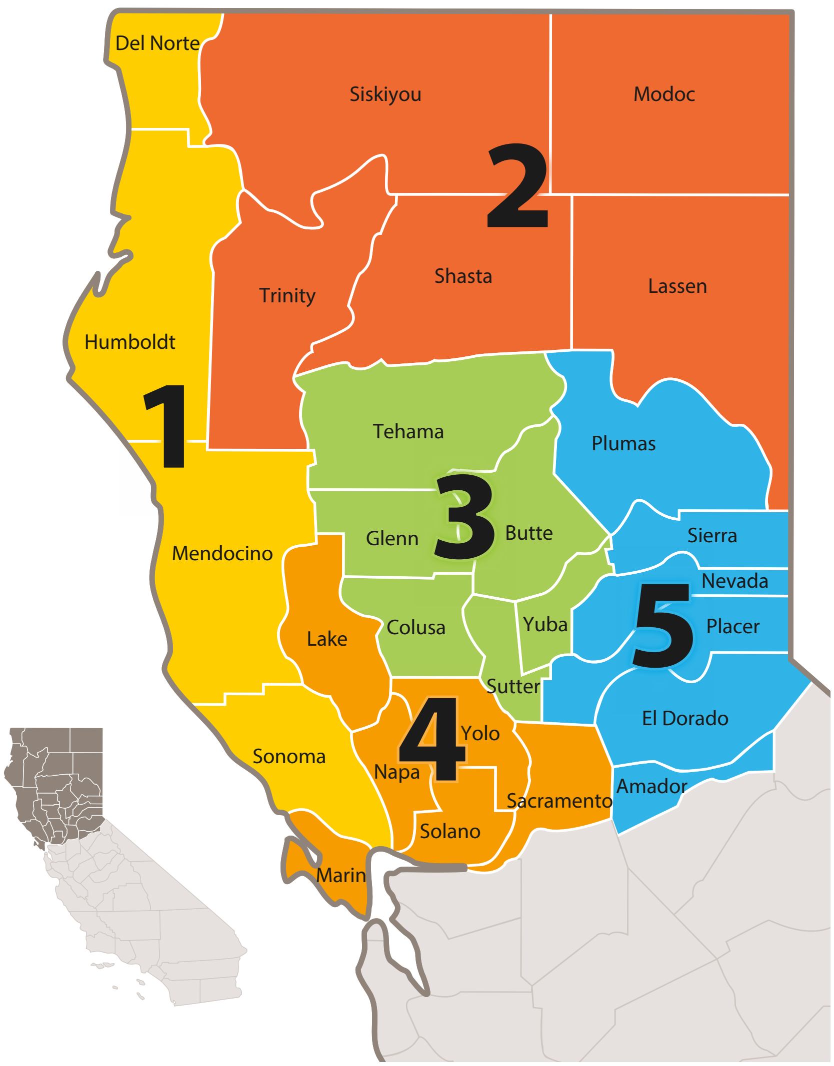

FIG. 1. Geographical regions coded from 1 to 5.

Density

Information from the U.S. Census Bureau (USCB 2010) was used to determine each county's population per square mile, or population density. All Census Bureau data on population and population density were collected from the 2010 census. Population per square mile by county is outlined in table 1.

Statistical analysis

To test the potential impact of multiple variables on 4-H enrollment, a GLM Type III sums-of-squares procedure was used in Statgraphics (Statpoint Technologies 2009). Quantitative variables included population density and enrollments in swine, sheep and cattle projects. Categorical variables included year (time) and region (space). Initially, all two-way interactions were included. However, it was found that including interactions caused multicollinearity, which can increase the amount of error in estimation and lessen reliability in inferences about data. All interactions were therefore removed from the model. Insignificant variables ($P > 0.05$) were eliminated from the final model. Estimates of

TABLE 1. Population density per square mile by county

Population density per square mile	County
2.5	Modoc
3.4	Sierra
4.3	Trinity
7.2	Siskiyou
7.7	Lassen
7.8	Plumas
18.6	Colusa
21.4	Glenn
21.5	Tehama
25.1	Mendocino
28.4	Del Norte
37.7	Humboldt
46.9	Shasta
51.5	Lake
64.1	Amador
103.1	Nevada
106.0	El Dorado
114.2	Yuba
134.4	Butte
157.3	Sutter
182.4	Napa
197.9	Yolo
247.6	Placer
307.1	Sonoma
485.1	Marin
503.0	Solano
1,470.8	Sacramento

enrollments per variable and standard errors were calculated on all significant quantitative variables. Least square mean figures were developed using Fisher's least significant difference test. An analysis of variance was used to examine the significance of density and region on individual livestock species projects and the influence of density on the ratio of total market projects to enrollment. Pearson product correlations were run between density and all three livestock projects.

Results

The overall model explained 84% of the variance in total enrollment ($R = 84$). Multiple variables were found to contribute to total 4-H enrollment. Swine ($P < 0.01$, estimate 0.62, standard error [SE] 0.21), sheep ($P < 0.01$, estimate 2.30, SE 0.30), cattle ($P < 0.01$, estimate 3.97, SE 0.67), density ($P < 0.01$, estimate 0.19, SE 0.03) and region ($P < 0.01$) (fig. 2) all significantly influenced enrollment (table 2). Year ($P = 0.91$) was not significant, indicating limited annual variation in total enrollment across the study period; year was thus eliminated from the final model. The resulting final model to predict enrollment, with density, region, sheep, swine and beef as variables, is presented as:

$$\text{total enrollment} = 92.3077 - 41.8653 \times I1(1) - 132.343 \times I1(2) - 54.8407 \times I1(3) + 144.675 \times I1(4) + 3.97672 \times \text{market beef cattle} + 2.29524 \times \text{market sheep} + 0.618433 \times \text{market swine} + 0.185265 \times \text{density per square mile}$$

where

$I1(1) = 1$ if region code $= 1$, -1 if region code $= 5$, 0 otherwise

$I1(2) = 1$ if region code $= 2$, -1 if region code $= 5$, 0 otherwise

$I1(3) = 1$ if region code $= 3$, -1 if region code $= 5$, 0 otherwise

$I1(4) = 1$ if region code $= 4$, -1 if region code $= 5$, 0 otherwise

Discussion

4-H market-animal projects are a highly visible component of the 4-H program. This analysis identified how multiple variables independently influence enrollment. These data indicate that traditional 4-H livestock projects play a critical role in encouraging youth to participate in the 4-H Youth Development Program.

This analysis indicates that the variables tested have a statistically significant relationship. The influence of these specific livestock market projects on 4-H enrollment can be inferred from the mechanics of program participation. Projects are the basis of the delivery method for traditional 4-H community clubs. Each

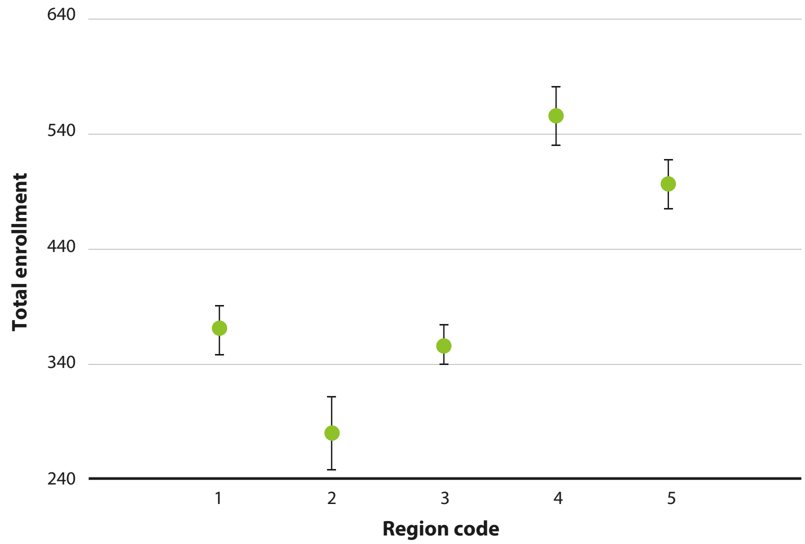

FIG. 2. Least square means of total enrollment per county by region in (1) northern coastal counties, (2) northern mountain counties, (3) northern valley counties, (4) southern valley and coastal counties and (5) southeastern foothill/mountain counties.

member is required to choose at least one project upon enrollment — it is not possible to complete the enrollment process without choosing a project. Youth are free to choose any project that interests them and may choose more than one project. They are not required to choose market-animal projects. New or returning members choose specific project(s), and those project(s) drive enrollment. The authors speculate that a member enrolling in 4-H creates awareness among siblings, peers and friends about the opportunities that 4-H offers. For example, if a youth is interested in raising a market animal, the youth's parents may reason that, since they will be taking one child to community club meetings, they might as well involve siblings as well because 4-H might offer projects that appeal to them. Determining the drivers that influence familial participation in the program is beyond the scope of this paper but should be explored.

TABLE 2. Estimated influence of the occurrence of a single additional market-animal project on total 4-H enrollment, along with standard error

Parameter	Estimated increase in enrollment for each market project	Standard error
Market beef cattle	3.98	0.67
Market sheep	2.3	0.3
Market swine	0.62	0.21
Density	0.19	0.03

The model indicates that the primary hypothesis of this research — that swine, beef and sheep projects are important to 4-H enrollment — is true. The three animal types, however, are important at different levels. The model shows that nearly two swine projects were required to encourage an additional enrollment in 4-H (beyond the two enrollments associated with the swine projects themselves). A single sheep project increased enrollment by just over two members and a beef project resulted in an increase of close to four members (table 2). The significance of these estimates is that, due to the modeling method, they are independent for each particular market project, regardless of location, year or population density.

Although estimates of beef cattle projects' contribution to enrollment were nearly double those of sheep projects, the overall contributions to enrollment of each project type did not differ markedly — because, in the average county statewide, youths in 4-H participate in nearly twice as many sheep projects as beef projects (table 3). This sort of relationship did not hold true for swine projects even though youth participated in nearly twice as many swine as sheep projects and nearly three times as many swine as beef projects. Though many more swine than beef or sheep projects are conducted on a statewide basis, the results show that swine projects contributed only half as much to increased enrollment as did the other two projects individually.

TABLE 3. Least square mean beef, sheep and swine projects on a county basis by region, with statewide true means

Region and code	Beef*	Sheep	Swine
Southern valley and coastal counties (4)	24a	62b	107b
Northern coastal counties (1)	25ab	41a	77a
Southeastern foothill/mountain counties (5)	26ab	38a	84a
Northern valley counties (3)	30b	69b	114b
Northern mountain counties (2)	35c†	35a	75a
Statewide	28	52	94

* Within each column, values followed by the same letter are not significantly different ($P > 0.05$).
† Value is significantly higher than corresponding values for all other regions.

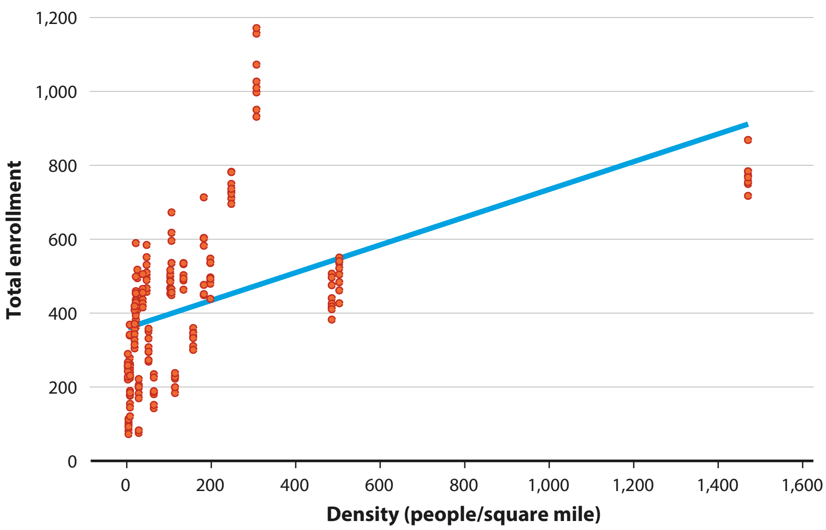

FIG. 3. Least square mean of total enrollment per county by population density.

It is difficult to quantitatively determine why swine projects' contribution to enrollment was so much lower than that of sheep and beef projects, and no literature could be found that helped address this question. Anecdotally, swine are commonly considered an entry-level project compared to cattle projects because the greater size of beef cattle, along with the time commitment involved in raising them, often limits these projects to older members. Perhaps the greater complexity of beef cattle projects increases their prestige and appeal. Maybe the sheer number of swine projects leaves little room for the high additive effect on enrollment seen in other livestock projects. On average, county swine projects statewide account for nearly one-quarter (94) of all 4-H enrollments (424).

The secondary hypothesis was shown to be only partially valid — that is, region and population density were significant factors in 4-H enrollment but year was not. In the 7 years of total enrollment data analyzed, year itself was not significant and very little variation appeared in total annual enrollment. The lack of significant year effect on total enrollment hints that interest in the program, as well as a pool of potential members, is relatively consistent across years.

On the whole, higher density led to more enrollment than did lower density (fig. 3), so a large population to draw from does tend to increase 4-H enrollment. But the effect of density wasn't perfectly linear, as some enrollment rates were somewhat variable by density.

Given the importance of market-animal projects on enrollment, and a reported lack of opportunities to engage in these projects in urban areas (Cano and Bankston 1992), a larger membership from more rural areas could have been expected. However, regression analysis of this Northern California dataset did not show that population density (urban versus rural) limited the number of market livestock projects ($P = 0.63$), even though considerable differences in density existed. Further exploratory analysis showed no significant correlations between beef cattle ($P = 0.85$), sheep ($P = 0.87$) or swine projects ($P = 0.42$) when compared to density.

Regions 4 (southern valley and coastal counties) and 5 (southeastern foothill/mountain counties) had the largest modeled enrollment, with region 4 higher

Results showed that a single 4-H sheep project increased enrollment by just over two members.

than region 5 (fig. 2). Since density was accounted for separately, urban versus rural demographics are not likely the cause of the higher enrollment in these two regions. 4-H educators would benefit if the reasons for higher enrollment in these two regions were explored. Perhaps study of these regions could lead to development of programmatic practices that would benefit other regions.

Region also appeared to be more pronounced in its effect on livestock projects than did density (table 3). Specific regions differed in the number and types of livestock projects. It is difficult to determine the cause of these differences. They could be cultural in nature or due to mimicry of local agriculture in the area.

Although multiple variables affect subsequent 4-H enrollment, traditional market-animal projects are considered a significant avenue for encouraging youth to join an organization that offers many additional benefits, including leadership training and self-responsibility. Rusk et al. (2003) have discussed the positive lessons gained from animal science projects.

The results of this research show that market-animal projects positively increase enrollment; through participation in these projects, youth are exposed to the other constructive aspects of the youth development program. Future research might usefully focus on barriers that prevent youth participation in market-animal projects. Overcoming these barriers could result in an increase in participation in the 4-H Youth Development Program. Lessons learned from market-animal projects, coupled with the structure of the traditional community club system, produce encouraging outcomes well documented among 4-H alumni. CA

J. Davy is UC Cooperative Extension (UCCE) Livestock and Natural Resources Advisor in Tehama, Glenn and Colusa counties, and County Director for Tehama County; L. Forero is UCCE Livestock and Natural Resources Advisor in Shasta and Trinity counties, and County Director for Shasta County; N. Caeton is UCCE Youth Development Advisor in Shasta, Tehama and Trinity counties; A. Hubbard is UCCE Community Education Specialist in Tehama County; and A. Gross is UCCE Community Education Specialist in Tehama County.

