California Agriculture

April–June 2018 | Volume 72 Number 2

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

California Agriculture

Peer-reviewed research and news published by University of California Agriculture and Natural Resources

ORDERS AND SUBSCRIPTIONS

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

California Agriculture (ISSN 0008-0845, print, linking; ISSN 2160-8091, online) is published quarterly. Postmaster: Send change of address "Form 3579" to *California Agriculture* at the address above.

California Agriculture is a quarterly, open-access, peer-reviewed research journal. It has been published continuously since 1946 by University of California Agriculture and Natural Resources (ANR). There are about 10,000 print subscribers.

Mission and audience. *California Agriculture* publishes original research and news in a form accessible to an educated but non-specialist audience. In the last readership survey, 33% of subscribers worked in agriculture, 31% were university faculty or research scientists and 19% worked in government.

Electronic version of record. In July 2011, the electronic journal (calag.ucanr.edu) became the version of record. Since then, some research article are published online only. All articles published since 1946 are freely available in the online archive, calag.ucanr.edu/Archive/.

Indexing. The journal provides article metadata to major indexing services, including Thomson (Web of Science), AGRICOLA, the Directory of Open Access Journals and EBSCO (Academic Search Complete), and has high visibility on Google Scholar. All articles are posted to eScholarship, UC's open-access repository. In the 2016 Thomson JCR, the journal's 5-year impact factor was 1.0.

Authors. Most authors (75%) are among the roughly 1,000 academics affiliated with ANR, including UC Cooperative Extension specialists, advisors and academic coordinators; and faculty in the following UC colleges: UC Berkeley College of Natural Resources, UC Davis College of Agriculture and Environmental Sciences, UC Davis School of Veterinary Medicine, and UC Riverside College of Natural and Agricultural Sciences. Submissions are welcome from researchers based at government agencies and at other campuses and research institutes.

Article submission and review. Guidelines for authors are here: calag.ucanr.edu/submitarticles/. The journal uses a double-blind peer-review process described at calag.ucanr.edu/About/. Roughly 50% of all submissions are rejected by the editors without peer review due to a mismatch with the journal's scope or clear weaknesses in the research. Of the subset of submissions that enter the peer-review process, roughly 60% are ultimately accepted. All accepted manuscripts are edited to ensure readability for a non-specialist audience.

Letters. The editorial staff welcomes letters, comments and suggestions. Please write to us at the address below, providing your contact information.

Print subscriptions. These are free within the United States and $24 per year abroad. Go to: calag.ucanr.edu/subscribe/ or write or call.

Permissions. Material in *California Agriculture*, excluding photographs, is licensed under the Creative Commons CC BY-NC-ND 4.0 license. Please credit *California Agriculture*, University of California, citing volume, number and page numbers. Indicate ©[year] The Regents of the University of California.

To request permission to reprint a photograph published in *California Agriculture*, please complete the UC ANR Permissions Request Form (http://ucanr.edu/survey/survey.cfm?surveynumber=5147). In general, photos may be reprinted for non-commercial purposes.

UNIVERSITY OF CALIFORNIA

University *of* California
Agriculture and Natural Resources

Contents

APRIL–JUNE 2018 • VOLUME 72, NUMBER 2

News and opinion

OUTLOOK

RESEARCH NEWS


Taylor Farms

Research and review articles

Corrections

Corrections to the January-March 2018 special issue:

The map of groundwater basins on the cover and page 5 omitted medium-priority basins in the northern Sacramento Valley and Sacramento Delta. The corrected map can be found at http://calag.ucanr.edu/archive/?issue=72_1.

On page 29, in an introductory paragraph about the provisions of the Sustainable Groundwater Management Act (SGMA), the article "How are Western water districts managing groundwater basins?" incorrectly states that the law applies to groundwater sustainability agencies in low-priority basins. SGMA only applies to high- and medium-priority basins. The corrected text can be found at http://calag.ucanr.edu/archive/?article=ca.2018a0004.

COVER: A romaine lettuce harvester. *Photo courtesy of Taylor Farms.*

The race in the fields: Imports, machines and migrants

Four ways farmers are responding to the tightening labor market.

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

The slowdown in unauthorized Mexico–U.S. migration has set off a race in U.S. agriculture between rising imports, more machines, and foreign guest workers. Trade policy, including North American Free Trade Agreement (NAFTA) re-negotiations, and immigration policy, including more enforcement and new or revised guest worker programs, will determine the winner.

Fewer and larger farms that depend on hired workers produce most U.S. fruits, vegetables, and horticultural crops such as nursery plants. The number of farms in the United States is stable at about 2 million, but the largest 10% of all farms account for three-fourths of U.S. farm sales. In fresh vegetables, the largest 10 producers account for more than half of the lettuce, broccoli and carrots produced.

Americans do not dream of growing up to be farmworkers. About 70% of the hired workers on U.S. crop farms were born in Mexico, and 70% of these Mexican-born workers are unauthorized, so half of crop workers are working illegally. California has a higher share of unauthorized workers because more of its workers were born in Mexico, 90% versus less than 70% in other states.

Crop workers are aging and settling. Most have families that include children born in the United States, and few are migrants who follow the crop harvests from south to north. Unauthorized newcomers, who are primarily Mexican-born workers in the United States less than a year, have been the flexible fresh blood of the farm workforce, willing to move to fill vacant jobs. Their share of crop workers peaked at a quarter in 2000, but today such newcomers represent just 1% of crop workers.

Farmers are responding to the end of large-scale Mexico–United States migration and California's rising minimum wage with four strategies: satisfy current workers to retain them, stretch them with mechanical aids that increase their productivity, substitute machines for workers, and supplement current workers with H-2A guest workers.

Seasonal farmwork is generally a decade-long job rather than a lifetime career. Training first-level supervisors to reduce favoritism and harassment, paying bonuses to workers who stay through the season, and offering other benefits helps to satisfy current workers and keep them in farmwork longer.

Stretching farmworkers involves management changes and mechanical aids that increase

Farmworkers harvest sweet corn in Santa Clara County. Due to a decrease in unauthorized immigration from Mexico, there has been a decline in the availability of farmworkers, in particular newcomers willing to move to follow short-term farm jobs. Farmers are stepping up their efforts to retain current workers and are turning to machines to help improve efficiency.

Bob Nichols, USDA

productivity. Most fresh fruits and vegetables are over 90% water, and workers spend much of their time carrying harvested produce down ladders to bins or to the end of rows to receive credit for their work. Dwarf trees mean fewer ladders and faster picking, reducing the need to fill 50- to 60-pound bags of apples and oranges from tall ladders. Slow-moving conveyor belts that travel ahead of workers in the fields reduce the need to carry harvested produce, increasing worker productivity and making jobs more attractive to older workers and women.

Substitution is replacing workers with machines. There are machines available to handle most tasks done by farmworkers, but human hands are gentler than mechanical fingers on fragile fresh fruits and vegetables, so that a higher share of hand-harvested produce can be sent to consumers. Machines have other disadvantages as well. They are fixed costs, meaning that farmers must pay for, say, a $200,000 harvesting machine whether there are apples to pick or not, while workers are variable costs who are not paid if storms or disease destroy the apple crop. Nonetheless, rising minimum wages, fewer flexible newcomers, and advances in mechanization have encouraged many farmers to experiment with machines, prompting manufacturers to develop and market labor-saving machines that are doing more planting and pruning and are improving rapidly to harvest blueberries, peaches and leaf lettuces.

The fourth option is to recruit guest workers under the federal H-2A program, which admits an unlimited number of foreign farmworkers to fill seasonal jobs. Receiving permission to hire H-2A guest workers requires farmers to try and fail to recruit U.S.-born workers, provide free housing, and pay an Adverse Effect Wage Rate (AEWR), which is $13.18 an hour in California in 2018.

The number of U.S. farm jobs certified to be filled by H-2A workers tripled over the past decade to 200,000 in fiscal year 2017 and may surpass the peak number of Braceros by 2025 (the Bracero guest worker program ran from 1942 to 1964; at its peak in the mid-1950s, more than 450,000 Mexican workers participated in it each year). The number of jobs certified to be filled by H-2A workers in California tripled in 5 years, from 3,000 in 2012 to 15,000 in 2017, and appears poised to continue increasing.