Evett Kilmartin

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RESEARCH ARTICLE

UC pistachio cultivars show improved nut quality and are ready for harvest earlier than 'Kerman'

In six commercial trials in the San Joaquin Valley, the percentage of split, in-shell nuts was higher for new cultivars 'Gumdrop', 'Golden Hills' and 'Lost Hills' than for 'Kerman', and bloom and harvest were earlier.

by Craig E. Kallsen, Dan E. Parfitt and Joseph Maranto

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Abstract

California pistachio growers have traditionally grown only one female cultivar ('Kerman') and one male pollenizer ('Peters'). Starting in 2005, the UC breeding program released several improved cultivars, which are being planted on increasing acreage — and tested now under commercial conditions at multiple sites over multiple years. We conducted six experimental trials in the San Joaquin Valley to evaluate the performance of the UC cultivars 'Gumdrop', 'Golden Hills' and 'Lost Hills' and their associated UC male pollenizers 'Famoso', 'Randy' and 'Tejon' against the performance of the traditional pair, 'Kerman' and 'Peters'. The new cultivars demonstrated a range of earlier bloom and harvest dates than 'Kerman' and some improved nut quality characteristics, such as a higher percentage of split, in-shell nuts. Results indicate that by growing the new female cultivars and synchronous pollenizers, producers can avoid the peak harvest period for 'Kerman', when equipment and processing facilities are limited, and maintain or improve their yield and nut quality.

Until the release of the first pistachio cultivars from the UC breeding program in 2005, the industry was almost entirely dependent on one female cultivar ('Kerman') and a single male pollenizer ('Peters'). While 'Kerman' remains a valuable commercial cultivar, it is not a perfect selection for all conditions. Some of the weaknesses of 'Kerman', described by Kallsen et al. (2009), include nut quality issues such as the failure of the nutshells to split, or to produce a kernel (blank nuts). Also, in years with an insufficient winter rest period such as occurred in 2014 and 2015, inadequate bloom synchrony has been evident between 'Kerman' and 'Peters'.

The biggest problem with 'Kerman', however, is the large and expanding 'Kerman' acreage planted during the last 30 years. Pistachio production, predominantly 'Kerman', has grown particularly rapidly in the last 15

'Golden Hills' nuts in the bin at harvest. Results from trials of UC-bred cultivars show that the new cultivars have earlier harvest dates and improved nut quality.

Craig E. Kallsen

Twelve-year-old variety trial showing earlier leaf-out and bloom of the 'Gumdrop' cultivar (left) compared to 'Golden Hills' (right) on April 10, 2019.

years; total planted pistachio acreage in California increased from 196,000 acres in 2008 to 330,000 in 2017 (CDFA 2018). Within the San Joaquin Valley, where most of the pistachio production occurs, the entire 'Kerman' crop ripens at about the same date, with a peak harvest duration of 3 to 4 weeks. Pistachio is an alternate-bearing crop, with a heavy-bearing year followed by a light-bearing year, and the cycle tends to become synchronized across the state, resulting in huge crops during the on-bearing years. Harvesting these huge crops is beginning to exceed the harvest capacity of the industry. Shortages of harvesting equipment, trucks, processing facility capacity and trained personnel are common.

Producers have begun to alleviate the worst of the peak demand problem by planting the new UC cultivars with harvest maturity dates different from 'Kerman'. Acceptance of UC-bred cultivars, especially 'Golden Hills', has been noteworthy. Since 2014, 'Golden Hills' has been the cultivar of choice for most of the new pistachio acreage (fig. 1). About 86,000 acres of 'Golden Hills' and 10,000 acres of 'Lost Hills' were in the ground as of 2018.

Commercial production history can be an important consideration for many producers when choosing a cultivar. 'Kerman' has been widely planted since it was made available to the industry in the 1950s, has been proven successful under a broad range of soil conditions, weather extremes, geographic conditions, tree maturity and producer production practices. 'Golden Hills' and 'Lost Hills' were released to the industry in 2005 and 'Gumdrop' in 2016. To help producers compare the commercial performance of the new cultivars to 'Kerman', we pulled together data from six long-term trials (some of them ongoing) in the San Joaquin Valley.

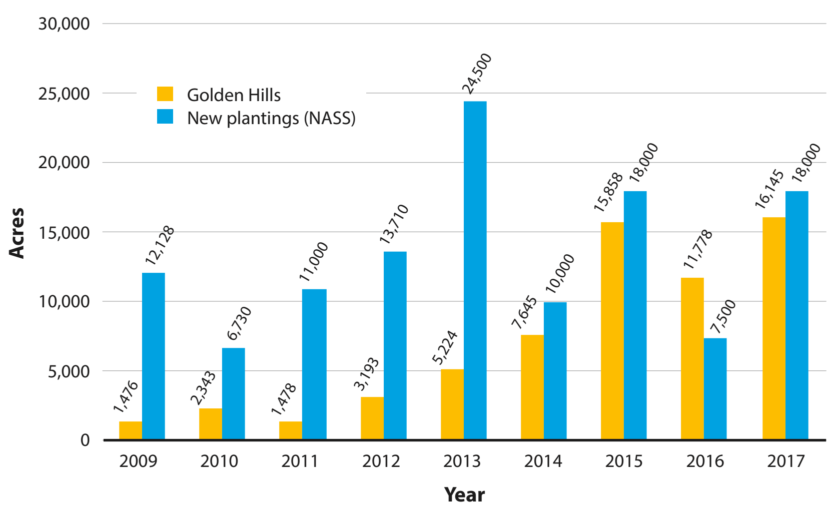

FIG. 1. Since 2014, 'Golden Hills' has accounted for most of the new planted acreage, according to National Agricultural Statistics Service (NASS) estimates of total new planting acreage from 2008 to 2017 and per-tree royalty payments for 'Golden Hills', assuming 140 trees planted per acre.

TABLE 1. Pistachio trial names, locations, elevations, year of planting, rootstock and orchard age when harvest data was collected

Trial name	California county	Location, nearest road intersection	Geographic coordinates of road intersection	Elevation above sea level	Year planted	Rootstock	Sample harvest period	Tree age when harvest data collected
				feet				*years*
Twisselman	Kern	Twisselman Rd. and King Rd.	35°43′51.42″N, 119°52′03.88″W	402	1997	PG1	2002–2010	5–13
Madera	Madera	Ave. 10 and Rd. 38	36°52′49.58″N, 119°51′25.94″W	336	1999	PG1 and UCB1 seedlings	2004–2010	5–11
Famoso	Kern	Famoso Rd. and Zerker Rd.	35°36′07.07″N, 119°09′03.57″W	561	2002	PG1	2007–2011	5–10
Tejon	Kern	Sebastian Rd. and Rancho Rd.	35°02′42.31″N, 118°50′48.49″W	684	2002	PG1	2007–2010	5–9
Buttonwillow	Kern	Buerkle Rd. and Palomas Rd.	35°22′58.94″N, 119°28′59.09″W	265	2007	UCB1 seedlings	2012–2018	5–11
Jasmine	Kern	Garces Hwy. and Grapefruit Rd.	35°45′42.50″N, 119°05′54.58″W	856	2010	UCB1 clones	2016–2018	6–8

TABLE 2. Full bloom data by trial and cultivar

Trial name	Observation period	Tree age range	Cultivars in trial	Sex*	Average full bloom date
		years			
Twisselman	2004–2010	5–13	'Kerman'	F	Apr 8
			'Golden Hills'	F	Apr 5
			'Lost Hills'	F	Apr 3
			'Peters'	M	Apr 10
			'Randy'	M	Apr 2
Madera	2007–2010	5–11	'Kerman'	F	Apr 11
			'Golden Hills'	F	Apr 5
			'Lost Hills'	F	Apr 6
			'Peters'	M	Apr 11
			'Randy'	M	Apr 4
Famoso	2007–2011	5–9	'Kerman'	F	Apr 16
			'Golden Hills'	F	Apr 10
			'Lost Hills'	F	Apr 10
			'Peters'	M	N/A
			'Randy'	M	Apr 11
			'Famoso'	M	Apr 15
Tejon	2007–2011	5–9	'Kerman'	F	Apr 16
			'Golden Hills'	F	Apr 10
			'Lost Hills'	F	Apr 8
			'Peters'	M	N/A
			'Randy'	M	Apr 11
			'Famoso'	M	Apr 14
Buttonwillow	2014–2018	7–11	'Kerman'	F	Apr 7
			'Golden Hills'	F	Apr 2
			'Gumdrop'	F	Mar 28
			'Peters'	M	Apr 11
			'Randy'	M	Apr 4
			'Tejon'	M	Mar 30
Jasmine	2016–2018	6–8	'Kerman'	F	Apr 12
			'Golden Hills'	F	Apr 9
			'Lost Hills'	F	Apr 10
			'Peters'	M	Apr 16
			'Randy'	M	Apr 6
			'Tejon'	M	Mar 31

* F = female, M = male.

TABLE 3. Suggested standard and supplemental male pollenizers for each female cultivar based on predicted average adequacy of winter rest period over life of orchard

Predicted adequacy of winter rest period	Female	Supplemental early male	Standard male	Supplemental late male
Low	'Gumdrop'	'Zarand'*	'Tejon'	
	'Golden Hills'/'Lost Hills'	'Tejon'	'Randy'	
	'Kerman'	'Randy'	'Famoso'	
Moderate	'Gumdrop'	'Zarand'*	'Tejon'	
	'Golden Hills'/'Lost Hills'		'Randy'	
	'Kerman'		'Famoso'	'Peters'
High	'Gumdrop'		'Tejon'	
	'Golden Hills'/'Lost Hills'		'Randy'	'Famoso'
	'Kerman'		'Peters'	'O2-18'*

* These male cultivars are not UC releases.

Six trials in San Joaquin Valley

We evaluated the growth and production characteristics of six pistachio cultivars bred, patented, technically described and released by UC. These cultivars are the females 'Golden Hills' (Parfitt et al. 2007), 'Lost Hills' (Parfitt et al. 2008) and 'Gumdrop' (Kallsen and Parfitt 2017) and the males 'Randy' (Parfitt et al. 2010), 'Famoso' (Kallsen and Parfitt 2018) and 'Tejon' (Kallsen and Parfitt 2019). Data were collected from six trials in the southern San Joaquin Valley (table 1), although not all cultivars were present in all trials (table 2).

Methods used for determining bloom, yield and nut quality characteristics were described in Parfitt et al. (2007) and Kallsen et al. (2009). The experimental trials were replicated, randomized and located within larger blocks of 'Kerman' under standard irrigated-production conditions (Brar et al. 2015). Row and tree spacing were variable among trials (18 to 20 feet between rows and 16 to 18 feet between trees). Depending on the trial, the cultivars were replicated in two to four blocks, with each replication consisting of one to 10 trees. The rootstocks to which the cultivars were grafted varied with the trial (table 1). The trees were harvested with poles or mechanical shaking. Nuts that remained firmly attached to the tree after harvest were not evaluated.

Bloom timing, suggested pollenizers

Pistachio is dioecious, and bloom synchrony between male and female cultivars is critical for adequate pollination and nut set. Specific pollenizers are associated with each female cultivar to provide pollen at female bloom. The mean full bloom dates across trials (table 2) for the female cultivars were April 12 for 'Kerman', April 7 for 'Golden Hills' and 'Lost Hills', and March 28 for 'Gumdrop'. Mean full bloom date for the male cultivars were April 12 for 'Peters', April 6 for 'Randy', and March 31 for 'Tejon'. On the basis of these mean full bloom dates across all trials and the mean full bloom dates at each trial location (table 2), we identified the most synchronous pollenizer for each female as its standard male (table 3).

However, pistachio bloom timing, and thus bloom synchrony in the spring, is affected by the adequacy of the rest period (also called chilling) in the previous winter, and the winter rest period requirement for pistachio is high compared to that of many fruit and nut crops (Ferguson and Kallsen 2016). Symptoms of an inadequate winter rest period include uneven and late foliation and bloom (Crane and Takeda 1979; Erez and Fishman 1988). On male and female trees, many buds fail to push, inflorescences desiccate before they flower or inflorescences remain small and nonproductive on the more sun-exposed leaf canopy.

Physiologists continue to grapple with how to quantify or measure the winter rest requirement of fruit and nut crops, in general (Luedeling et al. 2013; Melke 2015) and in pistachio in particular (Kallsen 2017; Zhang and Taylor 2011), because the underlying physiology is not well understood. Although difficult to quantify, it has been apparent that the adequacy of the winter rest periods for pistachio has ranged from low to high in the San Joaquin Valley, depending on orchard location and year. For the purposes of this article, the adequacy of the winter rest period in 2014 and 2015 was considered low, and the adequacy of the typical winter rest period in the San Joaquin Valley was considered moderate. For comparison, a high adequacy rating is more typical of the pistachio-growing area around Wilcox, Arizona.

Our suggestions for pollenizers in table 3 take account of canopy and flower development observations made in years when the adequacy of the winter rest period was low. Bloom synchronization between the female tree and the standard male pollenizer decreased during years with an inadequate winter rest period. In these years, the standard male pollenizer tended to bloom later than the associated female cultivar. For example, at the Buttonwillow trial in 2014 and 2015, 'Randy', the standard pollenizer for 'Golden Hills' and 'Lost Hills', was at full bloom at the same time as 'Kerman' (fig. 2). Similarly, 'Tejon', the standard pollenizer for 'Gumdrop', had closer synchrony with 'Golden Hills' (fig. 2), which left the early-blooming 'Gumdrop' without an overlapping pollenizer.

As the future winter rest period in the San Joaquin Valley is predicted to become even less adequate (Baldocci and Waller 2014; Leudeling et al. 2009), in some situations we suggest planting a supplemental pollenizer, in addition to the standard male (table 3). However, ensuring bloom synchronization does not guarantee adequate pollination and yield potential in years with an inadequate winter rest period. The quantity of pollen per flower in 'Randy' and 'Peters' was reduced measurably in 2015 at the Famoso trial (Kallsen and Parfitt 2017) compared to in 2016, when a more adequate winter rest period occurred; similar detrimental effects from inadequate winter rest are also likely on flower and seed development in female trees. It is noteworthy that 'Gumdrop' demonstrated less intense symptoms of inadequate winter rest than the other cultivars. There is some correlative evidence within other crops that earlier-blooming cultivars have a lower winter rest requirement than later-blooming cultivars (Gao et al. 2012).

Precocity matches

"Precocity" is defined as the number of years between planting and the first year of flowering. Females that are more precocious can produce a crop sooner if suitable pollen is available. 'Peters' tends to remain vegetative in the 4th and 5th years after planting as 'Kerman' begins to flower, reducing nut yield. In addition to its bloom synchrony with 'Kerman', one of the criteria used in identifying and selecting the new pollenizer 'Famoso', from the initial seedling evaluation trials, was its similar precocity with 'Kerman', which should allow for bigger nut yields in the early years of the orchard.

Tree growth characteristics

The female cultivars in this study vary in tree growth characteristics. 'Golden Hills' grew upright, with willowy branches. 'Kerman' and 'Lost Hills' had less upright growth and their trunk diameter increased faster than 'Golden Hills'. 'Gumdrop' had a stouter growth habit than the other cultivars; its trunk increased in girth quickly and its branches were much thicker and tapered less toward the tip. 'Kerman' was the most

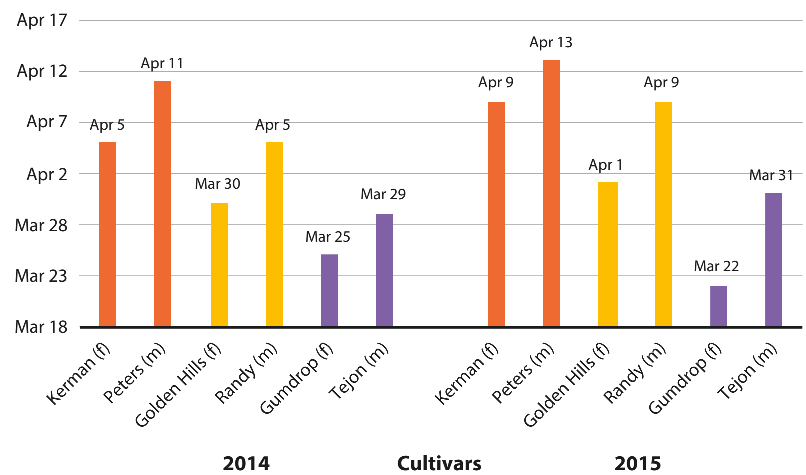

FIG. 2. Timing of full bloom for male (m) and female (f) cultivars in the Buttonwillow trial during the spring of 2014 and 2015, which were years with an inadequate winter rest period. The standard male cultivar has the same color as the associated female.

'Gumdrop' trees on July 2, 2018, showing the large leaves and unusual branching of this cultivar.

vigorous of the cultivars and required more pruning to maintain upright growth as a mature tree.

UC cultivars increased in trunk circumference faster than the rootstock. The result was overgrowth at the graft union. Overgrowth was most noticeable when UC cultivars were grown on PG1 rootstock (i.e., a rootstock with 100% *Pistacia integerrima* heritage) (Kallsen and Parfitt 2011). Overgrowth can make firm attachment of the harvest shaker to the tree trunk difficult and may result in bark damage. For this reason, grafting should occur at 28 to 32 inches (0.71 to 0.81 meters) above ground level (Brar et al. 2015).

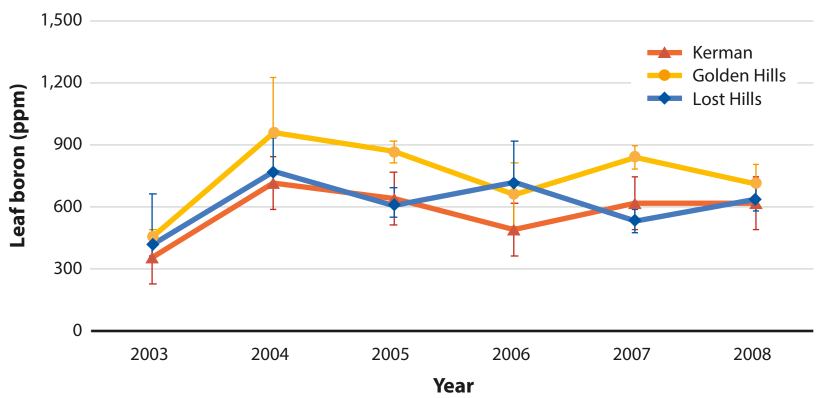

FIG. 3. Dry weight concentration of boron in leaf tissue of 'Kerman', 'Golden Hills' and 'Lost Hills' on PG1 rootstock at the Twisselman trial. 'Golden Hills' had greater leaf edge burn due to boron toxicity than did 'Lost Hills' or 'Kerman'. Error bars represent ± 2 times the SE of the mean.

Boron-related leaf necrosis

The concentration of boron in the leaves of 'Golden Hills' was greater than for 'Lost Hills' or 'Kerman' on PG1 and UCB1 rootstocks (Kallsen and Parfitt 2008). This resulted in leaf necrosis along the outer edge of the leaves when soil and water boron were elevated (fig. 3) and early defoliation where soil and water boron concentrations were high.

Harvest timing, extended season

The most valuable characteristic of the UC cultivars seen in these trials was their earlier harvest compared to 'Kerman' (table 4). The mean harvest readiness dates across the six trials were Aug. 20 for 'Gumdrop', Sept. 1 for 'Golden Hills', Sept. 4 for 'Lost Hills' and Sept. 15 for 'Kerman'. 'Gumdrop' was present only at the Buttonwillow trial (table 4). Nuts of 'Gumdrop' were ready for harvest approximately 23 days earlier on average than those of 'Kerman'. Earlier harvest increases the

TABLE 4. Harvest readiness, yield and mean nut quality characteristics* for 'Kerman', 'Golden Hills', 'Lost Hills' and 'Gumdrop' at six trials in the San Joaquin Valley

Trial name	Cultivars present	Mean harvest readiness date	Cumulative yield as edible weight	Individual nut weight	In-shell split nuts	Loose shells and kernels	Dark-stained nuts	Harvested blank nuts	Total insect damage
			lbs/acre†	*grams*	*%‡*	*%*	*%*	*%*	*%*
Twisselman	'Kerman'	Sep 17	25,213a§	1.25a	71.2a	0.5a	0.7a	7.5a	1.4b
	'Golden Hills'	Aug 29	33,919a	1.28a	86.1b	0.6a	0.5a	3.0a	0.2a
	'Lost Hills'	Sep 2	31,050a	1.45b	87.1b	2.8b	0.6a	3.4a	0.4a
Madera	'Kerman'	Sep 17	17,670a	1.40b	73.5a	1.5b	N/A	9.7b	0.6a
	'Golden Hills'	Sep 5	17,370a	1.32a	83.3b	0.6a	N/A	4.8a	0.6a
	'Lost Hills'	Sep 5	20,084a	1.43b	84.4b	3.0c	N/A	4.7a	0.6a
Famoso	'Kerman'	Sep 15	9,847a	1.33a	79.9a	1.3a	1.4a	5.6b	0.8a
	'Golden Hills'	Sep 4	9,167a	1.37a	87.8b	1.2a	1.4a	3.6a	0.5a
	'Lost Hills'	Sep 10	10,586a	1.44b	82.1a	4.2b	3.0b	3.7a	0.7a
Tejon	'Kerman'	Sep 16	8,237a	1.35ab	81.0a	0.7a	0.2a	5.1a	0.1a
	'Golden Hills'	Aug 31	8,847a	1.29a	91.0b	0.4a	0.3a	4.1a	0.2a
	'Lost Hills'	Aug 31	7,833a	1.38b	87.7b	4.0b	0.5b	6.2a	0.2a
Buttonwillow	'Kerman'	Sep 12	14,441a	1.37a	69.5a	0.3a	1.7b	9.7c	1.4c
	'Golden Hills'	Aug 30	16,586a	1.38a	86.9c	0.2a	0.6a	3.3a	0.4a
	'Gumdrop'	Aug 20	14,927a	1.35a	82.5b	0.8b	1.3ab	6.9b	0.7b
Jasmine	'Kerman'	Sep 13	5,346a	1.35a	64.7a	0.3a	0.5a	8.6b	0.3a
	'Golden Hills'	Aug 30	6,090a	1.32a	80.2b	0.2a	0.6a	4.2a	0.1a
	'Lost Hills'	Sep 3	9,201b	1.49b	88.4c	0.9b	2.2b	4.3a	0.4a

* Nut quality characteristics determined by USDA-trained technicians using mandated protocols as described by California Pistachio Commission (1990).
† lb/acre 1.1208 = kg/ha.
‡ Percentage by weight of a hulled nut sample dried to 5% moisture.
§ Values within the same column for each trial followed by different letters are significantly different by Fisher's protected LSD test at $P \leq 0.05$.

A visual comparison of the nuts of 'Gumdrop', 'Kerman' and 'Golden Hills'.

efficiency of the industrywide pistachio harvest by extending the harvest season and thus reducing peak demand for labor, harvesting equipment and nut processing facilities.

Nut yield and quality

A pistachio nut has an outer hull covering a shell, which encloses a kernel (i.e., meat). Yield in this study was expressed as edible weight, which also is called grower-paid weight. Edible weight is the weight of nuts after hull removal, adjusted to 5% moisture, minus culls and the weight of shells from nonsplit nuts (California Pistachio Commission 1990). Shell plus kernel, called an in-shell, split nut, is the major commercial product marketed in California although shell-less kernels are increasing in popularity. For the producer to be paid for the weight of the shell, the shell must be split and contain an edible kernel. If the shell is split but dark stained, the producer is paid only for the weight of the kernel.

Generally, cumulative edible weight at each trial site was similar among the cultivars (table 4). 'Golden Hills' and 'Lost Hills' produced a higher in-shell, split nut percentage by weight than did 'Kerman' (table 4), which had a higher percentage of nonsplit (i.e., closed-shell) nuts (data not shown). Dark shell staining is undesirable from a marketing standpoint (California Pistachio Commission 1990). No clear pattern was apparent among cultivars in the various trials for the degree of dark shell staining (table 4).

If the shell falls apart during hulling, the kernel is usually lost and discarded with the hulls. The percentage of loose shells and kernels is a measure of a cultivar's shell hinge strength. The percentage of loose shells and kernels was higher in 'Lost Hills' than the other cultivars (table 4).

Close-up of a 'Gumdrop' nut cluster near harvest on August 13, 2015.

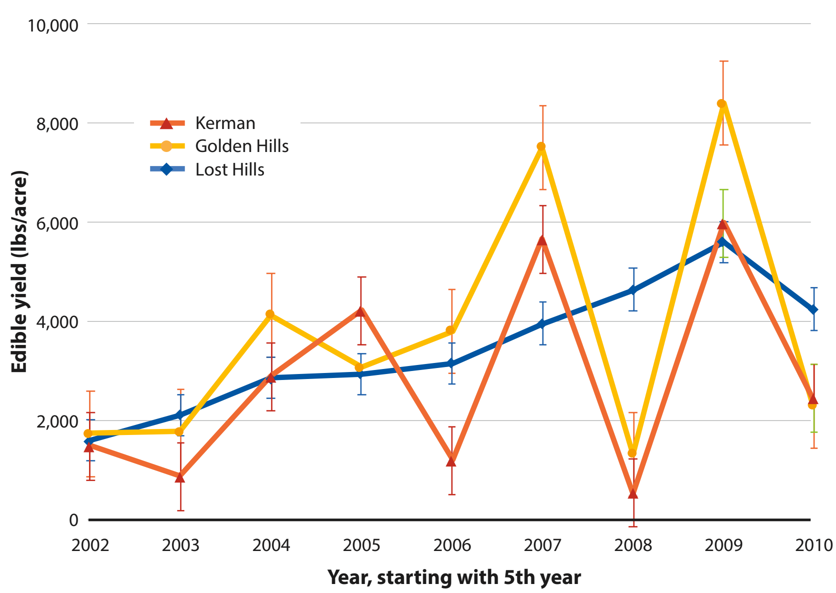

FIG. 4. Variation in annual edible yield at the Twisselman trial. 'Lost Hills' demonstrated less alternate bearing. Error bars represent ± 2 times the SE of the mean.

‘Kerman’ had a higher percentage of blank nuts than other cultivars (table 4); blank nuts have no kernel and are of no value to the producer. Individual nut weight was greatest for ‘Lost Hills’ (table 4), as was nut size (data not shown).

Alternate-bearing patterns

Pistachio trees tend to produce high and low yields in alternate years, beginning when they are 8 or 9 years old. Alternate bearing is considered an undesirable trait, especially so since the production across the industry becomes synchronized into high- and low-bearing years. This synchronization complicates efficient harvesting, processing and marketing.

‘Lost Hills’ demonstrated less alternate bearing than other cultivars at the Twisselman trial (fig. 4) (Kallsen et al. 2007). ‘Gumdrop’ showed the greatest alternate-bearing pattern at the Buttonwillow trial (fig. 5). ‘Kerman’ and ‘Golden Hills’ were distinctly alternate bearing at the Buttonwillow trial as well (fig. 5), but not as severely as at the Twisselman trial (fig. 4).

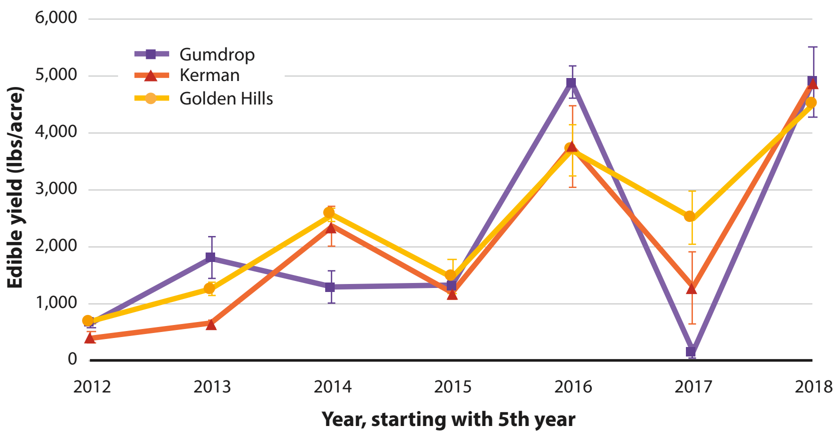

FIG. 5. Variation in annual edible yield at the Buttonwillow trial. ‘Gumdrop’ demonstrated more extreme annual bearing than the other cultivars beginning in 2016. Error bars represent ± 2 times the SE of the mean.

Insect pests and early harvest

Evaluations of nut quality at the processing plant include damage by insects. The most important insect pest in the San Joaquin Valley is navel orangeworm because of the nut damage, which can end up in consumer packaging and is associated with aflatoxin contamination (Doster and Michailides 1999; Haviland et al. 2016).

Navel orangeworm populations increase geometrically as the harvest season continues into the fall. A timely early harvest reduces navel orangeworm nut infestation in ‘Kerman’ (Haviland et al. 2016). The UC cultivars in our trial were ready for harvest earlier than ‘Kerman’ (table 4) and had less insect damage than ‘Kerman’ on average in two of our trials. However, in general, insect damage was low (table 4).

Choosing a cultivar, future cultivars

Choosing a cultivar should be based on characteristics important to the producer. The UC cultivars demonstrated characteristics distinct from those of ‘Kerman’

TABLE 5. Bloom, growth, harvest, nut quality and other characteristics of UC-bred female cultivars and ‘Kerman’

Characteristic	Meaning of rating values	‘Gumdrop’	‘Golden Hills’	‘Lost Hills’	‘Kerman’	Source for rating
Length of production history	1 is longer	3	2	2	1	Parfitt et al. 2016
Bloom date	1 is earlier	1	2	2	3	Table 2
Harvest readiness date	1 is earlier	1	2	2	3	Table 4
Alternate bearing*	1 is greater	1	2	3	2	Figs. 4 and 5
Nut maturity uniformity across tree†	1 is shorter	2	1	2	2	Trial observation
Yield, edible weight	1 is greater	1	1	1	1	Table 4
Individual nut weight	1 is greater	2	2	1	2	Table 4
In-shell, split %	1 is greater	1	1	1	2	Table 4
Shell hinge strength %‡	1 is greater	2	1	3	1	Table 4
Dark-stained nuts %	1 is greater	2	3	1	3	Table 4
Harvested blank nuts %	1 is greater	2	3	3	1	Table 4
Early split nuts§	1 is greater	1	3	1	2	Trial observation
Hull stickiness at harvest	1 is greater	1	3	2	3	Trial observation
Total insect damage %	1 is greater	2	2	2	1	Table 4
Boron-related leaf necrosis	1 is greater	No data	1	2	2	Fig. 3

* As evaluated in 13-year-old trees or younger.
† Time from when first nuts are ready for harvest to when last nuts are ready for harvest.
‡ As measured by loose shells and kernels percentage.
§ Nuts that split in July before maturity and are associated with early navel orangeworm damage.

and, thus, opportunities for choice when establishing a new orchard (table 5). The new cultivars demonstrated a range of earlier bloom and harvest dates than 'Kerman' and some improved nut quality characteristics, such as a higher percentage of split, in-shell nuts and fewer closed shell and blank nuts. Results indicate that by growing the new female cultivars and synchronous pollenizers, producers can avoid the peak harvest period for 'Kerman', when equipment and processing facilities are limited, and maintain or improve their yield and nut quality. Future cultivars should show improvements that will benefit the producer, processor, consumer, orchard worker and the environment. Through plant breeding, cultivars could, for example, have a reduced winter rest requirement, increased insect or plant disease resistance or tolerance, reduced need for pesticides, better harvestability and processability, greater salt tolerance and a lower water requirement. UC plant breeders are focusing their efforts on many of these objectives. Plant breeding and selection for a desired trait is not quick, even with the application of modern genomics. However, breeding and selection has a successful record and warrants continued investment. CA

C.E. Kallsen is UC Cooperative Extension (UCCE) Farm Advisor and J. Maranto is UCCE Farm Advisor Emeritus, Kern County; and D.E. Parfitt is AES Pomologist Emeritus, Department of Plant Sciences, UC Davis.