Half of the fresh fruit (including bananas, the most popular) and a quarter of the fresh vegetables available to Americans are imported, and imports of everything from avocados to raspberries are rising. Mexico is the major source of fresh fruit and vegetable imports, supplying half of the imported fresh fruit and three-fourths of the imported fresh vegetables. Many of the fruits and vegetables imported from Mexico are produced on farms that involve partnerships between U.S. and Mexican growers and shippers, with U.S. partners providing capital and technology and marketing Mexican-grown produce.

One legal option for farmers whose crops require manual labor is to hire guest workers under the federal H-2A program. To do this, farmers must first try and fail to recruit workers born in the United States and must provide free housing and a wage that averages $12 per hour.

Satisfying and stretching current workers are shorter term strategies to increase the productivity of an aging farm workforce. Substituting machines, hiring guest workers, and increasing imports are longer term strategies to supply fresh fruits and vegetables to Americans. Policy will help to determine the winner of the race in the fields between machines, migrants and imports. Technologies that could replace farmworkers are improving rapidly and decreasing in cost, potentially putting agriculture on the cusp of another wave of labor-saving mechanization. How fast machines are perfected and adopted depends on factors that range from labor costs to consumer acceptance.

Farmers have long sought new or revised guest worker programs that eliminate requirements to try to recruit U.S.-born workers, provide housing, and pay the super minimum AEWR wage. The House Judiciary Committee approved a bill in November 2017 that includes these farmer wishes, but it has drawn opposition from advocates for removing worker protections and from some farmers for capping the number of guest worker visas at 450,000 a year. If the new H-2C program included in the Agricultural Guestworker Act (HR 4092) is enacted, the influx of farm guest workers would likely accelerate, which may reduce support for the engineers and scientists developing machines to replace farmworkers.

The United States has an overall agricultural trade surplus, but a deficit in agricultural trade with Mexico reflecting ever-more Mexican avocado, tomato and berry imports. The Trump Administration aims to reduce the trade deficit with Mexico in NAFTA renegotiations, perhaps by imposing tariffs or other restrictions on Mexican imports. This could slow the integration of the North American produce industry, which has evolved to provide year-round supplies of fresh fruits and vegetables to Americans.

Agriculture has been at farm labor crossroads many times, asking who will pick the crops after the exclusion of the Chinese in the 1880s and the termination of the Bracero program in the 1960s. Today's race in the fields will determine whether Americans will consume more imported produce or whether fruits and vegetables will continue to be grown in the United States and picked by machines or guest workers. CA

RESEARCH NEWS

Next-generation mechanization

New advances in image-recognition technology and robotics are reducing the need for manual labor — and potentially herbicides as well.

On vegetable farms in the Salinas Valley, a shrinking farm labor pool and rising minimum wages are driving innovation and adoption of machinery that can automate manual labor tasks — thinning, weeding and, for some crops, harvest. The technology is evolving quickly, led mainly by small engineering firms collaborating with large growers.

Automation promises a number of benefits. Foremost, of course, is a reduced dependence on manual labor. But it could help in other ways too — for instance, automated weeding could remedy the declining effectiveness of some herbicides.

UC researchers and advisors are helping to advance the basic technologies involved, and also serving as key evaluators of the technology (see research article page 114). But the drive to automate also raises decades-old concerns about UC contributions to new technologies that are likely to primarily benefit only large-scale growers, at least in the short term.

Automated thinners and weeders

The automation of thinning (removing excess crop plants) and weeding (removing noncrop plants) involves two main steps: identifying each plant to be removed and then directing the killing of the undesired plant with a blade or a small dose of herbicide. It replaces work that would otherwise be done by hand with hoes.

Figures on the acreage being thinned by machine aren't available, but the use of automated thinners in some crops, notably lettuce, has been expanding in the Salinas Valley since its introduction in 2012 (see research article page 114).

Camera-guided automated weeders are now in use on a number of vegetable farms as well. The two in widest use in the Salinas Valley, according to several researchers and equipment suppliers, are made by two small northern European firms, Denmark-based F. Poulsen Engineering and Netherlands-based Steketee. Long-running concerns about farm labor cost and availability in Europe have driven automation innovation, and the technology has been more widely adopted there than in the United States, said Richard Smith, a UC Cooperative Extension (UCCE) farm advisor in Monterey County.

While the weeding machines are costly — roughly $150,000 to $200,000 — their use appears to be limited more by availability than by price, according to equipment suppliers and UCCE staff. Poulsen and Steketee are small operations with limited production capacity.

Britton Wilson of Pacific Ag Rentals, an equipment supplier to Salinas Valley farms, estimated that there are 15 to 20 Poulsen weeders (called Robovators) in the United States, a figure Poulsen corroborated.

"I'd love to get my hands on more" to meet local demand, he said.

Developing the machines

A crop like lettuce or broccoli represents a comparatively small market for major farm equipment makers like John Deere and Case IH. About 300,000 acres of lettuce (of all types) are grown in the United States, for instance, compared with 12 million acres of cotton or 90 million acres of soybeans.

As a result, vegetable crop automation is being led by small engineering and fabrication firms as well as growers themselves, often in close collaboration, said Mark Siemens, an associate specialist and associate professor of agricultural and biosystems engineering at the University of Arizona.

Because the technology is somewhat modular, it's possible to address the needs of a particular crop or grower by combining or modifying existing technologies and equipment.

An example: Harvest Moon Automation, a four-employee engineering firm with several clients in the

Harvest Moon Automation

This modified leafy greens harvester, developed by Harvest Moon Automation in partnership with two Salinas Valley growers, uses a camera and pattern-recognition technology to spot foreign objects and diseased or damaged plants. A mechanical arm pushes such contaminants out of the way of the harvesting blades, so they are left in the field instead of being fed into the processing line.

Salinas Valley, recently received a patent on a modified version of a leafy greens harvester developed in partnership with two Salinas Valley growers.

Steve Jens, Harvest Moon's president, said the new machine uses a camera and pattern-recognition technology to spot foreign objects (such as a piece of plastic or bird droppings on a leaf) and diseased (downy mildew) or damaged plants as the harvester moves across a field. A detection by the camera triggers an arm that pushes the crop leaves out of reach of the harvester's blades, keeping the contaminant from being harvested and fed into the processing line. The growers who partnered with Harvest Moon on the project funded the prototypes and testing, and now will be the first to use it.

UC Davis engineer Burt Vanucci (left) and Professor David Slaughter adjust the robotic hoes on an automated weeding machine for a trial in an organic tomato field at the Russell Ranch Sustainable Agriculture Facility near Davis.

Herbicide effectiveness and automated weeding

While John Deere isn't building automated weeders for vegetable crops, it is interested in the technology involved. In 2017, Deere paid $305 million to acquire Sunnyvale startup Blue River Technology, which had developed plant-recognition technology that was incorporated in a lettuce-thinning machine used by growers in the Salinas Valley.

Since then, however, Deere has focused Blue River's technology on cotton, and, according to UC and University of Arizona extension researchers, the company no longer offers lettuce thinning services in the Salinas Valley or Yuma, Arizona (another lettuce production region).

A major motivation for the focus on cotton, and potentially other commodity crops, is the declining effectiveness of widely used broadcast herbicides like Roundup that are applied to fields of crops genetically modified to tolerate the herbicide (weeds are evolving to tolerate the herbicides). Chemical companies are struggling to develop next-generation chemicals that are effective and satisfy environmental regulators.

Weed-recognition technology could lead to a new approach to weed control — replacing broadcast herbicides with higher-potency, focused, small doses aimed directly at weeds, or, for some applications, robotic hoes — that promises less overall use of herbicide and more effective weed control. Blue River says a viable version of its technology (which uses focused doses of herbicide) for cotton is still several years from commercial release (Burger and Polansek 2018).

In vegetable crops, as with commodity crops, existing herbicides are becoming less effective, said Steve Fennimore, a UCCE weed specialist based in Salinas. But the prospects for new herbicides suitable for vegetable crops are even dimmer than those for commodity crops because vegetable crops represent a relatively small market for chemical makers.

"The chemical industry invests very little — essentially nothing — on these crops," Fennimore said.

Due to the complexity of chemical development and the high cost of the regulatory approval process, large chemical companies are effectively the only entities capable of commercializing a new herbicide, for any crop.

But for automated weeding, Fennimore noted, there are essentially no regulatory hurdles, and it doesn't take the resources of a giant company to develop working prototypes. Small firms can innovate meaningfully.

As a result, Fennimore said, the best prospects for advances in vegetable weed control are likely to be through improved machines, developed by small firms and growers, with support from UC and the research community.