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Craig E. Kallsen

A 'Kerman' harvest in an experimental trial, September 19, 2019.

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RESEARCH ARTICLE

Grape erineum mite: Postharvest sulfur use reduces subsequent leaf blistering

As vectors of a grapevine pathogen, erineum mites pose a potential new threat but are vulnerable to sulfur applications after harvest.

by Monica L. Cooper, Malcolm B. Hobbs, Becky Strode and Lucia G. Varela

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Abstract

The occurrence of eriophyid mites (*Calepitrimerus vitis* [rust mites] and *Colomerus vitis* [erineum mites and bud mites]) in vineyards worldwide is associated with leaf deformation, stunted shoot growth and reduced yield potential. In the North Coast region of California, leaf blistering by the erineum strain of *Colomerus vitis* is the most widespread symptom of eriophyid mite damage. Unlike rust and bud mites, erineum mites are generally considered a nuisance pest that is incidentally controlled by sulfur-dominated management programs for powdery mildew. However, recent reductions in the use of sulfur have allowed erineum mite populations to expand, highlighting the need for alternative management options. In this study, we posited that, during autumn, mites moving to buds from erinea (leaf blisters) to overwinter could be susceptible to sulfur applications. During four growing seasons, we documented patterns of mite movement to identify key sulfur application timing. We found the greatest numbers of migrating erineum mites from late September to early November. Concurrently, in replicated trials, we evaluated the efficacy of postharvest sulfur applications to reduce blistering. Sulfur applied during the migration period in 2013 appeared to eradicate leaf blistering in the 2014 growing season. In subsequent trials, sulfur treatments reduced blistering to less than 10% incidence, compared to 40% to 50% incidence in control plots.

The grapevine eriophyid mite group (Acari: Eriophyidae) includes the rust mite (*Calepitrimerus vitis)*, the bud mite and the blister (or erineum) mite. The bud and blister mites, both *Colomerus vitis*, are morphologically similar but genetically distinct (Carew et al. 2004). Rust mite feeding, which results in malformed leaves, incomplete cluster formation and severely stunted, scarred and deformed shoots, can cause economic losses that reach as high as 23% (Walton et al. 2007). Damage from the bud mite can be equally severe (Bernard et al. 2005; Carew et al. 2004), requiring management interventions such as modified pruning strategies (Dennill 1991) or pesticide applications (Bernard et al. 2005). In contrast, damage resulting from the blister or erineum mite is limited to the formation of blisters (erinea) on grapevine leaves (Carew et al. 2004). Although these blisters may affect the photosynthetic capacity of the vines (Carew et al. 2004), the erineum strain has generally been

Leaf blistering by grape erineum mite. UC Cooperative Extension trials conducted in Napa County vineyards demonstrated that applying sulfur in late September through early November significantly reduced the incidence of leaf blistering in the subsequent growing season.

Monica L. Cooper

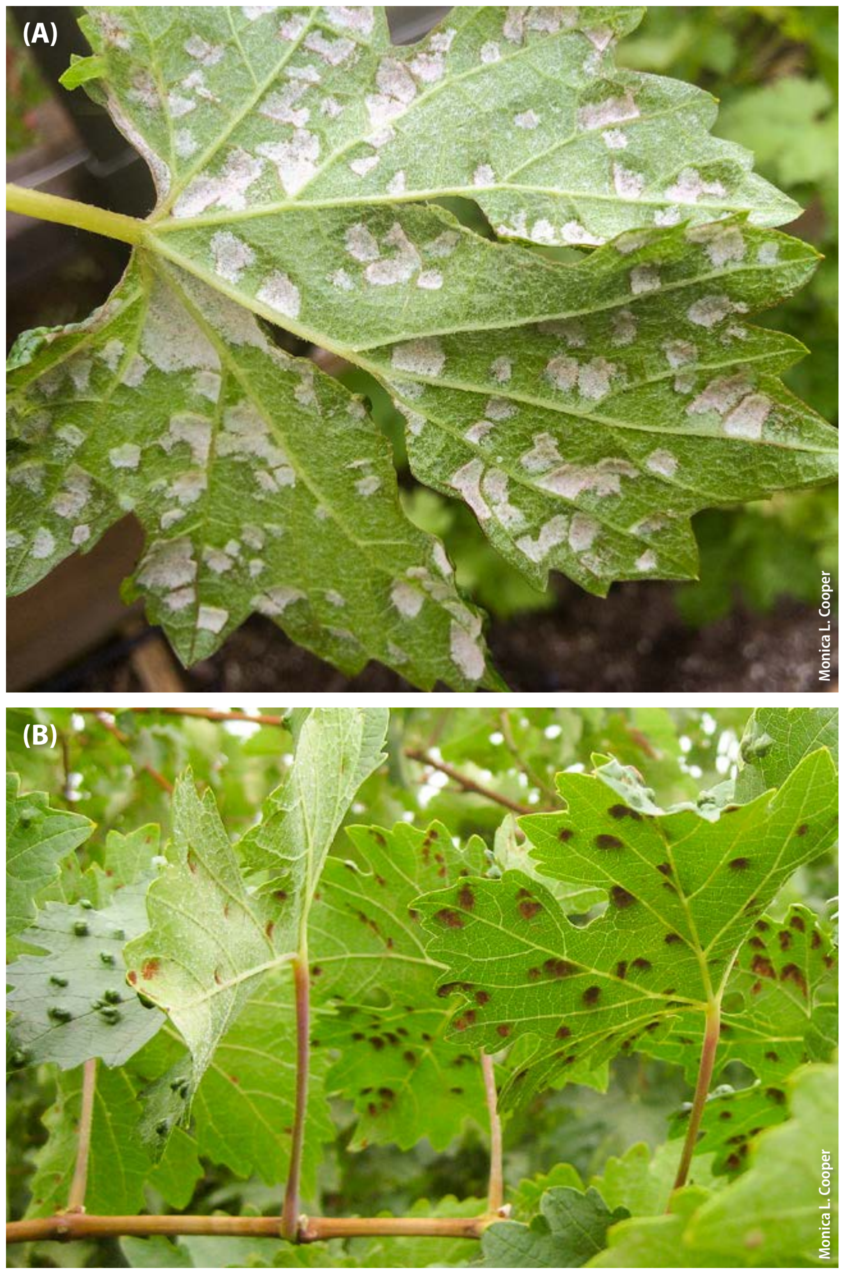
considered a nuisance pest, except to certain grapevine cultivars (Khederi et al. 2018), or when elevated populations cause stress to young vines in the field (Varela et al. 2013) or in plant propagation facilities (Ferragut et al. 2008). Recently, however, erineum mites have been implicated as a potential vector of grapevine pinot gris virus (GPGV) (Malagnini et al. 2016), a pathogen whose damage is characterized by leaf mottling, deformation and stunted shoot growth (Saldarelli et al. 2015). As with other arthropod-transmitted diseases of grapevine (Almeida et al. 2013; Daugherty et al. 2015), disease management efforts for GPGV may incorporate a vector management component to reduce populations of erineum mite.

Erineum mite is widely distributed in vineyards throughout California, in both coastal and interior locations (Smith and Stafford 1948). (In the Pacific Northwest and Australia, on the other hand, rust and bud mites predominate [Walton et al. 2007; Duso et al. 2010].) Erineum mite damage is characterized by the formation on the upper leaf surface of elevated leaf galls or blisters (erinea), from which the mite gets its common name. Plant hairs grow profusely on the lower leaf surface in the galled area; hairs are white in young galls, aging to a reddish-brown color in older galls, as the leaf hairs die. These distinctive galls are readily identifiable, and form only on newly emerging leaves. Once leaves reach a diameter greater than 0.5 inches (1.3 centimeters), they are no longer susceptible to infection (Smith and Stafford 1948). In the North Coast American Viticultural Area — composed of Napa County and five other counties — damage to young leaves is commonly observed early in the season (prebloom); later in the season (during berry ripening), blisters are often found on leaves at the shoot tip and on lateral shoots. Both bud and erineum mites overwinter as adults in grapevine buds, where they remain active and feed on dormant bud tissue (Carew et al. 2004). After budbreak, the bud mite moves to newly developing buds, whereas erineum mites exit the buds to feed on the leaves. Consequently, in autumn, erineum mites must migrate from the leaves back to the buds to overwinter.

While phytoseiid mites may provide biological control of erineum mite populations under some conditions (James and Whitney 1993; Ferragut et al. 2008), sulfur applications for grapevine powdery mildew (*Erysiphe necator*) generally provide incidental control of erineum mite (Smith and Stafford 1948). The authors, however, have recently observed a shift toward reduced sulfur use during the growing season in the North Coast region, driven both by increased reliance on alternate products (such as oils) early in the season and by external factors aimed at limiting the use of sulfur in vineyards. One consequence has been an increased prevalence of leaf blistering, both early and late in the season. As an alternative to in-season treatments, we proposed in this study that sulfur applications in autumn (after harvest, but before leaf fall) could target erineum mites as they moved to the buds to overwinter. We therefore initiated this study (1) to document erineum mite migration patterns in the autumn and to identify periods of elevated activity in the North Coast region and (2) to evaluate the efficacy of an autumn sulfur application in reducing leaf blistering in the subsequent growing season.

Autumn migration patterns of erineum mites

We tracked patterns of erineum mite movement during the late summer and autumn of 2013, 2014, 2015 and 2016. In 2013 and 2016, we monitored four unique



(A) Profuse growth of plant hairs on the underside of a grape leaf resulting from erineum mite feeding (white hairs indicate young galls). (B) In older galls, the leaf hairs darken to a reddish brown.

Double-sided tape on grapevine cane, used to monitor erineum mite migration patterns.

Mites captured on double-sided tape.

vineyard sites and in 2014 and 2015 we monitored two unique vineyard sites (table 1). At all sites, the predominant symptom of eriophyid mite damage was leaf blistering associated with erineum mite. Symptoms of rust or bud mite damage, including malformed leaves and shoots, reduced shoot growth and reduced cluster number, were not present on any of the vines in any of the study years. In 2013, we monitored six vines at each site, and in subsequent years we monitored 12 vines per site. On each monitored vine, we selected three shoots with obvious leaf blistering and deployed double-sided tape (Scotch, St. Paul, Minnesota) at one location on each of the selected shoots, corresponding to (1) basal, (2) middle and (3) upper shoot positions. We defined the basal position as the internode between the clusters, of which there were generally two, on the shoot. Depending on the year, the middle position was two (2015, 2016) or five (2013, 2014) internodes up from the basal position (internode 5 or 8, counting from the base of the shoot). The upper position was five internodes up from the middle position (internode 10 or 13, counting from the base of the shoot). Monitoring was initiated from early August to mid-August; tapes were changed on a 7- to 10-day interval and monitoring concluded around leaf fall (mid-November to late November) or when mites were no longer detected (table 1).

Because it was not feasible to individually count erineum mites, a score representing the absolute number of mites on each tape was generated. Mite activity was quantified by overlaying a grid measuring 2.36 inches (6 centimeters) by 0.79 inches (2 centimeters) on each tape and judging the coverage of mites in each square using a 5-point scale (0 = no mites; 1 = up to 5% coverage; 2 = 6% to 33%; 3 = 34% to 66%; 4 = 67% to 100%). Each tape was then scored by summing the ratings, yielding a single score per tape. Across sites and study years, 12 tapes were missing (that is, they had fallen off

TABLE 1. Description of trial sites and research activities

Site description		Monitoring dates (dates of sulfur application)					
Cultivar (*Vitis vinifera*)	**Location (site code)**	**2013 Aug 16–Nov 8**	**2014 Aug 15–Nov 21**	**2015 Aug 4– Nov 20**	**2016 Aug 5–Nov 30**	**2016 Aug 11–Nov 30**	**2016 Aug 22–Nov 30**
Sauvignon blanc*	St. Helena (DK)	X† (Sep 17)					
Cabernet Sauvignon	Calistoga (FH)	X					
Cabernet Sauvignon	Calistoga (LD)	X					
Cabernet Sauvignon	Rutherford (RD)	X	X				
Cabernet Sauvignon	Coombsville (LT)		X	X			
Sauvignon blanc	St. Helena (WB)			X			
Cabernet Sauvignon*	Stags Leap (FV)			(Oct 2)	X		
Cabernet Sauvignon	Stags Leap (CK)				X		
Cabernet Sauvignon*	Atlas Peak (CR)					X (Oct 19)	
Cabernet Sauvignon	St. Helena (JS)						X

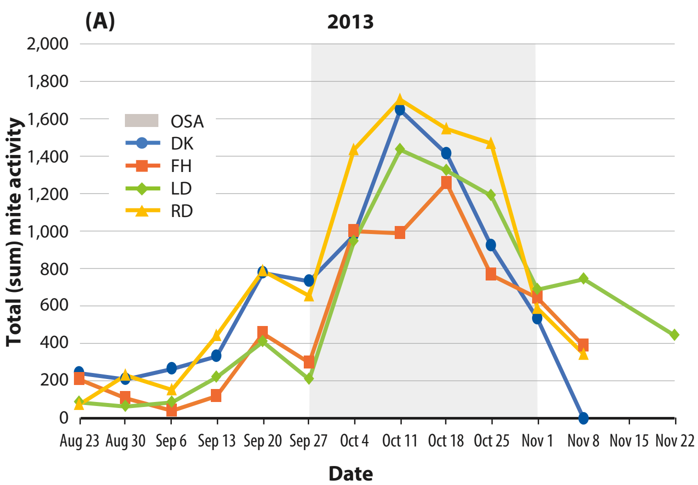
* Spray trials were conducted at site.

† Indicates the time frame during which erineum mite migration was monitored with double-sided tape at the site.

the vine prior to collection). In order to avoid distorting overall scores on days when tapes were missing, we calculated average scores and inserted them in place of the missing data. In addition, we calculated total (summed) mite activity at each vineyard site per monitoring date (fig. 1). To assess annual trends in migration patterns, mite activity was compared to calendar date and average heat accumulation, measured in terms of growing degree days (GDD) for grapevines. The GDD model was initiated on April 1 of each growing season. The lower threshold was set at 50°F (10°C) and temperature data was collected from a network of private weather stations operating in Napa County. Significant seasonal differences in mite activity were explored at each site by analyzing mean tape scores using repeated-measures ANOVA and post hoc *t*-tests to explore changes in activity on specific dates/degree days (see "Data analysis" section at end of article). A secondary analysis then used ANOVA to test for significant differences between shoot positions (basal versus middle versus upper); for these comparisons, data were aggregated across sites for each year to generate sufficient data points in each case.

Postharvest sulfur applications

In 2013, 2015 and 2016, we established trials to evaluate the impact of postharvest sulfur applications on the incidence of leaf blistering in the following growing season. We compared one application of dry flowable sulfur at a rate of 5 pounds per acre (in 75 gallons of water) to an untreated control. Because sulfur may also be formulated as a dust for powdery mildew management, the 2016 trial included an additional treatment: 12 pounds per acre of dusting sulfur. Treatments



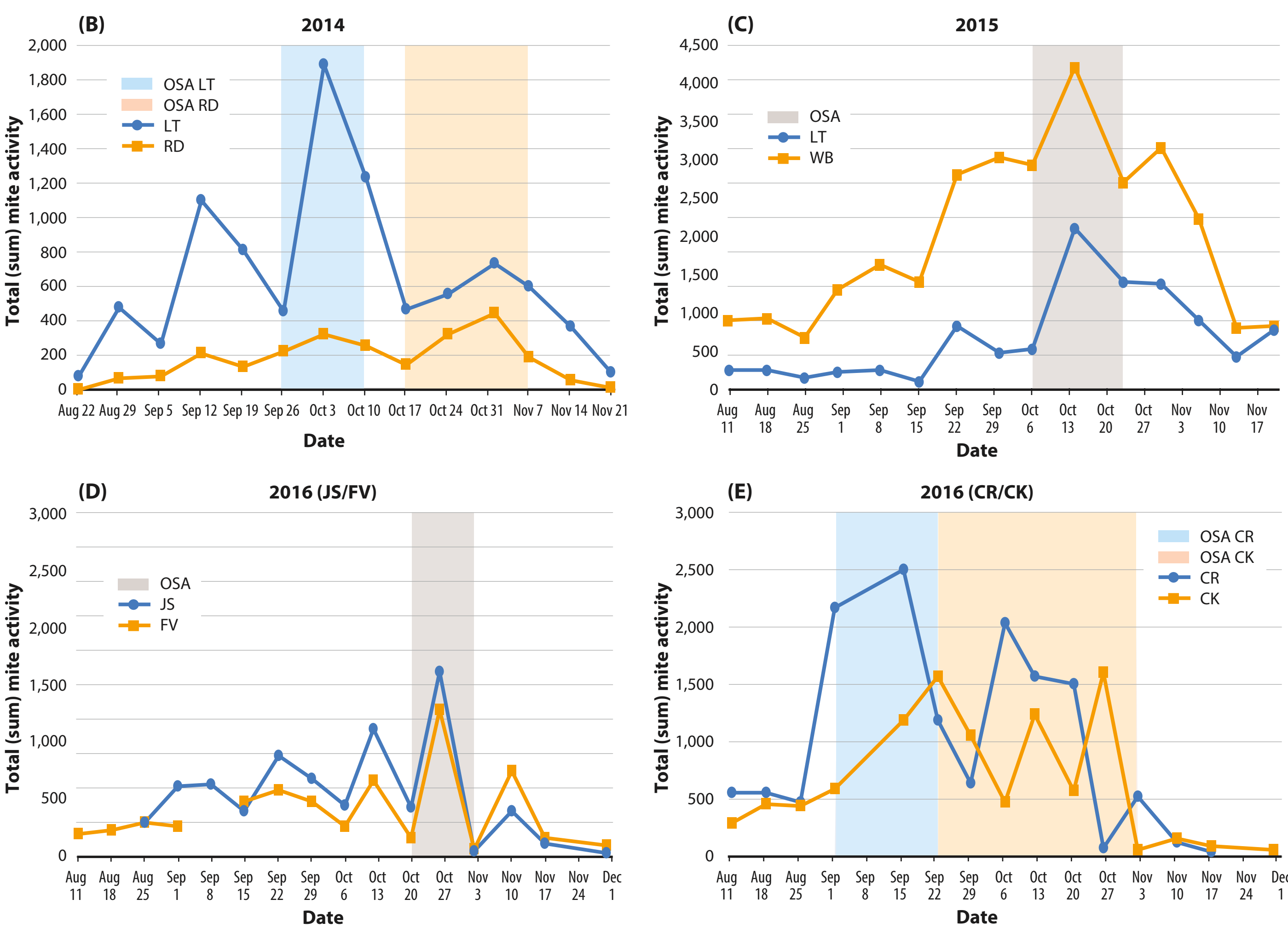


FIG. 1. Total erineum mite activity on double-sided monitoring tape at each vineyard, with optimal sulfur application (OSA) indicated by the shaded area(s). CK = Stags Leap; CR = Atlas Peak; DK = St. Helena; FH = Calistoga; FV = Stags Leap; JS = St. Helena; LD = Calistoga; LT = Coombsville; RD = Rutherford; WB = St. Helena.

were applied after harvest (table 1) and each treatment was applied over 10 rows and replicated three times at each site. Pretreatment monitoring was conducted in the growing season in which the treatment was applied (with the exception of 2013) and posttreatment monitoring was conducted at two or three time points in the growing season following the treatment. All monitoring was conducted in the two middle rows of each treatment area. On each monitoring date, 30 vines per replicate (90 vines per treatment) were inspected and the presence or absence of blisters was recorded on 10 leaves per vine (five leaves at each of two unique node positions corresponding to basal and upper shoot positions).

For the purposes of analysis, these 10 observations were combined to create a mean score (blister value) for each vine. Mean blister scores were then calculated at each date for each treatment group. For the 2013 trial, a 2 x 3 mixed ANOVA was conducted [Treatment (control versus dry flowable sulfur) x Monitoring Date (posttreatment 1 versus posttreatment 2 versus posttreatment 3)]. Another 2 x 3 ANOVA was run for the 2015 trial; the monitoring date comparisons were pretreatment versus posttreatment 1 versus posttreatment 2. This became a 3 x 3 mixed ANOVA for the 2016 trial due to an additional dusting sulfur treatment.

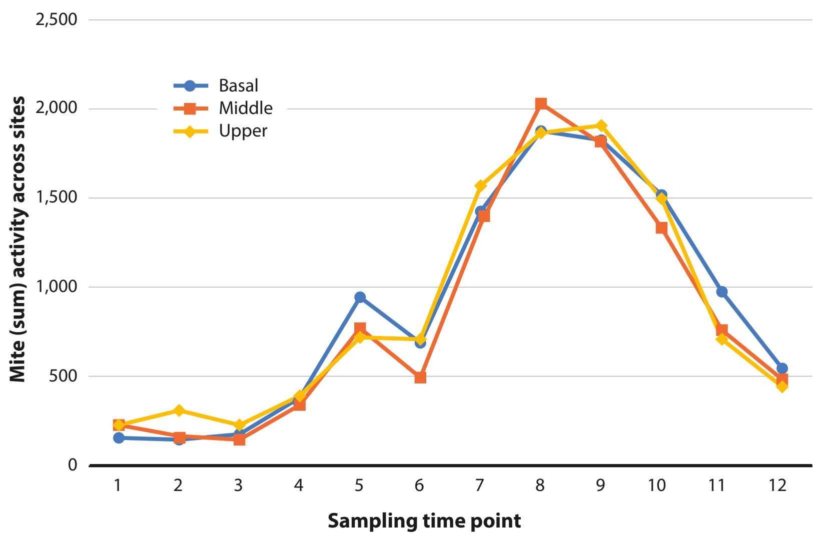


FIG. 2. Erineum mite activity on monitoring tapes was similar across shoot positions (basal, middle, upper) where tapes were deployed.

Erineum mite autumn migration patterns

Aside from one site in Rutherford (RD), where mites were not detected until Aug. 29, 2013 mites were found in all vineyard sites at the time that monitoring was initiated (no earlier than Aug. 11 or 1,687 degree days); mites increased to a peak before declining to (near) zero at the end of the monitoring period (no later than Nov. 30 or 4,073 degree days). Across all study periods, mite activity did not differ significantly between shoot positions, with very similar activity observed throughout the canopy (fig. 2). Peak mite activity across sites aligned more closely with calendar date than with accumulated GDD, likely due to the importance of photoperiod as the most predictable environmental indicator of changing seasons and hence the trigger for

TABLE 2. Accumulated growing degree days (GDD) and calendar date for peak erineum mite activity and optimal timing of sulfur applications targeting migrating erineum mites

Site* (code)	Numerical peak of mite activity (cumulative GDD [°F])	Optimal timing for sulfur application (cumulative GDD [°F])†	Optimal timing for sulfur application (date)	Numerical peak of mite activity (date)
2013				
St. Helena (DK)	3,464	3,374–3,617	Oct 4–Oct 25	Oct 11
Calistoga (LD)	3,421	3,337–3,631	Oct 4–Nov 1	Oct 11
Calistoga (RD)	3,350	3,161–3,576	Sep 27–Nov 1	Oct 11
Calistoga (FH)	3,533	3,271–3,617	Sep 27–Oct 25	Oct 17
2014				
Calistoga (RD)	3,604	3,427–3,664	Oct 17–Nov 7	Nov 1
Coombsville (LT)	3,292	3,162–3,435	Sep 26–Oct 10	Oct 3
2015				
Coombsville (LT)	2,813	2,669–2,936	Oct 6–Oct 23	Oct 14
St. Helena (WB)	3,370	3,209–3,518	Oct 6–Oct 23	Oct 14
2016				
Stags Leap (FV)	3,524	3,433–3,593	Oct 19–Nov 2	Oct 26
Stags Leap (CK)	3,030	2,493–3093	Sept 22–Nov 2	Oct 26
Atlas Peak (CR)	2,316	2,199–2,447	Sept 1–Sept 22	Sep 15
St. Helena (JS)	3,772	3,674–3,859	Oct 19–Nov 2	Oct 26

* All monitoring sites were commercial vineyards located in Napa County, California.

† Period determined by when mite activity scores significantly increased to peak levels, compared to earlier in the season, and when mite scores subsequently dropped significantly after the peak.

migration and dormancy (Gullan and Cranston 2000). We are therefore reporting mite activity as a function of calendar date rather than GDD (fig. 1A–1E). A bell-shaped pattern in mite activity was recorded at seven of 12 monitoring sites in 2013–2015 (fig. 1A–1C). In 2014, the Rutherford site (fig. 1B) recorded low mite activity compared with other sites but a small peak remained evident. We documented greater fluctuation in activity at the sites monitored in 2016 (fig. 1D and 1E), and we noted more than one peak in activity at several sites. At every site, ANOVA revealed that changes in mite activity were statistically significant at some point (*ps* < 0.05). Post hoc *t*-tests were employed to determine when mite activity differed significantly at the numerical peak from the rest of the season. This helped to identify the optimum window for sulfur applications that target migrating mites (table 2).

With few exceptions (fig. 1E; table 2), the optimal window for sulfur applications across all years was between Sept. 1 and Nov. 7 (2,199 to 3,859 GDD). At 10 of 12 sites, mite activity peaked numerically in October. For 11 of 12 sites, the optimal sulfur application period fell between the last week of September (after Sep. 21) and the first week of November (before Nov. 8). We therefore concluded that in the North Coast region, this six-week period is the best application window for sulfur treatments. This lengthy period should allow for some flexibility to delay applications until after the grape harvest. Because we recorded variability in mite activity across location and season, site-specific monitoring of the migration could determine peak activity and ensure that sulfur applications are responsibly applied. Monitoring practices could incorporate the use of double-sided tape, as demonstrated in this and other studies (Walton et al. 2007; Bernard et al. 2005), although further work is needed to optimize techniques for use by practitioners.

Sulfur applications reduced leaf blistering in the following season

Across all trial sites and study years, a postharvest application of sulfur significantly reduced the incidence of leaf blistering in the subsequent growing season (fig. 3). In the 2013 trial (fig. 3A), no blisters were found on any treated vines — on any of the posttreatment monitoring dates (compared to the untreated vines ($p < 0.001$). In the 2015 trial (fig. 3B), there was no pretreatment difference in the incidence of leaf galling. However, there was a significant reduction in mean blister score on both the posttreatment monitoring dates, compared to the control (*ps* < 0.001) (fig. 3B). During posttreatment monitoring, mean blister scores in the control fell to 39% to 40% of the pretreatment score, whereas the dry flowable sulfur treatment reduced blistering to less than 10% of pretreatment values. In the 2016 trial (fig. 3C), there was a significant effect of sulfur treatment ($p = <.001$) but also a significant treatment x date interaction ($p = < 0.001$). Post

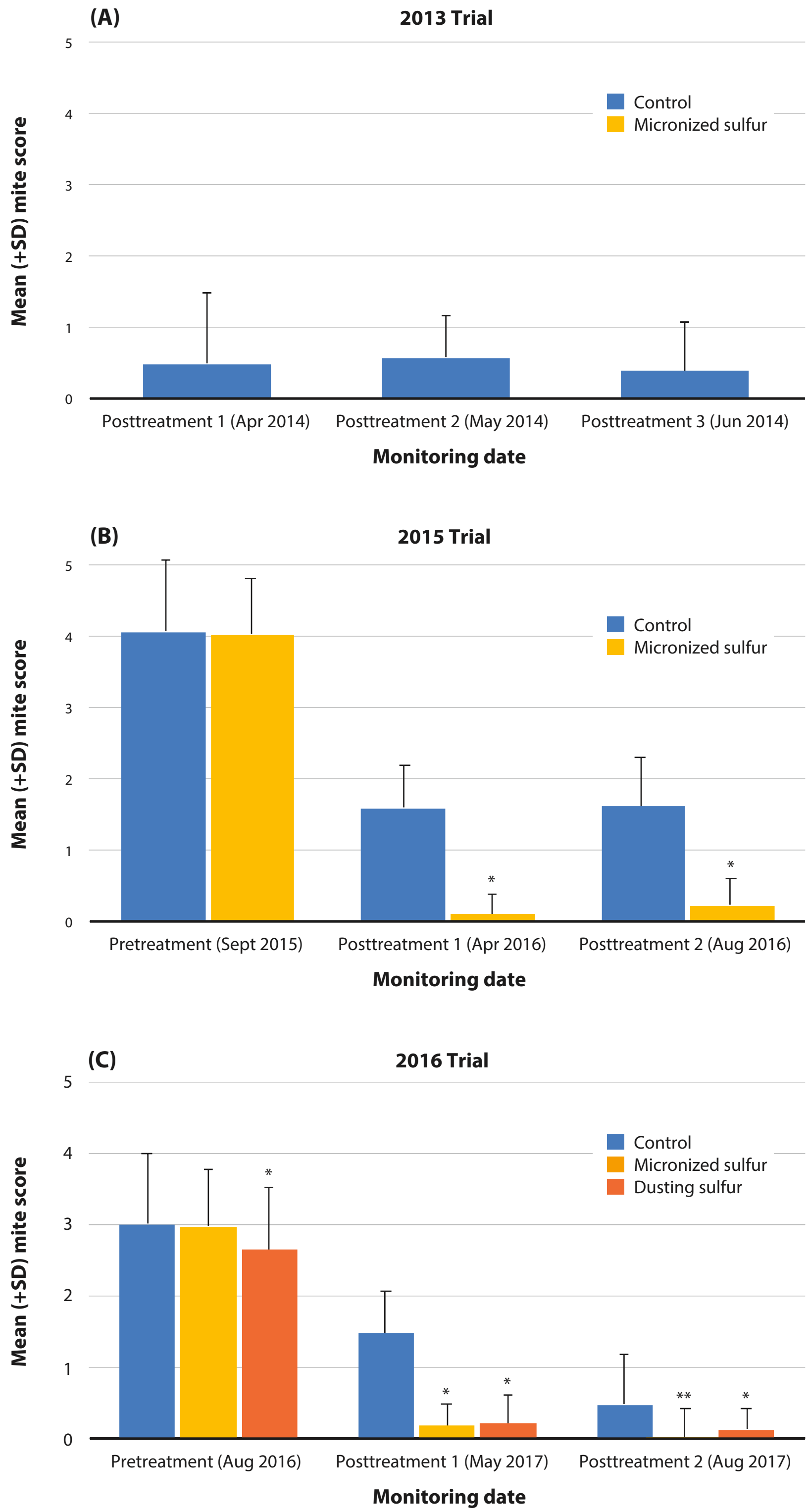


FIG. 3. Summary of mean blister scores for (A) 2013 trial site, (B) 2015 trial site and (C) 2016 trial site. In 2013 and 2015, a postharvest dry flowable sulfur application (5 lb per acre in 75 gallons of water) was compared to an untreated control. In 2016, sulfur treatments included both dry flowable sulfur (5 lb per acre in 75 gallons of water) and sulfur dust (12 lb per acre). An asterisk (*) above the treatment bar indicates a significant effect of treatment compared to control. A double asterisk (**) indicates significant effect of the dry flowable treatment compared to both control and dusting treatment.

hoc *t*-tests exploring the interaction revealed that pretreatment blister scores started lower ($ps < 0.05$) in the dusting sulfur blocks, compared with the control blocks. At posttreatment, both dry flowable and dusting sulfur blocks had significantly lower blister scores compared with the control blocks: Control scores were reduced to 49% and then 16% of pretreatment scores. Blistering in the dry flowable and dusting sulfur treatments were reduced to less than 10% of pretreatment incidence. By the second posttreatment monitoring, incidence of leaf blistering was significantly lower ($p < 0.01$) in the dry flowable compared to dusting sulfur treatment.