Next steps for weeding technology

Currently, automated weeding systems work well in relatively simple settings — low weed density, little or no overlap of weeds and crop plants. In more complex settings, current image-recognition technology struggles to reliably identify which plants should be removed.

David Slaughter, UC Davis professor of biological and agricultural engineering, is working with nine collaborators — from UC Davis, UCCE, Washington State University and the University of Arizona — on a $2.7 million USDA-funded project to improve mechanized weed control by developing better systems for what's called crop signaling — distinguishing crop plants from weeds.

One approach uses a biodegradable straw with a fluorescent coating inserted into the soil with the crop plant. The coating is readily detected by a camera, which can then tell the weeding equipment which spots to avoid.

Another crop-signaling method uses high-precision GPS to record planting locations. "We can make a map of every seedling," said Slaughter. When it's time for weeding, all plants that aren't on the map are removed.

Slaughter noted that another general path of evolution for automation is the adaptation of growing practices — plant spacing, crop varieties, the timing of weeding and so on — to suit the available technologies.

The grant is also funding a study of factors influencing vegetable growers' adoption of automation technology (see sidebar).

Automating harvest

Harvest is generally the most costly step in vegetable production, due chiefly to the amount of labor required.

Salinas-based Taylor Farms, the world's largest salad producer, has invested heavily in harvest automation, developing romaine lettuce and cabbage harvesting equipment used by the growers it contracts with to supply the bagged salad market (see cover photo).

But for many vegetable crops, as well as other major Central Coast crops like strawberries, effective automated harvesters have yet to be proven.

"Automating the harvest — that's the Holy Grail for pretty much everybody," said Brian Antle, who runs the planting automation company PlantTape and is a member of the family that co-owns Tanimura & Antle, one of the largest fresh produce growers in the Salinas Valley.

An intermediate step is "co-robotics" — designing robots to work alongside human laborers, with the robots handling simple tasks while people continue to perform the more complex and delicate actions. One example is self-guided carts that assist human strawberry pickers by carrying full trays of (hand-picked) strawberries out of the field and returning with empty trays.

"The recognition is that the agricultural environment is very complex, and we may not see full autonomy in the next decade," said Slaughter.

Automation and farm scale, fraught history

In the 1960s, the release of a processing tomato harvester, developed by two UC Davis researchers, transformed the production of that crop. Only larger growers could afford one, and because the machine dramatically reduced the costs of harvesting, it created a powerful economy of scale that encouraged big growers to expand. In the first few years after the harvester's introduction, a large fraction of the state's tomato growers left the business.

Advocates for small farmers and farm workers organized to criticize UC's role in developing the harvester and to push for more UC support for small farmers. In a 1979 lawsuit, they argued that the tomato harvester favored large farmers, violating the public benefit mission of land-grant university research as established by the Hatch Act of 1887.

UC prevailed in court after a 10-year legal battle. But the conflict drove lasting changes at UC and elsewhere. Federal funding for automation research declined, and agricultural engineering departments shifted focus to other types of research, Slaughter said. UC also created programs focused on small farms. Today, UC ANR programs targeting small farms include the Sustainable Agriculture Research and Extension Program and the UC ANR Small Farm Working Group.

Like previous waves of mechanization, automation in vegetable crops stands to mainly benefit larger farms, at least initially. Large, highly standardized fields of a single crop tend to be better suited to mechanization than the fields of a small farm growing a variety of crops. And, as noted earlier, large growers are currently the main market for — and often the lead investors in — novel automation technologies, which tend to be designed to solve the problems they face on their own (large) farms.

Margaret Lloyd, a UCCE small farms advisor in Yolo County, said that automation technologies can benefit small farms too — but small growers need versions of the machines that are less expensive, more versatile, and designed with small scale in mind.

"Could you make a machine that does four rows at a time, but also make one that is simpler and cheaper and only does one row?" she said.

Yes, probably, said UCCE's Fennimore — once the technology is well developed.

"Do tractors only benefit large growers? No, because we now know how to build tractors and there are lots of them, new and used, and thousands of grower customers are each paying a small fraction of the research and development cost to improve tractors," he said.

"Eventually this will be true for weeders and other smart technology." CA

—Jim Downing

Reference

Burger L, Polansek T. 2018. Robots fight weeds in challenge to agrochemical giants. Reuters. Published May 21, 2018. www.reuters.com/article/us-farming-tech-chemicals-insight/robots-fight-weeds-in-challenge-to-agrochemical-giants-idUSKCN1IN0IK

Adoption of automation technologies: Preliminary survey results

Laura Tourte, UCCE farm advisor for Santa Cruz, Monterey and San Benito counties, is leading a study of vegetable growers' adoption of automation technologies for transplanting, thinning, weeding and harvest. The study is part of the USDA-funded project led by David Slaughter of UC Davis (see main text).

Initial results indicate that, in deciding whether to use these technologies, top considerations for vegetable growers include labor issues (difficulty finding workers, cost of labor, related regulations and workforce productivity), the desire to reduce production costs, and the reliability of the technology. Considerations that ranked lower include vulnerability to hacking, and access to specialized training and tech support.

Some of the reported barriers to technology adoption are problems with reliability and accuracy of automated equipment (seen as a definite obstacle). The investment cost and need for technical support or specialized training were seen as less of an impediment (only somewhat of an obstacle).

The initial results are based on surveys of 98 vegetable growers in California. Most farm more than 1,000 acres, and many are mixed conventional and organic operations.

Tourte plans to conduct an additional survey of Washington state vegetable growers as part of the project. She and her UCCE colleagues are also evaluating costs and labor savings associated with these new types of equipment.

NEWS

Research highlights

Recent scientific articles from the Agricultural Experiment Station campuses.

Tree mortality reduces the impact of a long drought on mountain runoff

Predicting the impacts of a lasting drought and a warming climate on mountain water runoff is complex, and critical for California's water security. A recent study identified four biogeophysical mechanisms that controlled the impact of the 2012–2015 drought on mountain runoff across the Kings River basin. One of them — mountain vegetation changes, from tree dieback and wildfires — is often overlooked in water runoff projections. That may result in the impact of drought being overestimated.

A team of scientists led by UC Merced Professor of Engineering Roger Bales, and including scientists at UC Irvine and UC Davis, analyzed data from their measurements at different elevations in the Kings River basin before, during and after the 2012–2015 drought. During those drought years, mean precipitation in the southern Sierra Nevada was about 50% of average, and temperatures were higher than in past dry periods.

They identified four mechanisms affecting runoff. Evapotranspiration assumed a greater fraction of precipitation as the drought continued, which they calculated would result in a decrease in the runoff across the basin by 30% compared to the long-term average runoff. The temperature increase of 1°C during the drought years compared to the previous 10 years was calculated to have decreased runoff by at least another 5%. The high elevation of the water source regions became more important as the drought progressed; because of those high slopes where precipitation consistently exceeded evapotranspiration, runoff was on average 10% higher than it would have been for a spatially more homogenous basin.

These three mechanisms are captured by state-of-the-art hydrologic models, but the fourth mechanism is not. In 2015 widespread conifer death occurred, and also a wildfire affected nearly 20% of the basin; the subsequent decline in evapotranspiration could increase the basin-wide runoff by 15% of the long-term average. If this mechanism of drought-affected vegetation loss is not accounted for, the researchers conclude that predictions of mountain water runoff may be too low.

Bales RC, Goulden ML, Hunsaker CT, et al. 2018. Mechanisms controlling the impact of multi-year drought on mountain hydrology. Scientific Rep 8(1):690. https://doi.org/10.1038/s41598-017-19007-0

The death of more than 100 million trees from drought and bark beetle damage in the Sierra Nevada has led to concerns about the large amount of combustible material and the potential for mass fires. A team of UC and USDA scientists studied 50 mixed-conifer plots affected by tree mortality that burned in the 2015 Rough Fire, a wildfire in the Sierra National Forest that consumed an estimated 139,133 acres. The results suggest that fire spread increased as prefire tree mortality increased, but only up to prefire mortality levels of 30% of plot trees.


U.S. Forest Service

Unprecedented tree mortality increased risk of mass fires

More than 100 million trees have died recently in California, primarily in the southern and central Sierra Nevada, prompting the governor to declare a state of emergency in 2015. The main causes were acute drought and bark beetle damage. By suppressing fires in forests that historically depended on frequent fires for their survival, forest managers created very dense tree stands that are prone to both.