These findings indicate that postharvest dry flowable sulfur applications in commercial vineyards can be used to reduce blistering associated with erineum mite. Dusting sulfur also appeared effective, though our evaluations were confounded by the low pretreatment mite populations in these blocks. However, in posttreatment sampling, blister formation in the dry flowable sulfur treatment was eventually lower than dusting sulfur, suggesting that the former may be more effective.

Conclusion

Postharvest applications of dry flowable sulfur significantly reduced the incidence of blistering of grapevine leaves by erineum mites in the subsequent growing season. Dusting sulfur may also be effective, although our results were confounded, suggesting that future studies should reassess the effects of this treatment. Future studies should also evaluate potential multiyear effects to determine application frequency, establish treatment thresholds and evaluate efficacy in other growing regions. Sulfur applications should be made during the period when mites are moving between their in-season feeding sites (leaves) to overwintering sites (buds). In our trial sites in Napa County, most of this activity occurred between the last week of September and the first week of November, indicating this as a key period to target applications aimed at reducing blistering. Variations across monitoring sites and seasons indicate the value of site-specific monitoring to elucidate local patterns of movement. The occurrence of the peak activity period should also be explored for other growing regions. Successful monitoring strategies will likely incorporate the use of double-sided tape, though these methods need to be optimized for uptake by practitioners. Postharvest sulfur applications are an alternative to in-season applications, particularly when leaf blistering is not obvious until later in the growing season (during berry ripening). CA

Data analysis

Migration patterns

Each vineyard was analyzed independently when testing for changes in mite activity over the monitoring period. Total (summed) mite activity was calculated for descriptive purposes to represent total number of mites found on each sampling date. Mean mite activity scores were then analyzed using a repeated measures ANOVA with tape scores as the dependent variable and time points (date) as the repeated measure variable. In each case this confirmed that mite activity varied at some point over the season. We then conducted selected post hoc paired *t*-tests between specific time points of interest to confirm when peak mite activity was significantly different from earlier and later in the season to justify when sulfur should be applied. A minority of time points were somewhat skewed (skewness statistic between 1 and 2), which transforming the data did not entirely correct. For this reason, we conducted exploratory non-parametric analyses using Friedman's Test and Wilcoxon Sign Tests, but the conclusions remained the same so in the main text we report results of the ANOVA and *t*-tests.

Shoot location

To generate sufficient data points at each shoot location (basal, middle, upper) to analyze effects of shoot location on mite activity, we examined collated mite activity across all monitored vineyards for each year.

General

Greenhouse-Geisser values were used where Sphericity was violated. In all statistical tests a *p*-value of 0.05 was taken as the criterion for significance, and where appropriate Holm's sequential Bonferonni adjustment was applied to post hoc tests.

M.L. Cooper is Farm Advisor and M.B. Hobbs is Research Associate, UC Cooperative Extension (UCCE), Napa County; B. Strode was formerly Research Associate, UCCE Sonoma County; and L.G. Varela is North Coast Advisor Emeritus, UC Integrated Pest Management Program, Santa Rosa.

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REVIEW

Supporting evidence varies for rangeland management practices that seek to improve soil properties and forage production in California

The authors synthesized the effects of silvopasture, grazing, compost application and riparian restoration on soil properties and forage production.

by Chelsea J. Carey, Kelly Gravuer, Sasha Gennet, Dillon Osleger and Stephen A. Wood

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Abstract

California is increasingly investing in policies and programs that promote soil stewardship on natural and working lands as a way to help achieve multiple goals, including improved forage production and climate change mitigation. To inform the growing expectations for rangeland management activities to promote such services, we conducted an evidence synthesis assessing how four commonly suggested practices (silvopasture, prescribed grazing, compost application and riparian restoration) affect a suite of soil properties and plant-related metrics throughout the state. We extracted data on soil properties that are potentially responsive to management and relevant to soil health. We also extracted data on aboveground forage production, forage nitrogen content and herbaceous species richness. Our search resulted in 399 individual soil observations and 64 individual plant observations. We found that the presence of oaks had the largest effects on soil properties, with soil organic carbon, microbial biomass and other measures of soil fertility increasing beneath oak canopies. The presence of grazing increased compaction and total nitrogen, and decreased pH. Compost applications did not significantly affect any of the measured soil properties, but did boost forage production. Due to a lack of published data, we were unable to characterize the influence of rangeland riparian restoration on any of the soil or plant metrics in our review.

Rangelands make up approximately 57 million acres of California's land area, with Mediterranean-type grasslands, shrublands and woodlands accounting for 30% of this estimate (FRAP 2018). The predominant economic use of California's rangelands is forage production, which supports a $2.6 billion cattle industry (CDFA 2018). These landscapes are also globally recognized as hot spots of biological diversity (Myers et al. 2000), and they provide an array of ecosystem services beyond food production, including water and nutrient cycling (Byrd et al. 2015), pollination (Chaplin-Kramer et al. 2011), carbon storage for climate change mitigation (Dass et al. 2018), and recreational opportunities (Plieninger et al. 2012).

As the land area of California's rangelands continues to shrink due to dramatic population growth and concomitant cropland and urban expansion (Cameron et al. 2014), societal demands from each acre are increasing. Private ranchers and public rangeland managers now desire, or are expected, to predictably optimize production of the full array of values and

Over 3 miles of riparian area at Tolay Lake Regional Park, Petaluma, California, that have been actively restored by Point Blue Conservation Science's Students and Teachers Restoring a Watershed (STRAW) program. The white squares are plants installed by volunteers, including coast live oak, buckeye, coffeeberry, California rose and more.

Isaiah Thalmayer, Point Blue Conservation Science services (Boyd and Svejcar 2009; Ferranto et al. 2014; Plieninger et al. 2012) in a way that promotes ecosystem resilience and adaptation to global and regional pressures (Hruska et al. 2017; Sayre et al. 2012).

Soils are receiving increased attention within the scientific discourse on rangeland management because of their role in supporting ecosystem services like forage production and, in some cases, climate change mitigation (Byrnes et al. 2018; Derner et al. 2016; Derner et al. 2018). In California, as elsewhere, this recognition is making its way into the public sphere, influencing both policy and practice (Bradford et al. 2019; Byrnes et al. 2017).

Indeed, a 2011 survey of California ranchers identified that maintaining or improving soil "health" was, on average, a midpriority goal that ranked similarly to managing weeds and water quality (Roche et al. 2015). Although the same survey revealed that managing soils to promote carbon sequestration was not an important goal for ranchers (Roche et al. 2015), since 2011 there have been several new policies and incentive programs put in place to promote carbon sequestration on rangelands. For example, rangeland soil management is now named by the California 2030 Natural and Working Lands Climate Change Implementation Plan as a critical climate change mitigation strategy, and policy and funding through the California Department of Food and Agriculture's Healthy Soils Program aim to maximize this outcome.

The growing expectation for range management activities to promote on-site (e.g., forage production) and public (e.g., carbon sequestration) ecosystem services demands a quantitative synthesis of the literature summarizing whether, and to what degree, desired outcomes have been shown to be achievable by implementing these activities. To that end, we synthesized the documented effects of four commonly prescribed rangeland management practices on a suite of soil properties and plant-related metrics in California. These management practices, which are currently incentivized by the Healthy Soils Program, are silvopasture establishment (USDA NRCS 2016, 381), prescribed grazing (USDA NRCS 2016, 528), compost application, and riparian restoration (USDA NRCS 2016, 391).

Previous work indicates that these practices have the potential to influence plant dynamics and increase soil organic carbon (hereafter soil C) in some rangeland ecosystems (Byrnes et al. 2018; Dybala, Matzek, et al. 2019; Gravuer et al. 2019) — and there is reason to believe they can also affect other soil properties, such as soil compaction and nitrogen (N) availability (Byrnes et al. 2018; Dahlgren et al. 1997; Zhou et al. 2017). In California's arid and semiarid Mediterranean climate, however, the effects of rangeland management may be overwhelmed by strong interannual variability in precipitation (Jackson and Bartolome 2007), spatial variability in soil type and topography (Booker et al. 2013; Graham and O'Geen 2016) and land-use history (Huntsinger et al. 2007).

This variability results in mixed evidence for California rangelands to respond to management practices and generates risks associated with extrapolating results from single studies or from other, perhaps more malleable, mesic regions (Allen-Diaz and Jackson 2005). Our targeted search and synthesis of California's literature at least partially addresses these risks, and supplements ongoing work in the state that is providing scientific underpinnings for an expanding rangeland management framework.

Literature review and synthesis

We performed a subject-wide evidence synthesis on data derived exclusively from California rangelands. A subject-wide evidence synthesis is a way to review and summarize the effects of multiple practices or interventions simultaneously using some combination of qualitative and quantitative methods, and it can be a cost-effective approach to support management and policy decision making (Shackelford et al. 2019). In our synthesis, we extracted soil and plant data from relevant studies that fulfilled specific requirements and aggregated similar response metrics into umbrella categories (e.g., the cations category combines values of individual exchangeable cations, base saturation and cation exchange capacity).

For composite metric-management pairs that had soil observations across at least three sites, we assessed the overall influence of management practices on each metric using random effects meta-analysis modeling, with log response ratios as the effect size (Hedges et al. 1999). For composite plant metrics, we took the same approach but relaxed the criteria to two (rather than three) sites so we could include the effects of compost amendments. Where possible, we also broke apart the composite categories to look at the effect of management practices on contributing variables (on individual exchangeable cations, base saturation, etc.) and explored whether soil texture and aridity moderated the response of metrics to management across studies.

Because we were interested in documenting published evidence in addition to identifying gaps for metric-management pairs regardless of their potential to be included in a formal meta-analysis, we retained all management practices regardless of their support in the literature and qualitatively described our findings in those cases where evidence was limited. See the technical appendix online for more details.

Levels of evidence: Highly variable across management practices

Our literature review resulted in 399 individual soil observations compiled from 37 publications, reports or unpublished data sets, and 64 individual plant community observations from 26 publications (table 1; table 2). The resulting data set represented 35 unique study areas located across California's Mediterranean-type

TABLE 1. Studies included in the literature review

Publication	DOI (or other identifier)	Treatment category
Soil properties		
Callaway et al. 1991	https://doi.org/10.2307/1941122	Silvopasture
Camping et al. 2002	PSW-GTR-184	Silvopasture
Dahlgren et al. 1997	Biogeochemistry 39	Silvopasture
Dahlgren et al. 2003	https://doi.org/10.3733/ca.v057n02p42	Silvopasture
Eastburn et al. 2017	https://doi.org/10.1371/journal.pone.0166595	Silvopasture
Frost and Edinger 1991	https://doi.org/10.2307/4002959	Silvopasture
Herman et al. 2003	https://doi.org/10.1890/1051-0761(2003)013[0593:NDIAAG]2.0.CO;2	Silvopasture
Jackson et al. 1990	https://doi.org/10.1016/0167-8809(90)90126-X	Silvopasture
Marañón and Bartolome 1994	Madroño 41	Silvopasture
Moody and Jones 2000	https://doi.org/10.1016/S0929-1393(00)00053-6	Silvopasture
Parker and Muller 1982	The American Midland Naturalist 107(1)	Silvopasture
Perakis and Kellog 2007	https://doi.org/10.1007/s11258-006-9238-9	Silvopasture
Rice and Nagy 2000	https://doi.org/10.2307/2656747	Silvopasture
Stahlheber and D'Antonio 2014	https://doi.org/10.1111/rec.12103	Silvopasture
Tate et al. 2004	https://doi.org/10.2307/4003867	Silvopasture
Waldrop and Firestone 2006a	https://doi.org/10.1007/s00248-006-9100-6	Silvopasture
Waldrop and Firestone 2006b	https://doi.org/10.1007/s00248-006-9103-3	Silvopasture
Waldrop and Firestone 2004	http://dx.doi.org/10.1007/s00442-003-1419-9	Silvopasture
Camping et al. 2002	PSW-GTR-184	Grazing
Dahlgren et al. 1997	Biogeochemistry 39	Grazing
Esch et al. 2013	https://doi.org/10.1007/s11104-012-1463-5	Grazing
Funk et al. 2015	https://doi.org/10.1111/rec.12162	Grazing
Gennet et al. 2017	https://doi.org/10.1371/journal.pone.0176367	Grazing
George et al. 2004	https://doi.org/10.3733/ca.v058n03p138	Grazing
Hayes and Holl 2003	https://doi.org/10.1111/j.1523-1739.2003.00281.x	Grazing
Hayes (unpublished)	Personal communication	Grazing
Herman et al. 2003	https://doi.org/10.1890/1051-0761(2003)013[0593:NDIAAG]2.0.CO;2	Grazing
Marty 2015	https://doi.org/10.1111/rec.12226	Grazing
Oates et al. 2008	https://doi.org/10.1007/s11273-007-9076-0	Grazing
Ratliff and Westfall 1971	PSW-GTR-254	Grazing
Skaer et al. 2013	https://doi.org/10.1111/j.1654-1103.2012.01460.x	Grazing
Steenwerth et al. 2002	https://doi.org/10.1016/S0038-0717(02)00144-X	Grazing
Stromberg and Griffin 1996	https://doi.org/10.2307/2269601	Grazing
Tate et al. 2004	https://doi.org/10.2307/4003867	Grazing
Ryals et al. 2014	https://doi.org/10.1016/j.soilbio.2013.09.011	Compost amendment
Silver et al. 2018	CCCA4-CNRA-2018-002	Compost amendment
Briar et al. 2012	https://doi.org/10.1016/j.ejsobi.2011.11.006	Riparian restoration
Plant-related metrics		
Bartolome and McClaran 1992	https://doi.org/10.2307/4002536	Silvopasture
Callaway et al. 1991	https://doi.org/10.2307/1941122	Silvopasture
Eastburn et al. 2017	https://doi.org/10.1371/journal.pone.0166595	Silvopasture
Femi et al. 2005	https://doi.org/10.2111/1551-5028(2005)058[0352:TEOLOC]2.0.CO;2	Silvopasture
Frost and McDougald 1989	Journal of Range Management 42	Silvopasture
Jackson et al. 1990	https://doi.org/10.1016/0167-8809(90)90126-X	Silvopasture
Marañón and Bartolome 1994	Madroño 41	Silvopasture
McLaran and Bartolome 1989	Madroño 36	Silvopasture
Perakis and Kellog 2007	https://doi.org/10.1007/s11258-006-9238-9	Silvopasture
Ratliff et al. 1991	Journal of Range Management 44	Silvopasture
Seabloom et al. 2009	https://doi.org/10.1890/08-0671.1	Silvopasture
DiTomaso et al. 2008	https://doi.org/10.1614/IPSM-07-031.1	Grazing
Funk et al. 2015	https://doi.org/10.1111/rec.12162	Grazing
Gornish et al. 2018	https://doi.org/10.1071/RJ18020	Grazing
Harrison et al. 2003	https://doi.org/10.1046/j.1523-1739.2003.01633.x	Grazing
Hayes and Holl 2003	https://doi.org/10.1111/j.1523-1739.2003.00281.x	Grazing
Jackson et al. 2006	https://doi.org/10.1007/s10021-005-0166-7	Grazing
Keeley et al. 2003	https://doi.org/10.1890/02-5002	Grazing
Marty 2015	https://doi.org/10.1111/rec.12226	Grazing
Safford and Harrison 2001	https://doi.org/10.2307/3061016	Grazing
Skaer et al. 2013	https://doi.org/10.1111/j.1654-1103.2012.01460.x	Grazing
Stromberg and Griffin 1996	https://doi.org/10.2307/2269601	Grazing
Ryals et al. 2016	https://doi.org/10.1002/ecs2.1270	Compost amendment
Ryals and Silver 2013	https://doi.org/10.1890/12-0620.1	Compost amendment
Briar et al. 2012	https://doi.org/10.1016/j.ejsobi.2011.11.006	Riparian restoration
Gornish et al. 2017	https://doi.org/10.1371/journal.pone.0176338	Riparian restoration

TABLE 2. Control and treatment scenarios for each management practice, and associated number of studies and unique observations (parentheses) recovered for soil properties and plant-related metrics

Management practice	Control	Treatment	Soil properties	Plant metrics
Silvopasture	No oak present (e.g., open grassland)	Oak present (e.g., oak canopy)	18 (237)	11 (28)
Grazing	Ungrazed	Grazed	16 (131)	11 (22)
Compost amendment	Unamended	Amended	2 (20)	2 (8)
Riparian restoration	Unrestored	Restored	1 (11)	2 (6)
Total	—	—	**37 (399)**	**26 (64)**

A unique observation is delineated by a combination of publication ID, management practice, study area and response variable.