Of concern now, after this unprecedented death of standing trees, is the massive amount of dry, combustible material over extensive areas, and the potential for large severe fires, or "mass fires." Scott Stephens, professor of fire science at UC Berkeley, led a team of UC and USDA scientists in collecting and analyzing field data from 50 mixed-conifer plots affected by tree mortality that subsequently burned in the 2015 Rough Fire wildfire. Results showed that fire spread increased as prefire tree mortality increased, but only up to prefire mortality levels of about 30% of plot trees. Further increases in prefire mortality did not result in greater fire severity.

The researchers conclude that in the first decade after a forest suffers significant mortality from bark beetles, wildfire severity may be little affected. However, in future decades, with more large-sized, long-burning dead material on the forest floors, mass fires could occur. A mass fire creates dangerously strong winds, resulting in fast-spreading fire and complicated fire patterns.

The implications for public safety and the future composition of forests, and the ecological services they provide, are serious. Public policy needs to shift, say the authors, because many management tools and tactics could be adopted, including prescribed fire, to help reduce future tree mortality and increase forest resilience.

Stephens SL, Collins BM, Fettig CJ, et al. 2018. Drought, tree mortality, and wildfire in forests adapted to frequent fire. Bioscience 68(2):77–88. https://doi.org/10.1093/biosci/bix146

Flowering cover crops support wild bees and a regional sustainability agenda

Wild bees pollinate flowering plants in natural habitats and can play an important role in the pollination of several key agricultural crops, such as almonds, stone fruits and melons. Populations of wild bees are in decline, mostly due to habitat loss, which is largely driven by agricultural expansion. Grape growers in Napa and Sonoma counties sought to add habitat for beneficial insects, including wild bees, by planting flowering cover crops in row middles. Although pollinators are not necessary for grape production, growers see the potential for such practices to bring added value to their wines as a result of increased consumer perceptions of vineyard sustainability.

Houston Wilson, assistant Cooperative Extension specialist with the Department of Entomology at UC Riverside, is the lead author of a 2-year study in the North Coast wine grape region evaluating bee response to summer-flowering cover crops. In fall 2011–2012, at 10 vineyard sites, rows were tilled and seeds of purple tansy, bishop's flower and wild carrot were sown in alternate row middles. These flower species bloom sequentially from April to September and don't require any supplemental irrigation. Control plots were tilled to leave alternate rows of weedy vegetation.

Total abundance and diversity of wild bees increased on all three flowering cover crop species relative to the resident weedy vegetation, where bee numbers were uniformly low. Researchers also studied the effect on wild bees of changes in landscape diversity — that is, the proportion of natural habitat, consisting primarily of riparian, oak woodland and chaparral habitats, within 0.5 kilometer of the study sites. Landscape diversity had no effects on numbers or species diversity of wild bees.

Wine grape growers' interest in conserving bees is part of a regional sustainability and conservation agenda. Farming practices that support biodiversity conservation attract consumers' attention and may lead indirectly to added crop value. Plus, the flowers add a stunning visual element to the vineyard, which consumers may appreciate as they taste wines on site.

Wilson H, Wong JS, Thorp RW, et al. 2018. Summer flowering cover crops support wild bees in vineyards. Environ Entomol 47(1):63–9. https://doi.org/10.1093/ee/nvx197

A study of wild bee populations at vineyards found that bee abundance and diversity increased after flowering cover crops were planted. *Phacelia tanacetifolia* (top), *Ammi majus* (bottom).

Children's high calorie, poor diets: sugar-sweetened beverages may be ground zero

Sugar-sweetened beverages (SSBs) are the main source of added sugar in children's diets. Evidence already exists that these beverages — soft drinks, fruit drinks with added sugar, sweetened coffee and tea drinks, sports and energy drinks, and sweetened bottled water — are associated with higher risks of obesity, metabolic syndrome, type 2 diabetes and heart disease. But how much does beverage choice explain children's dietary quality and calorie consumption that may lead to higher or lower risk for obesity and chronic disease?

A team of researchers from UC ANR, UC Berkeley and the University of Michigan investigated this question. They analyzed plain water and SSB consumption data from a nationally representative sample of 7,757 children from ages 2 to 18 years, drawn from the National Health and Nutrition Examination Survey. They were looking for the relationship between beverage intakes and children's diet quality and calorie intake. They used 24-hour dietary recalls to measure dietary intake and the Healthy Eating Index (HEI) 2010 to measure overall diet quality.

High SSB intake — more than two cups a day — was significantly associated with lower diet quality in every age group (2 to 5 years, 6 to 11 years, and 12 to 18 years). High water intake —also more than two cups a day — was significantly associated with higher diet quality in every age group. But, SSBs alone didn't account for the poor diet quality in the high SSB group. Compared with non-SSB drinkers, children with high SSB intake also had lower intakes of greens and beans, fruit, and other nutritious food groups, suggesting that children drinking high amounts of SSB were lacking proper nutrition.

Not surprisingly, children with high SSB intake consumed more calories. In fact, children with high SSB intake consumed an average of almost 400 calories more per day than their non-SSB drinking peers. Most of these excess calories were explained by calories from the SSBs, except among children aged 6 to 11 years old, for whom other foods also contributed to excess calories. Water consumption was not associated with calorie intake — high and low water drinkers did not consume a significantly different average caloric level.

Thus, the most effective public health efforts will explicitly discourage SSB consumption while encouraging water. Further, while swapping water for SSBs may contribute substantially to reducing obesity, additional efforts to improve diet also are needed, since high SSB consumers also consumed fewer fruits, vegetables, whole grains, and dairy.

Leung CW, DiMatteo SG, Gosliner WA, Ritchie LD. 2018. Sugar-sweetened beverage and water intake in relation to diet quality in U.S. children. Am J Prev Med 54(3):394–402. https://doi.org/10.1016/j.amepre.2017.11.005

RESEARCH ARTICLE

Employment and earnings of California farmworkers in 2015

A review of wage data from agricultural employers suggests that most California farmworkers were employed for less than a full year in 2015.

by Philip Martin, Brandon Hooker and Marc Stockton

Abstract

The average employment of hired workers in California agriculture (NAICS 11) rose over 10% between 2005 and 2015, when some 16,400 agricultural establishments hired an average 421,300 workers who were paid a total of $12.8 billion, which was 27% of the state's $47 billion in farm sales. This means that a full-time equivalent (FTE) employee would earn $30,300, implying an hourly wage of $14.55 for 2,080 hours of work. We extracted all Social Security numbers reported by California agricultural establishments and found that the average annual pay received by the 848,000 workers who had at least one job on California farms was $20,500 in 2015, two-thirds of the average annual wage of an FTE worker, reflecting some combination of lower wages and less than full-year work.

California has led the nation in farm sales since 1950, when Los Angeles County had more farm sales than any other county in the United States, largely because of specialization in the production of high-value fruit, nut and vegetable (FVH) crops. California's farm sales in 2015 were $47 billion, including $18 billion from the sale of fruits and nuts, $9 billion from vegetables and melons, and $5 billion from horticultural specialties such as floriculture, nurseries and mushrooms. That is, $32 billion, or two-thirds, of farm sales were from these FVH crops. The leading farm counties, Tulare, Kern and Fresno, each had farm sales of almost $7 billion in 2015 (CDFA 2017).

The production of many fruits and vegetables is labor-intensive, meaning that labor represents 20% to 40% of production costs for table grapes, strawberries and other commodities.

Average employment of 421,300 farmworkers in 2015 represents 12 monthly snapshots of persons on the payroll during the pay period that includes the 12th of the month. However, total wages of $12.8 billion are all wages paid to all workers, including those who were employed at other times during the month (but not during the pay period that includes the 12th of the month) and those who earned wages from nonfarm employers.

A worker who was employed 2,080 hours — the number of hours California's Employment Development Department (EDD) considers full-time

Online: https://doi.org/10.3733/ca.2017a0043

Published online November 16, 2017

Farmworkers harvest lettuce at Lakeside Organic Gardens in Watsonville, Santa Cruz County. In 2015, two-thirds of California's farm sales were from fruit, nut and vegetable crops, many of which are labor intensive.

Bob Nichols, USDA

and full-year employment — would earn an average annual pay of $30,300, which prompted the *Los Angeles Times* to ask why, despite implied hourly wages of almost $15 per hour, U.S.-born workers reject farm jobs (Kitroeff and Mohan 2017). The answer is that few farmworkers are employed year-round; many are employed fewer than 2,080 hours a year. In 2015, the average earnings of all workers with at least one farm job was $20,500.

EDD does not collect hours of work data from employers who are paying unemployment insurance taxes, but does collect the earnings and employment data that we use in this article. The National Agricultural Workers Survey (NAWS) collects hours of work data from California crop workers, and found that they were employed an average of 47 hours during the week before they were interviewed in 2015–16. American Community Survey (ACS) data, also collected from workers, shows that both crop and livestock workers were employed slightly more than 40 hours a week. The NAWS and ACS do not collect data on annual hours worked. However, if workers averaged more than 40 hours a week over 52 weeks, average hourly earnings would be lower than $15.

Nonsupervisory production workers do most of the work on the state's largest farms that produce labor-intensive FVH crops. About 90% of California crop workers were born in Mexico, and 60% are unauthorized, according to the NAWS, which is 10 percentage points higher than the U.S. average of 50% unauthorized crop workers (Carroll 2017). The reason for more unauthorized workers in California is that it has a higher share of foreign-born workers: most foreign-born workers are unauthorized, and California's 90% share of foreign-born crop workers exceeds the 60% foreign-born share in the rest of the United States. A slowdown in unauthorized migration can put upward pressure on wages.

The dominance of labor-intensive crops in California, and the Trump administration's efforts to step up border and interior enforcement, has increased interest in the availability of farmworkers. EDD regularly obtains data on farmworkers and wages paid when employers pay unemployment insurance taxes. Employers who pay more than $100 in quarterly wages are required to register with the EDD and pay taxes of up to 6% on the first $7,000 of each worker's earnings to cover the cost of unemployment insurance benefits for laid-off workers.

We extracted all Social Security numbers (SSNs) reported by California agricultural employers (NAICS 11) in 2015 and tabulated all of the farm and nonfarm jobs and earnings of these farmworkers. This allowed us to assign workers who had more than one job to their primary commodity, the North American Industry Classification System (NAICS, www.census.gov/eos/www/naics/) code of the employer(s), and the county where they had their maximum earnings.

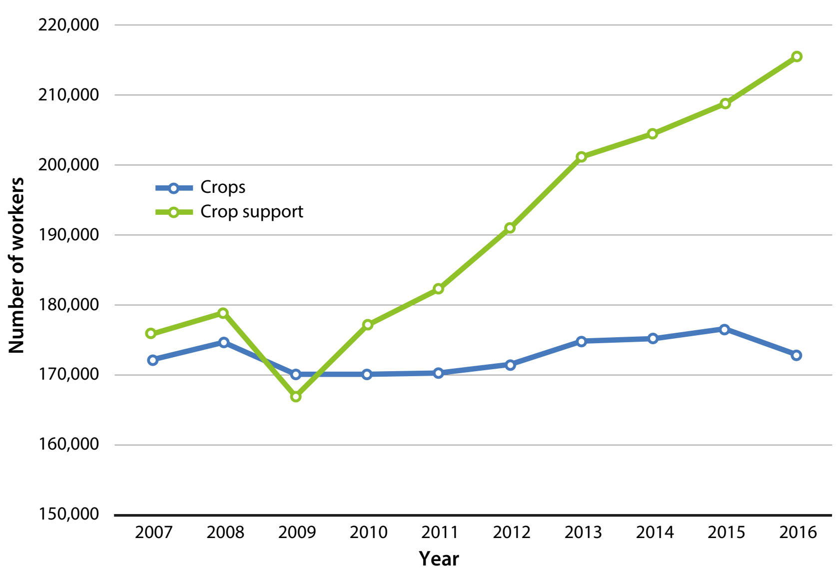


Fig. 1. Average California crop and crop support employment, 2007–2016. Crop employment refers to workers hired directly by farmers, and crop support refers to nonfarm employers that bring workers to farms, such as farm labor contractors.

Average employment and farmworkers

Figure 1 shows average employment in California crop agriculture since 2007. Average employment rose over 10%, but there was an important change in crop agriculture after 2007, when nonfarm crop support employers — those who bring workers to crop farms, such as farm labor contractors (FLCs) — began to bring more workers to farms than were hired directly by crop farmers. There are several reasons why farmers may turn to FLCs for workers, including the ability of FLCs to assemble crews of workers at lower cost than farmers who hire workers directly.

According to EDD data, over the past decade crop farmers (NAICS 111) have hired a few more workers directly, animal agriculture (NAICS 112) has had stable average employment, and there has been a sharp increase in crop support employment (1151), most of it with FLCs. The average employment of crop support establishments has been rising by 10,000 a year, so that in 2016 nonfarm crop support firms brought an average 215,000 full-time equivalent (FTE) workers to crop farms, more than the average 173,000 FTE workers that these farms hired directly (fig. 1). Average FTE employment in animal agriculture has been stable at about 29,000, while animal support employment fell slightly.

The total number of farmworkers employed sometime during the year is larger than average employment because of seasonality and turnover. In 2015, employment peaked at 475,000 in July and reached a low of 350,000 in December, guaranteeing at least 475,000 unique farmworkers. The actual number of workers is higher because of turnover: some workers do only a few days or weeks of farm work and quit, and workers employed in the Coachella and Imperial Valleys during the winter and spring rarely migrate to the San Joaquin Valley for the summer harvest, so different workers are required in different areas.

Our analysis captures all workers hired by farm employers. After making adjustments for what appeared to be false or shared SSNs, in 2015 there were 848,000 unique SSNs reported by agricultural establishments, twice the average FTE employment of 421,000 (fig. 2). This suggests two workers per FTE job, a ratio that has been stable over the past decade. Average FTE employment and the number of unique farmworkers each rose 10% between 2007 and 2015.

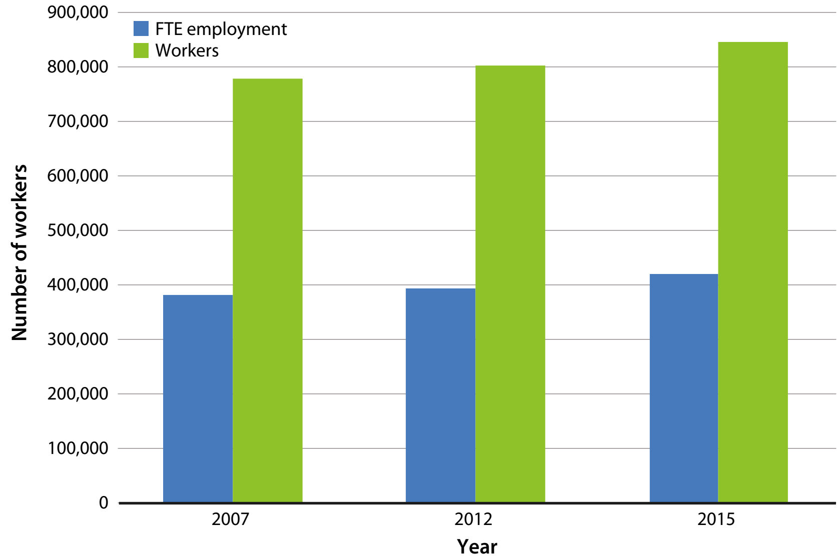


Fig. 2. Average FTE employment and unique farmworkers: 2007, 2012 and 2015.

FTE employment, average earnings

The average annual pay of FTE agricultural workers varies by commodity. In 2015, the average annual pay of a directly hired FTE crop worker was $32,500, that of an FTE animal worker was $35,900, and that of an FTE crop support worker was $27,500.

Table 1 presents data on the number of establishments, average employment and average annual pay for California commodities where average employment was at least 10,000 employees. The four crop categories in the table accounted for almost all establishments and average employment in the NAICS code for crops (111); dairies accounted for half of NAICS 112 animal employer establishments and two-thirds of animal employment and total wages. The four crop support services listed under NAICS 1151 in the table accounted for almost all of the establishments, average employment, and total wages in the crop support category.