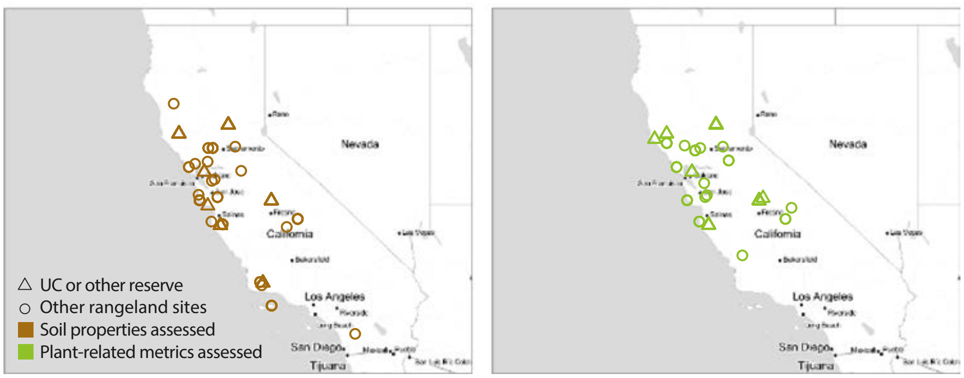

FIG. 1. Map of study sites included in the literature review, showing where soil properties and plant-related metrics were assessed.

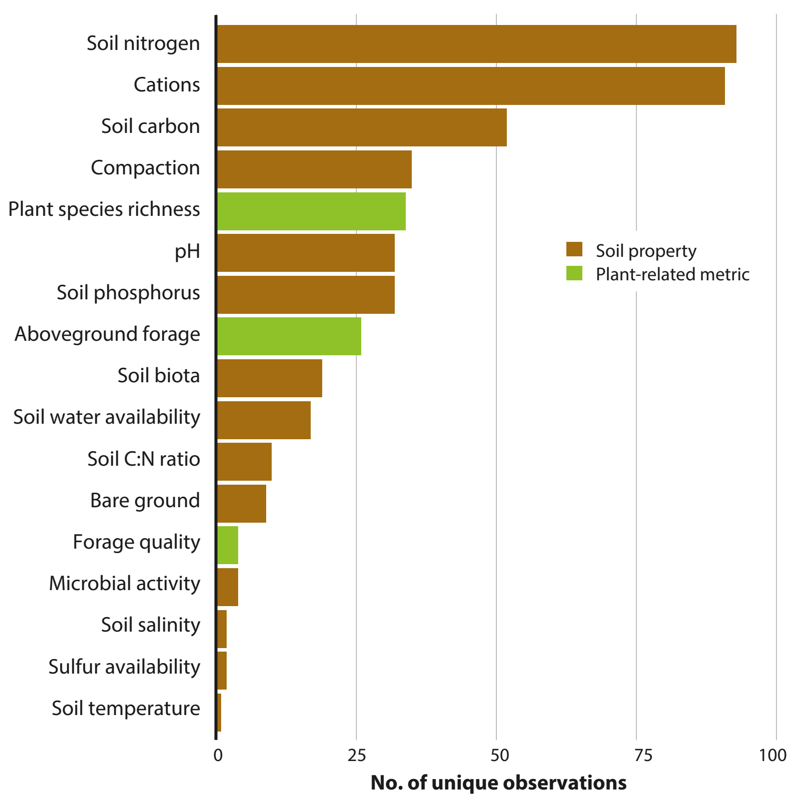

FIG. 2. The number of unique observations representing each soil property and plant-related metric recovered from the literature.

grassland, shrubland and woodland systems (fig. 1); eight of these areas were UC reserves or other research stations, from which 71% and 50% of the soil and plant-related data sets were derived, respectively. Oak presence had the greatest number of soil observations (59% of the compiled data set), followed by grazing (33%), compost additions (5%) and riparian restoration (3%). This pattern held for plant metrics as well, with 44%, 34%, 13% and 9% of the observations associated with oak presence, grazing, compost additions and riparian restoration, respectively.

Across all studies, the number of unique observations per metric varied from one to 93 (fig. 2), with soil N being the most frequently measured parameter, followed by cation availability and soil C content. Only 12 studies presented both soil and plant-related metrics, limiting our ability to draw direct relationships between the response of soil properties and plant dynamics to management intervention.

Silvopasture: Oaks enhance soil fertility

Silvopasture is an ancient practice that has been implemented in many regions around the world and is recognized for its potential to optimize economic and ecological production while building resilience into some working landscapes (Jose and Dollinger 2019). The Natural Resources Conservation Service defines silvopasture as the establishment or management of desired trees and forages with the purpose of providing improved forage production, shelter for livestock, soil quality and carbon sequestration, biological diversity and reduced erosion (USDA NRCS 2016).

In California's published literature, silvopasture establishment on rangelands is best represented by work on oak trees (*Quercus* spp.). And while oaks were historically clear-cut with the intention of maximizing forage production in California (a foundational assumption that was later challenged) (Huntsinger and Fortmann 1990), hardwood rangeland landowners increasingly value and manage for oaks, and the state is striving to increase the pace and scale of oak stewardship by tripling funding for oak savanna reforestation by 2030 (CNWL CCIP 2019; Huntsinger et al. 2010). As such, we focused specifically on assessing the effects of oak presence on soil properties and plant-related metrics in our review, and we included oak removal studies in addition to observational studies measuring conditions under oaks versus in nearby open grasslands.

We found the presence of oaks had the largest effects on soil properties of any of the management practices assessed. When the data were pooled across all studies and contexts, soils beneath oak canopies were more fertile (higher levels of soil phosphorus [P], soil N and cation availability), had greater amounts of soil C and microbial biomass, were less compacted and contained more soil moisture than nearby open grasslands (fig. 3). The effects of oaks on soil N were reflected in both the total N and plant-available N pools, and the effects on cations were largely driven by increases in exchangeable potassium, magnesium and calcium (fig. 4).

When accounting for environmental context, we found that soil texture moderated the effect of oaks on soil C such that the increase beneath oaks was amplified in soils with higher clay content (fig. 5). The effect of oaks on soil P was also greatest in finer-textured soils, and in less arid sites (data not shown). This context dependency aligns with expectations from theory and practice (Booker et al. 2013; Byrnes et al. 2018), suggesting that silvopasture-induced gains in soil C and some metrics of soil fertility, while still apparent, may be muted in sandy soils and hotter, drier areas.

While it is possible that oaks preferentially establish on sites that are inherently more fertile, rapid declines in soil fertility have been observed following the removal of oaks, indicating that the trees create rather than respond to these conditions (Dahlgren et

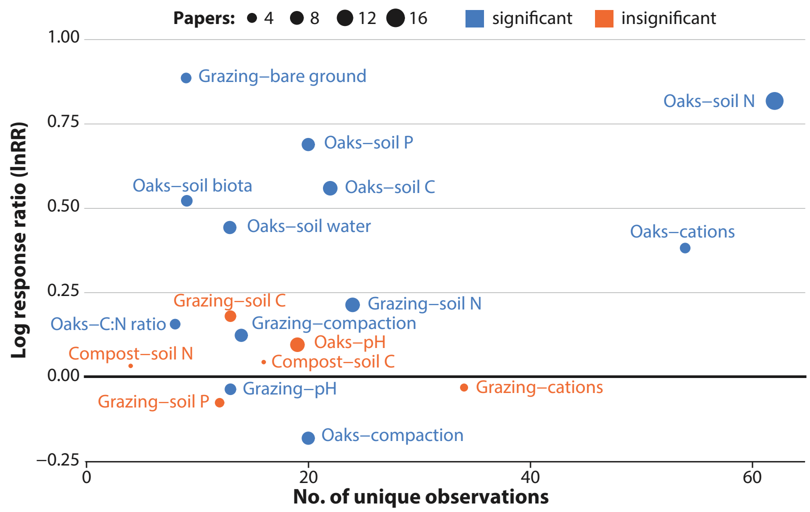

FIG. 3. Mean response ratio (lnRR), number of unique observations and significance of management–soil property relationships. Significant difference between treatment and control for a given soil property is denoted by color, with blue points significant and red points insignificant. The size of each circle is a function of the number of papers supporting that relationship.

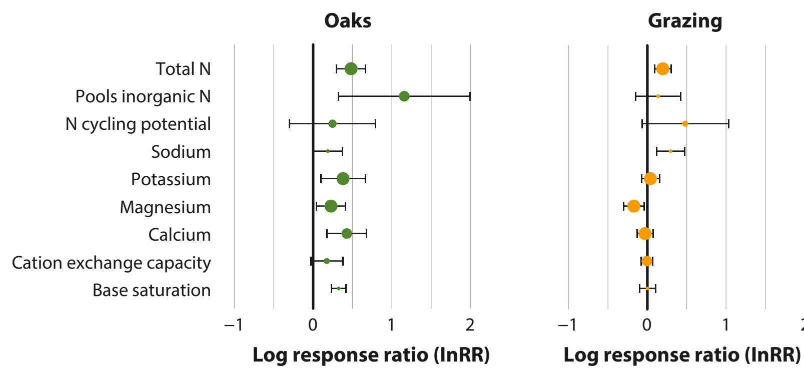

FIG. 4. Mean response ratio (lnRR) and 95% confidence intervals (CI) for the response of soil N availability and individual cation metrics to oaks and the presence of grazing. If a metric has lnRR > 0 and a 95% CI that does not overlap zero, it significantly increased in the presence of oaks or grazing. The size of each circle is a function of the number of unique observations supporting that relationship.

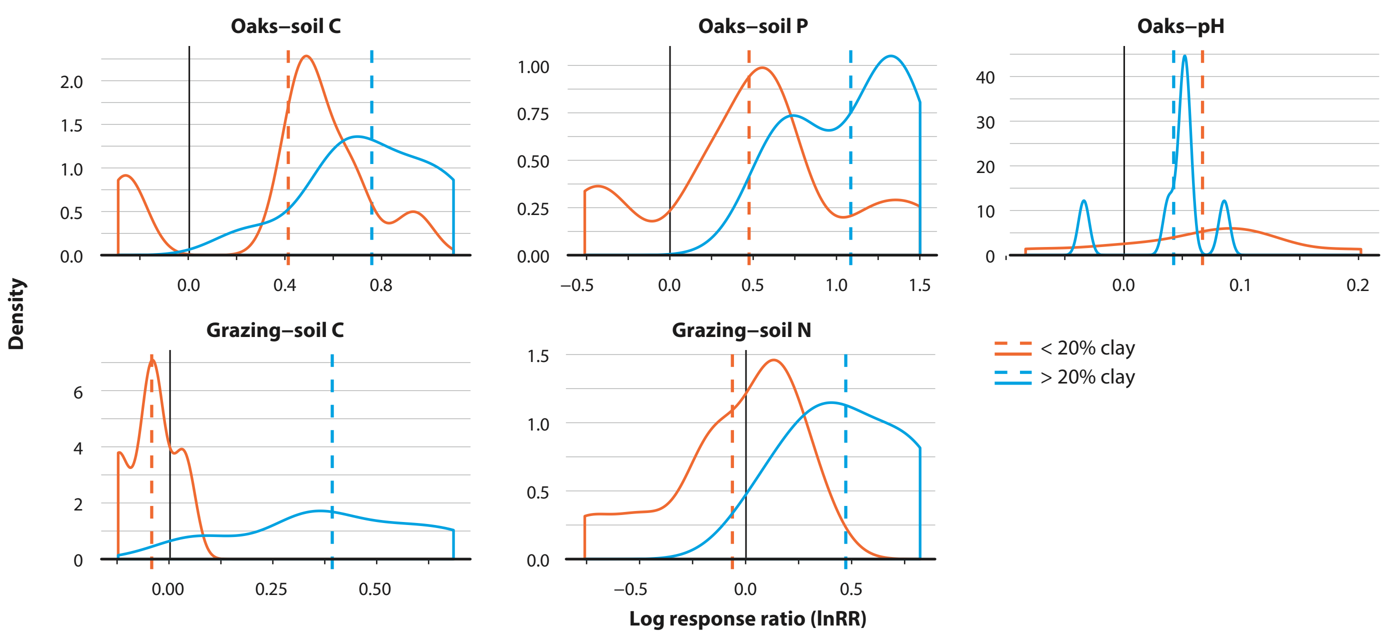

FIG. 5. Density plot displaying significant relationships between oak and grazing response ratios (lnRR) and soil texture (percentage clay). Dashed lines = mean response ratio for a given texture category. Nine other management-soil property relationships were assessed and returned nonsignificant results (data not shown). The modulating effects of soil texture were also assessed for oaks on forage, and grazing on plant species richness. Neither relationship was significant (data not shown). Where possible, a similar exercise was performed to assess how aridity moderates management impacts. Aridity was found to only significantly moderate the effects of oaks on soil phosphorus levels and forage production (data not shown).

al. 2003; Herman et al. 2003). This "island of fertility" effect associated with oaks has been attributed to multiple potentially interacting mechanisms. These include the interception of wet and dry nutrient deposition by oak canopies (Callaway and Nadkarni 1991; Perakis and Kellogg 2007), greater litter inputs beneath oak trees (Dahlgren and Singer 1991; Knops et al. 1996), increased soil faunal activity (Dahlgren et al. 2003), hydraulic lift (Ishikawa and Bledsoe 2000) and increased root interception of nutrients that would otherwise be leached from the system (Perakis and Kellogg 2007).

It is also possible that oak roots relocate nutrients from adjacent open grasslands, concentrating them beneath their canopy — or that livestock elevate soil nutrients as they seek shade beneath these trees. However, both of these mechanisms appear unlikely (Dahlgren et al. 1997; Perakis and Kellogg 2007). Whatever the driving cause, it is clear that oaks create patches of soil fertility associated with increased levels of soil C and microbial biomass across California's rangelands, with possible consequences for public benefits such as climate change mitigation.