Farm employment is concentrated in a few commodities. Fruits and nuts accounted for 57% of average direct-hire crop employment in 2015, dairy for 64% of direct-hire animal employment, and FLCs for

TABLE 1. FTE and primary worker average annual pay, 2015

Code	Commodity	No. establishments	Average no. employees	Total wages ($000)	Average annual pay	Hourly earnings
NAICS 11	Agriculture, forestry, fish	16,408	421,288	12,757,819	30,283	14.56
NAICS 111*	Crop production	9,567	176,537	5,734,489	32,483	15.62
NAICS1112	Vegetables and melons	927	34,010	1,256,717	36,951	17.76
NAICS1113	Fruits and nuts	5,731	100,512	3,019,122	30,038	14.44
NAICS1114	Greenhouse	997	27,317	910,934	33,347	16.03
NAICS1119	Other crops	1,209	11,269	415,618	36,882	17.73
NAICS 112	Animal production	2,534	28,496	1,021,973	35,864	17.24
NAICS1121	Cattle & ranch	1,867	22,885	819,089	35,792	17.21
11212	Dairy cattle	1,187	18,057	633,899	35,105	16.88
NAICS 115	Support activities for forestry & agriculture	3,810	213,178	5,856,656	27,473	13.21
NAICS 1151	Support activities for crop production	3,028	208,857	5,685,346	27,221	13.09
115112	Soil preparation	642	10,347	387,768	37,476	18.02
115114	Postharvest crop activities	559	38,578	1,471,818	38,152	18.34
115115	Farm labor contractors	1,130	141,439	3,177,222	22,464	10.80
115116	Farm management services	385	11,420	418,194	36,619	17.61

Source: California EDD analysis of unemployment insurance payroll tax data.

NAICS codes add digits to reflect specialization, so that 2-digit NAICS 11 is agriculture, 3-digit NAICS 111 is crops, and 4-digit NAICS 1113 is fruits and nuts. NAICS 115 is support activities for agriculture, that is, nonfarm employers who bring workers to farms to perform specific activities.

* Bold indicates 4-digit umbrella categories for the more detailed commodities below.

two-thirds of average crop support employment. For a FTE worker, the implied average hourly earnings ranged from a low of $10.80 for FLC employees to $18.34 for other post-harvest activities such as cooling and cleaning crops after they are harvested. California's minimum wage was $9 per hour in 2015.

Since we have data on all workers who were employed in a commodity, we can calculate the difference between the earnings of an FTE worker and the earnings of an average worker. We assigned farmworkers to the commodity or NAICS code in which they had their highest earnings, and found that 705,000 workers had their maximum earnings from a farm employer; we call these workers primary farmworkers. Table 2 shows that these primary farmworkers averaged $17,434, or 58%, of what an FTE worker employed in agriculture would have earned.

We assigned the 705,000 primary farmworkers to the NAICS code or commodity in which they had their maximum earnings in order to determine what share of FTE earnings in that commodity a typical worker received; for over 100,000 farmworkers, this was a nonfarm NAICS or employer. Primary crop workers were those whose maximum earnings were from employers with NAICS 111, and they averaged $21,467, two-thirds of what an FTE crop worker would have earned (table 2). Those whose maximum earnings were in greenhouses and nurseries earned 84% of FTE earnings in this commodity, while those whose maximum earnings were in more seasonal fruits and nuts earned 57% as much.

Primary workers in animal agriculture earned 86% of what an FTE animal worker would have earned, and dairy workers, who were almost two-thirds of primary animal agriculture employment, earned 87% of what an FTE dairy worker would have earned (table 2), likely reflecting more hours of work during the year.

Support service workers outside of crops earned almost as much as an FTE worker, but not crop support workers, who earned only half of what an FTE crop support worker would receive. The seasonality and turnover in crop support means that primary workers employed by FLCs, the largest group of workers, earned only 44% as much as an FTE worker employed by FLCs (table 2).

Since the implied hourly wage for an FTE worker employed by FLCs was only slightly above the state's minimum wage, the low average earnings of primary FLC employees must arise from fewer hours of work. A worker employed 1,000 hours at $9.86 an hour would have earned the average amount of a primary FLC employee in 2015, $9,878.

Most primary agricultural workers, 70%, had only one job in 2015; this was a farm job, since having a farm job was necessary to be selected. Over 85% of animal workers employed in sheep, hogs and poultry had just one job in 2015, but less than 60% of workers who were employed in strawberries and vegetables had only one job. About 70% of primary FLC employees had one job in 2015.

A quarter of farmworkers, some 223,000, had two or more jobs, and 18% had three or more jobs. Half of

TABLE 2. Primary worker average annual pay, 2015

Commodity	No. primary workers	Primary worker earnings	Average primary worker earnings	Average primary / average FTE earnings
		$ mil	*$*	
Agriculture, forestry, fish	705,000	12,288.00	17,434	58%
Crop production	260,000	5,553.90	21,467	66%
Vegetables and melons	48,500	1,232.30	25,818	68%
Fruits and nuts	154,000	2,850.00	17,008	57%
Greenhouse	32,700	981.1	30,007	84%
Other crops	18,000	452.1	25,117	68%
Animal production	32,700	983	30,061	86%
Cattle & ranch	25,800	788.7	30,389	85%
Dairy cattle	20,234	614,889	30,389	87%
Support activities for agriculture & forestry	408,670	5,602.30	13,709	50%
Support activities for crop production	403,000	5,440.00	13,498	50%
Soil prep	17,900	358.4	19,971	53%
Postharvest crop activities	62,310	1,549.00	24,859	65%
Farm labor contractors	293,900	2903.1	9,878	44%
Farm management services	16,800	407.2	24,307	66%

Source: EDD analysis of unemployment insurance payroll tax data.

the 51,500 primary FLC workers who had two or more jobs in 2015 had one farm and one nonfarm job, while two-thirds of the 11,300 post-harvest crop support workers had one farm and one nonfarm job. Half of the primary FLC workers with two or more jobs got at least 75% of their annual pay from FLCs, just as half of the dairy workers with two or more jobs got at least 75% of their annual pay from dairies. This same pattern held for most commodities, viz, half or more of two-job workers with primary earnings from strawberries or vegetables got at least 75% of their annual pay from this same commodity.

A quarter of the 51,500 primary FLC workers with two or more jobs in 2015 had at least two farm jobs and one nonfarm job. However, these 14,000 workers were only 5% of the 293,000 workers whose primary earnings were with FLCs and less than 2% of all farmworkers, suggesting that combining farm and nonfarm jobs is relatively rare.

Employment by county

The 848,000 workers with at least one farm employer in 2015 can be assigned to the county where they had their highest-earning job, which could be a farm or a nonfarm job. Kern (119,000), Fresno (96,000) and Monterey (94,000) had 36% of the state's farmworkers, and the eight counties that each had at least 30,000 farmworkers had over 60% of the total, including Tulare (72,000), Ventura (36,000), San Joaquin (35,000) and Santa Barbara and Los Angeles (32,000 each) (fig. 3).

Workers are assigned to the county of their employer, so that an employee of an agribusiness operating

Fig. 3. Primary workers by county, 2015.

TABLE 3. Major employers of farmworkers, 2015

County*	No. employers	Farm labor contractors	Tree nuts	Grapes	Postharvest	Vegetables	Top 3
Kern	119,613	65%	7%	7%			79%
Fresno	96,169	47%		8%	13%		68%
Monterey	94,098	41%			15%	12%	68%
Total	**309,880**						

Source: EDD analysis of unemployment insurance payroll tax data.

* These three counties had 36% of the 848,000 farmworkers who had at least one farm employer in 2015.

in several counties could be assigned to the headquarters county.

The largest employer in most counties was an FLC (NAICS 115115): they employed 65% of primary workers in Kern County, 47% in Fresno County and 41% in Monterey County (table 3). In Kern County, the next largest employers were tree nuts (111335) and grape vineyards (111332), each with 7% of primary workers. In Fresno, the next largest were employers engaged in postharvest activities (115114) with 13% of workers and grape vineyards with 8%. In Monterey, postharvest activities employed 15% of primary workers, vegetable farming (111219) 12% and strawberry farming (111333) 11%.

In Tulare County, FLCs accounted for 54% of farmworkers, followed by 9% for postharvest activities and 7% for dairy (112120). In Ventura County, 32% of farm workers were in strawberry farming, followed by 19% with FLCs and 16% with other berries (111334).

Los Angeles was the most unusual county. All workers had to have one farm employer to be included in the analysis, but the largest employers of farmworkers who had their highest earnings in Los Angeles County were employment services (NAICS 5613), with 12% of farmworkers; restaurants (7225), 8%; nurseries (111421), 4%; and strawberries, 3%. In Napa County, 34% of the 8,000 farmworkers were employed by grape vineyards, followed by 32% employed by farm management services (115116); 7% each were employed by FLCs and beverage manufacturers (3121).

Conclusions

These data, which approximate a census of hired workers in California agriculture, show significant gaps between the earnings a full-time employee would receive and the average earnings of farmworkers. Since a full-time employee is defined as working 2,080 hours per

Farmworkers harvest corn in Gilroy, Santa Clara County. Few farmworkers are employed year-round due to seasonality and turnover. In 2015, the average earnings of all workers with at least one farm job was $20,500, which is about two-thirds the average annual wage of a full-time equivalent worker.

Bob Nichols, USDA

year, a $30,283 annual wage suggests an hourly wage of $14.56 per hour. However, the actual average earnings of California farmworkers were $17,445 in 2015, suggesting fewer hours of work or lower hourly earnings.

Data on hours worked are not collected by EDD, making it difficult to explain the gap between average and FTE earnings. However, the analysis leads to three conclusions. First, there are far more farmworkers than year-round equivalent jobs even as agriculture is becoming less seasonal and more workers are settling in one area and working for only one farm employer. An earlier study found almost three workers for each year-round farm job in the 1990s and more workers with more than one farm job (Khan et al. 2004). Since 2007, there have been two unique workers for each average agricultural job in California.

Second, apparent stability in the farm labor market, defined as more workers having only one farm employer, may be misleading. A third of FTE employment and unique workers are employed by FLCs, and workers with one FLC employer during the year may nonetheless work on more than one farm. The shift from farmers hiring workers directly to relying on nonfarm intermediaries to bring workers to their farms may suggest stability in the sense that more workers have one employer, but the jobs of these workers may be on many farms, sometimes necessitating the lengthy commutes described by *the Los Angeles Times* of workers who lived in Stockton and commuted almost 2 hours one way to jobs in Napa (Kitroeff and Mohan 2017).

Third, procuring farmworkers via intermediaries should increase labor market efficiency, as FLCs specialize in finding a series of farm jobs for their employees (Thilmany 1996). However, workers employed primarily by FLCs earned only 44% of what an FTE employee would have earned, suggesting that FLCs are unable to provide their employees with full-year work. The implied average hourly wage of an FTE employee of a FLC was $10.80 an hour when the state minimum wage was $9 in 2015, suggesting that many FLC employees worked fewer than 1,000 hours per year. Farmers may be using FLCs to fill many of the seasonal jobs on their farms, explaining why workers employed by FLCs have fewer hours of work.

Farmers, worker advocates and governments have struggled to rationalize the farm labor market so that the fewest workers can maximize worker earnings while accomplishing the work to be done. The ratio of unique workers to FTE jobs fell from three to two during the 1990s, and since 2007 this ratio has stabilized at two to one. The past decade has been marked by the growing importance of nonfarm intermediaries, especially FLCs, bringing farmworkers to crop farms, converting what in the past may have been migration from one farm employer to another to workers with the same FLC moving from farm to farm.

Immigration trends and policy could speed or slow the trend toward more workers being brought to farms by FLCs and earning less than half of an FTE worker. Farmers are responding to the slowdown in new and unauthorized arrivals via the four S's: satisfying them to keep them in farm work longer, stretching them with productivity-increasing mechanical aids and management changes such as fewer re-picks of fields and orchards, substituting machines for workers where possible, and supplementing an aging and settled workforce with young and legal H-2A guest workers (Martin 2017). The H-2A program could be modified to make it easier to employ guest workers, which could mark a return to the 1950s, when legal Mexican Braceros who were housed on the farms where they worked were the norm (Martin 2003). CA

Processing green peppers in Gilroy. In the past 10 years, some farmers have shifted from hiring workers directly to using farm labor contractors to bring workers to their farms. However, research suggests that contractors aren't able to provide full-year work.

P. Martin is Professor Emeritus of Agricultural and Resource Economics at UC Davis; and B. Hooker and M. Stockton are Research Specialists at the state of California's Employment Development Department. The views expressed in this report do not necessarily reflect the policies of the Employment Development Department or the state of California.

References

Carroll D. 2017. California crop worker characteristics: Preliminary 2015-2016 findings from the National Agricultural Workers Survey. UC Davis Gifford Center for Population Studies presentation. April 14, 2017. https://gifford.ucdavis.edu/events/.

[CDFA] California Department of Food and Agriculture. 2017. California Agricultural Statistics Review, 2015-16. www.nass.usda.gov/Statistics_by_State/California/Publications/California_Ag_Statistics/Reports/2015cas-all.pdf.

Khan A, Martin PL, Hardiman P. 2004. Expanded production of labor-intensive crops increases agricultural employment. Calif Agr 58:35–9. https://doi.org/10.3733/ca.v058n01p35.

Kitroeff N, Mohan J. 2017. Wages rise on California farms. Americans still don't want the job. *Los Angeles Times*, March 17, 2017. www.latimes.com/projects/la-fi-farms-immigration/.

Martin P. 2003. Does the US need a new Bracero program? UC Davis Journal of International Law and Policy 9(2):127–41. http://heinonline.org/HOL/Page?handle=hein.journals/ucdl9&div=18&id=&page=&collection=journals.

Martin P. 2017. Immigration and farm labor. Challenges and opportunities. Giannini Foundation. UC Division of Agriculture and Natural Resources. http://bit.ly/2tvaUSw.

[NAICS] North American Industry Classification System. US Census Bureau. www.census.gov/eos/www/naics/.

Thilmany D. 1996. FLC usage among California growers under IRCA: An empirical analysis of farm labor market risk management. Am J Agr Econ 78(4): 946–60. www.jstor.org/stable/1243851?seq=1#page_scan_tab_contents.

RESEARCH ARTICLE

Automated lettuce thinners reduce labor requirements and increase speed of thinning

Automated thinners were as accurate in thinning lettuce as manual thinning, produced comparable yields, and were more than three times faster than thinning crews.

by Elizabeth Mosqueda, Richard Smith, Dave Goorahoo and Anil Shrestha

Abstract

Salinas Valley lettuce growers are adopting automated lettuce thinners to improve labor efficiency. We conducted field studies in 2014 and 2015 to compare the time involved in automated and manual thinning of direct-seeded lettuce and any differences in lettuce quality and yield. We recorded the number of doubles (two closely spaced plants) left behind after thinning, time taken to remove the doubles, final crop stand, efficiency in weed removal, crop yield and disease incidence. Using an automated thinner in place of manual hoeing reduced the thinning labor requirement from 7.31 ± 0.5 person-hours per acre to 2.03 ± 0.5 person-hours per acre. Automated thinning left more doubles than manual thinning, resulting in additional time to remove them, but was overall more labor-efficient and had no impact on yield or disease incidence.

In recent years, California's agriculture industry has been hindered by a declining supply of farm labor (Taylor et al. 2012), generating interest among growers in methods to reduce labor requirements for thinning, weeding, irrigating and harvesting (Fennimore et al. 2010; 2014). Thinning lettuce is particularly labor intensive, and most lettuce fields in California are hand-thinned (manually thinned). Automated lettuce thinners that use machine vision and computer image processing, and a spray system to remove unwanted plants, were introduced to the Salinas Valley 4 years ago. Growers are evaluating their cost and performance to see if they have a fit in their operations.

An automated thinner, which typically needs only one person to run it, removes plants to ensure accurate final plant spacing and provide a measure of weed control (Chu et al. 2016). Machine vision technology

Online: https://doi.org/10.3733/ca.2017a0018

Published online May 15, 2017

California growers are adopting automated lettuce thinners to improve labor efficiency. An automated thinner pulled behind a tractor can thin up to 18 seedlines at 2 mph. However, doubles left behind must be removed manually.

allows the thinner to distinguish plants from soil, but the machines in our studies could not distinguish crop plants from weeds. The vision system chooses keeper plants, based on the plant spacing settings set by the operator, calculates the spacing and selects the next keeper plant and eliminates unwanted plants between. Unwanted plants are removed by spraying a registered herbicide such as carfentrazone or topical applications of fertilizers.

The majority of lettuce fields in California are planted using coated seeds with a precision planter (Turini et al. 2011). Seeds are generally planted about ⅛ inch deep and 2 to 3 inches apart on 40-inch raised flat beds with two rows, or on 80-inch beds with five or six rows (Cahn 2014; Smith et al. 2011; Turini et al. 2011). After the seedlings emerge, they are thinned to a spacing of 10 to 12 inches (Cahn 2014; Smith et al. 2011) at approximately the four-leaf stage (Chu et al. 2016).