The effects of oaks on soil fertility did not seem to translate into similar effects on forage productivity and herbaceous species richness, at least with enough consistency to be significant when summarized across all

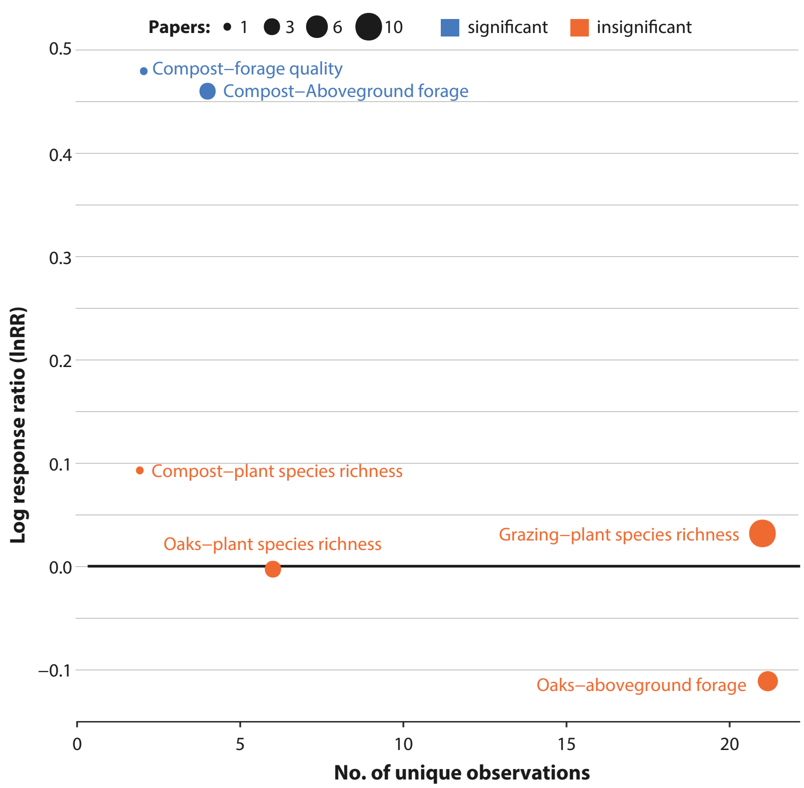

FIG. 6. Mean response ratio (lnRR), number of unique observations and significance of management-plant metric relationships. Significant difference between treatment and control for a given soil property is denoted by color, with blue points significant and red points insignificant. The size of each circle is a function of the number of papers supporting that relationship.

studies and contexts (fig. 6). In the case of forage production, this is perhaps not surprising since considerable variability exists among individual oak trees, with some trees promoting forage production and others inhibiting it (Callaway et al. 1991).

Prior work has found oak individuals that inhibit understory production typically have shallower root systems, a phenomenon that may be due to any number of environmental or genetic reasons and which results in competition for limiting resources or suppression of herbaceous plant growth by allelopathic chemicals (Callaway et al. 1991; Koteen et al. 2015). At a watershed-scale, forage productivity may also show an inverse relationship with the density of oak trees (Battles et al. 2008). Despite the potential importance of these factors in driving oak-forage productivity relationships across the state, we were unable to account for either in our review. However, we were able to detect a relationship with aridity, with forage production decreasing beneath oak trees in cooler, wetter sites (data not shown).

A number of areas for future work stand out as priorities for this management practice. First, research is needed to quantify rates of change in soil properties with oak establishment, as the literature to date generally focuses on comparing established trees (> 80 years old) to adjacent open grasslands. Understanding how quickly and how much each soil property changes after an oak planting will be important for policy and practice, which have expectations on much shorter time scales (< 5 years).

At the same time, given the strong and relatively consistent influence of mature oaks on soil properties, priority should be placed on determining how to improve oak regeneration and ensure the success of silvopasture projects presently and in California's future climate (Bernhardt and Swiecki 2015). Finally, because forage dynamics are critical to livestock production systems, future work should continue disentangling patterns in forage productivity and bolstering evidence for oak impacts on forage quality.

Grazing: Soil texture affects response of soil C

In California's rangelands — which typically receive minimal inputs like irrigation and fertilizer — livestock grazing is the dominant land use and is therefore one of the most readily available management tools for landowners (Huntsinger et al. 2010). The ability of grazing to influence ecosystem outcomes particularly in water-limited systems is an area of active debate (Booker et al. 2013; Sanderson et al. 2020; Stanton et al. 2018; Teague et al. 2013). However, grazing management has been shown through meta-analysis to alter soil properties such as soil C, total N and bulk density globally (Abdalla et al. 2018; Byrnes et al. 2018) and plant community dynamics regionally (Stahlheber and D'Antonio 2013).

Unfortunately, although our intent was to assess the effects of different grazing strategies, we were unable to go beyond presence-absence of grazing. Over half of the grazing studies (63%) reported grazing intensity, and most of these reported grazing during the growing season at low-moderate or moderate intensities.

Observations of extreme grazing intensities (low and heavy) were lacking, as were studies documenting the effects of year-round and dormant-season grazing (table 3). The near absence of these strategies in the literature probably reflects the fact that very little land is managed this way in California (Huntsinger et al. 2007), although management will certainly vary from site to site based on resource needs and management goals, and some regions may rely on year-round grazing more than others (Liffmann et al. 2000).

The relative uniformity of grazing strategies across presence-absence studies, along with the lack of studies that explicitly manipulate and compare deferment and within-season rest and rotation (i.e., compare among "grazing systems"), prevented us from quantitatively assessing the effects of these finer-level, but potentially important, moderators.

Our literature review revealed that the presence of grazing, when pooled across all studies and contexts, significantly influenced a number of soil properties (fig. 3). Specifically, grazed sites had greater soil compaction and considerably more bare ground than ungrazed sites, a pattern that has been shown elsewhere (Augustine et al. 2012; Byrnes et al. 2018), with possible consequences for outcomes such as water infiltration (reduced infiltration) (Savadogo et al. 2007) and grassland breeding bird habitat (increased suitability) (Gennet et al. 2017).

Grazed sites also had higher levels of soil N, driven by a small but significant increase in total N (fig. 4), and lower levels of exchangeable magnesium (fig. 4) and soil pH (fig. 3). This collectively indicates that grazing can influence soil fertility across California's landscapes. Increases in soil N with grazing have been reported in some global reviews (Abdalla et al. 2018) but not others (Byrnes et al. 2018), and without more information we are unable to determine the cause of such an increase in California. However, possible explanations include changes in plant species composition, biomass production and allocation, and spatial redistribution of N with livestock waste (Piñeiro et al. 2010).

Policymakers are increasingly interested in leveraging grazing management to help sequester carbon and achieve climate change mitigation goals (Byrnes et al. 2017). While evidence is mixed and estimates are highly uncertain, prescribed grazing has been suggested to sequester carbon at rates up to 1.8 metric tons per hectare per year in some mesic regions (Conant and Paustian 2002). Whether the sequestered carbon remains in the ground long enough to help mitigate climate change depends on various aspects of the system, including how protected the carbon is from microbial decomposition (Lavallee et al. 2020).

TABLE 3. Representation of different grazing strategies (intensity, season) in the literature

Grazing intensity				
Low	Low to moderate	Moderate	Heavy	Unreported or variable
1.7%	32.0%	13.4%	2.5%	50.4%

Grazing season			
Year-round	Growing season	Dormant season	Unreported
2.5%	56.3%	4.2%	37.0%

Numbers indicate the percentage of unique observations that comprised each category.

In California, the influence of grazing on soil C is thought to be small relative to factors such as climate and soil type, with the net effect depending on a number of site-specific conditions such as management history and soil texture (Stanton et al. 2018). Supporting this expectation, and in line with prior work (Silver et al. 2010), we found that across all studies the presence of grazing had no significant effect on soil C.

However, similar to oaks, we found that soil texture significantly modified the effect of grazing, such that grazing had more of a positive effect on soil C in soils with higher clay content (fig. 5). McSherry and Ritchie (2013) report a similar pattern for arid sites in their global meta-analysis. Possibly, sandier soils are more susceptible to C loss through reductions in vegetation cover and increased wind erosion of fine particles (Steffens et al. 2008). Finer-textured soils also have a greater capacity to stabilize increased inputs of organic material that may occur through compensatory growth of vegetation (Jackson and Bartolome 2007; Singh et al. 2018).

While this result is derived from a relatively small sample size and should therefore be interpreted with caution, it suggests that soils with higher clay content, such as those of the Central Coast and Sacramento Valley, may be more amenable to grazing-induced improvements in soil C — and other measures of soil fertility (fig. 5) — than those with lower clay content, such as soils of the San Joaquin Valley. Future work should focus on understanding whether, and to what degree, this relationship holds true with an expanded data set across the state.

A number of priorities for future grazing research emerged from our review. Specifically, robust long-term and well-replicated experiments are needed to assess how soil properties and plant metrics co-vary in response to grazing strategies across California's diverse rangeland landscapes. These experiments should aim to go beyond presence-absence and begin identifying the impact of strategies such as within-season rest and rotation. Soil properties that may deserve elevated attention include microbial biomass and soil moisture (or other proxies of soil water availability), as these lacked enough evidence to be included in the current review and yet are important components of semi-arid Mediterranean-type systems.

Finally, while some work has been done to assess the effects of residual dry matter — a proxy for grazing intensity — on forage productivity (Bartolome et al. 2007), few studies directly compare the effects of grazing strategies on this plant metric; therefore, measurements of forage productivity and quality in response to different grazing strategies are needed.

An experimental plot at TomKat Ranch, Pescadero, California, receives a one-time compost application as part of a larger statewide NRCS project to evaluate the effects of compost on soil- and plant-related outcomes.

Compost amendments: Applications increase forage

Applying composted organic amendments to rangeland soils is a practice increasingly promoted by government and nongovernment agencies across the state. These amendments have been shown to improve on-ranch soil C sequestration and forage quantity and quality at two sites in Northern California (Ryals et al. 2014; Ryals et al. 2016). In addition, a recent global meta-analysis by Gravuer et al. (2019) showed that rangeland forage production and soil C increase in the first few years following application of organic amendments. However, Gravuer et al. (2019) caution that these benefits may come with trade-offs depending on the type of organic material used and the rates of application.

If the potential on-site ecosystem benefits of compost amendments lead to increased demand for compost across the state, that could drive greater diversion of organic wastes away from traditional fates such as landfills and help to mitigate greenhouse gas emissions downstream as well (DeLonge et al. 2013). For these reasons, expert opinion ranks rangeland compost amendments as one of the most promising ways to help achieve statewide climate change mitigation goals (Stanton et al. 2018), and this practice is currently incentivized through the Healthy Soils Program. The expectation by many, although perhaps not all (Booker et al. 2013), is that these amendments will improve forage dynamics for livestock production systems while simultaneously promoting climate adaptation and resiliency of the state's working landscapes (Flint et al. 2018).

In our review, we were able to assess the effects of compost on soil C and total soil N, and from two sites we were able to assess plant-related metrics. We found that forage production and quality increased with compost addition (fig. 6) but that soil C and total soil N remained unchanged (fig. 3). The lack of significant differences in these soil properties possibly reflects the limited amount of observations derived from within California and also the short duration in which effects have been tracked over time. For example, one of the primary soil C data sets contributing to our review came from samples collected just 1 year after compost was applied (Silver et al. 2018).

Given more time, changes in soil properties may start to emerge (Gravuer et al. 2019). Indeed, modeling efforts have demonstrated the potential for compost to improve on-site and public ecosystem benefits across California over longer time frames (Flint et al. 2018; Ryals et al. 2015; Silver et al. 2018). However, well-replicated long-term studies are needed to validate those models, improve the evidence base for compost amendments to achieve desired outcomes across California's diverse rangelands, and determine whether the currently limited supply of compost would provide greater benefits in other systems, such as irrigated cropland.

Riparian restoration: Limited published evidence

Riparian corridors are globally recognized for their potential to provide multiple values and services, including carbon sequestration (Dybala, Matzek, et al. 2019), wildlife habitat (Dybala, Steger, et al. 2019; RHJV 2004) and maintenance of water quality and quantity (Bedard-Haughn et al. 2004; George et al. 2011). In California, where more than 90% of riparian ecosystems have been lost or degraded (RHJV 2004), state investment in riparian restoration is set to triple by 2030 (CNWL CCIP 2019).

Expectations from both private and public sectors are that riparian restoration will help to recoup lost ecosystem services and build resilience and adaptation into California's landscapes (Jackson et al. 2015; Seavy et al. 2009). However, evidence documenting the benefits of riparian restoration on California rangeland soils and understory vegetation is lacking in the literature (Jackson et al. 2015; Matzek et al. 2018). As a result, we were unable to characterize the influence of rangeland riparian restoration on any of the soil properties or plant metrics in our review.

The few studies that exist present mixed evidence for this practice's influence on ecosystem properties on California rangelands. For example, Lewis et al. (2015)

demonstrated considerable soil C accrual following a combination of active (e.g., planting) and passive (e.g., grazing removal) restoration of riparian forests in Marin, Napa and Sonoma counties. That pattern has also been recently demonstrated with riparian restoration of agricultural lands in the Central Valley (Dybala, Steger, et al. 2019). Moreover, in rangelands of Marin, Sonoma and Mendocino counties, Gornish et al. (2017) found higher native herbaceous plant richness in actively restored sites than in control sites. In contrast, Briar et al. (2012) found that 3 years of passive restoration had limited effects on soil nematode communities in Yolo County.

Adopting monitoring protocols and performing research to supplement implementation will be critical to help bolster peer-reviewed evidence, constrain estimates on the rate and magnitude of change over time and provide the groundwork for evaluating the effects of this rangeland management practice on soil properties and plant metrics across California.

Three takeaways

Three general takeaways emerge from our quantitative synthesis of California's literature: (1) rangeland management signals can be observed for some soil and plant-related metrics but not others, suggesting that climate and inherent spatial variability in soil type, topography and land-use history can, but do not always, overwhelm the effects of management on California's rangelands; (2) soil texture moderates how some soil properties respond to management, and so it may be an important contextual variable to consider in modeling activities and land management decisions; (3) levels of in-state evidence that support our understanding of these four management practices vary by metric, but

Left, fifth grade students learn how to plant acorns as part of a riparian restoration project in Sonoma County, California. *Right*, coast live oak acorns are protected from herbivory after planting in Sonoma County.

overall fall in this descending order: oaks > grazing > compost amendments > riparian restoration.

Continued support for research on these management practices will help to inform recommendations and adoption at scale. Predicting the effects of each management approach could further be supported by the refinement of organizing frameworks such as ecological site descriptions and state-and-transition models (Jackson and Bartolome 2002; Ratcliff et al. 2018), which are currently less developed for California than other Western states. In addition to more traditional research approaches, demonstration projects supported through the Healthy Soils Program offer one promising avenue to gain additional data, as does monitoring associated with state-funded projects through the California 2030 Natural and Working Lands Climate Change Implementation Plan.

C.J. Carey is Working Lands Research Director and Principal Soil Ecologist, Point Blue Conservation Science; K. Gravuer is NatureNet Science Fellow, Arizona State University and The Nature Conservancy; S. Gennet is Director, North America Sustainable Grazing Lands, The Nature Conservancy; D. Osleger is Research Assistant, National Center for Ecological Analysis and Synthesis; and S.A. Wood is Senior Scientist, Agriculture and Food Systems, The Nature Conservancy, and Associate Research Scientist, School of Forestry and Environmental Studies, Yale University.

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UNIVERSITY OF CALIFORNIA
Agriculture and Natural Resources

California Agriculture

2801 Second Street
Room 181A
Davis, CA 95618-7779

Phone: (530) 750-1223
Fax: (530) 756-1079

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Upcoming UC ANR events

DroneCamp – Online: Drone mapping short course

http://ucanr.edu/dronecamp

Date: June 23–25, 2020
Time: 9:00 a.m. to 4:00 p.m.
Contact: Sean Hogan sdhogan@ucanr.edu or 530-750-1322, or Andy Lyons andlyons@ucanr.edu

California Forest Stewardship Workshop — UC Berkeley Forest Camp

https://ucanr.edu/sites/forestry/ForestStewardshipWorkshops/

Date: September 12–13 and 26, 2020
Time: 8:00 a.m. to 5:00 p.m.
Location: UC Berkeley Forest Camp, Meadow Valley (Plumas County), CA
Contact: Kim Ingram kcingram@ucanr.edu

2020 UC Master Gardener Conference

https://ucanr.edu/sites/2020MGConference/

Date: September 28–October 2, 2020
Location: Granlibakken Tahoe, Tahoe City, CA
Contact: Shannon Martin mgevents@ucanr.edu or 530-750-1328