Thinning is accomplished manually with a hoe. Weeds are removed in the thinning process (Fennimore et al. 2014), but some weeds escape. At 2 to 3 weeks after thinning, a second manual operation removes weeds and doubles (two closely spaced lettuce plants missed in the thinning operation).

Studies have reported that the time taken to thin a lettuce field is positively correlated with the number of weeds present (Haar and Fennimore 2003). Weeds are the most persistent pest in vegetable crops, and they compete with crops for essential nutrients and water in the soil, hold the potential to transmit diseases, delay harvests and, if present in harvested produce, contaminate the crop (Bell 1995; Fennimore et al. 2014; Haar and Fennimore 2003). Weeds in lettuce production are managed primarily with herbicides and hand-hoeing (Fennimore et al. 2014). Weed control provided by herbicides depends on weed species in lettuce fields (Bell et al. 2000). If weed species are present that are not controlled by herbicides, they create a greater dependence on hand-weeding.

Top, lettuce beds were thinned by an automated thinner. *Bottom,* the unwanted plants were sprayed with an herbicide and marked with blue dye; the unsprayed plant is the keeper plant. Note the buffer area around the keeper plant.

After automated thinning, lettuce plants were adequately spaced in the seedline. Notice the two sprayed lettuce between the keeper plants.

When a double occurs, it is difficult to thin one of the plants with an automated thinner or by hand-hoeing.

Our studies compared the accuracy of spacing, weed control and impact on lettuce head drop (*Sclerotinia minor*) of automated thinning and manual thinning in direct-seeded lettuce. The studies also evaluated the time to remove doubles, time of thinning and subsequent weeding operations, lettuce stand counts, size of unthinned lettuce plants and the ultimate yield of the two thinning systems. The goal was to provide information to growers considering adopting automated thinners.

We used automated lettuce thinners from the following manufacturers: Mantius Ag Technologies, Gonzales, CA; Blue River Technology, Mountain View, CA; Vision Robotics, San Diego, CA; and AgMechtronix, Silver City, NM (Smith 2014).

Commercial field experiments

Field experiments were conducted in 2014 and 2015 in various locations in the Salinas Valley of California. Trials were conducted with cooperating growers on commercial lettuce production fields. In 2014, seven sites were established in which half the field was manually thinned and the other half was thinned with an automated thinner (table 1). The experimental design was arranged as a randomized complete block in which each field served as a replicate.

TABLE 1. Details on lettuce study location, variety, type of lettuce, planting and harvesting dates, and thinner manufacturer, 2014 and 2015

Location	Year	Variety	Lettuce type	Planting date	Harvest date	Thinner manufacturer
Gonzales	2014	Declaration	Head	May 2	Jul 17	Blue River
Salinas	2014	Champion	Head	Apr 26	Jul 1	Blue River
Salinas	2014	Mondo	Romaine	May 11	Jul 18	Blue River
Salinas	2014	Telluride	Head	May 27	Jul 28	Mantius Ag Technologies
Salinas	2014	Telluride	Head	Jun 10	Aug 12	Mantius Ag Technologies
Salinas	2014	Big Star	Green leaf	Jun 2	Aug 1	AgMectronix
Salinas	2014	Mondo	Romaine	Jul 11	Sep 16	Blue River
Soledad	2015	Darkland	Romaine	May 30	Jul 29	Vision Robotics

Lettuce beds were 40 inches wide with two seedlines at all sites except one site with 80-inch beds with five seedlines. Within each treatment plot, four to 10 subplots were randomly chosen for sampling; edges of the field were avoided. These subplots were one bed wide and 30 feet long. For the one experimental site with 80-inch beds, each subplot was 15 feet long. Lettuce seeds were planted ⅛ inch deep and 2 to 3 inches apart with a precision seeder. Planting and harvest dates, and details about the lettuce variety and type are shown in table 1.

In 2015, the experiment was conducted in one field in Soledad, California. At this site, a randomized complete block design was established with four replications each of automated thinning and manual thinning treatments. Each plot consisted of four 80-inch beds with six seedlines. The subplots were one 80-inch-wide bed 10 feet long. Seeding date and other experimental details are shown in table 1. Seeding depth and spacing were similar to those for the 2014 studies.

Lettuce stand counts were taken in the subplots at each experimental site prior to the thinning process. Weeds in each subplot within 1 inch of the seedline were also counted by species and recorded. These weeds are the weeds most difficult to remove and cause the greatest yield losses. Weeds outside of that area on the bed top and weeds in the furrows were removed by traditional mechanical cultivation. The number of lettuce doubles left by the thinning operation within each subplot was also counted.

For the manually thinned plots, a crew of approximately 15 to 25 members was typically used. Each crew member was equipped with a hoe. Crew members typically thin one seedline on a bed of lettuce at a time. They work their way down the crop row on one side of the bed thinning one seedline and then work their way back thinning the other seedline on the other side of the bed. For lettuce beds with more than two seedlines, crew members often will thin two or three seedlines as they move down the field and two or three seedlines as they move back, which makes the process much slower on 80-inch-wide beds compared to beds with two seedlines.

The time taken by one crew member to thin a designated measured area was recorded with a stopwatch. This process was continued until every crew member was timed at least once. The data collected for each crew member was combined to calculate the average timing for the entire crew and converted to person-hours per acre. This process was done for each manually thinned area. For plots thinned with an automated thinner, the time taken to thin the entire treatment plot was recorded. The data was then converted to person-hours per acre. Automated thinners used in this experiment thinned two to four 40-inch beds at a time, or one 80-inch bed at a time. Chemicals used to thin plants were carfentrazone (1.0 ounce per acre), N-pHuric (20 gallons per acre) and 14-0-0-5 (N, P, K, S) fertilizer (20 gallons per acre).

A day or two after the lettuce thinning process, crop stand, weed density by species and doubles were counted. Spacing between each lettuce plant within a crop row, from the center of one plant to the center of the next, was measured in each subplot with a measuring tape.

Approximately 2 weeks after lettuce thinning, both automated thinning and manual thinning plots were

Two weeks after thinning, a crew removed doubles and weeds from both automated thinning and manual thinning plots.

weeded with hand hoes to remove doubles and weeds missed in the thinning process and weeds that had emerged after thinning. The time taken to perform this action for each subplot was recorded using the method described earlier and converted to a per-acre basis.

One day prior to crop harvest, counts were made of lettuce plants infected with *S. minor*. In both 2014 and 2015, this was performed by dividing each treatment plot into nine sections. Within each section, two or three randomly chosen beds were selected for evaluation. In each of these beds, a 30-foot section was measured, and each lettuce plant infected with *S. minor* was recorded.

Yield was estimated by taking the total weight of 24 lettuce plants from a random spot within each subplot on the day of the main harvest. Within each subplot, 12 lettuce plants were harvested from two adjacent rows. All 24 plants were then weighed together to estimate total yield on a fresh weight basis. After the plants were weighed, each plant was inspected for blemishes and quality, stripped, and sorted for marketable and unmarketable heads and weighed again to estimate marketable yield.

The number of unharvested lettuce plants per plot were also counted the day after the field was completely harvested in both years of the study. The yield data was not subjected to statistical analysis in 2014 because lettuce varieties were not similar at all sites. However, the total and marketable crop yields in 2015 were statistically analyzed. Labor costs for the two thinning systems were also calculated based on estimates of Tourte et al. (2016).

All data were analyzed using the general linear model procedures (PROC GLM) in SAS v. 9.3. Assumptions of ANOVA were tested prior to the analysis. All data met these assumptions; therefore, no transformations were necessary. Whenever the ANOVA showed significance at 0.05 level, mean separation was done using the Tukey's honestly significant difference test. Year and blocks were considered as random effects. Interaction between year and treatment was also tested for each variable. There were no interactions between year and treatment for any of the variables; therefore, data were combined for the 2 years and analyzed.

Thinning time and costs

Automated thinning required less than one-third of the labor of manual thinning (table 2). Automated thinners took an average of 2 person-hours per acre to thin the lettuce plots; manual thinning took more than 7 person-hours per acre. Labor costs were estimated at $43.40 per acre for automated thinning and $112.70 per acre for manual thinning (using an equipment operator wage rate of $21.70 per hour and field labor rate of $16.10 per hour, including 40% benefits, Tourte et al. 2016). These costs did not include capital costs, depreciation or overhead costs for the automated thinner,

TABLE 2. Results of field trials of automated and manual thinning conducted in 2014 and 2015. Note: since these trials were conducted, bigger machines capable of thinning three 80-inch beds with a total 18 seedlines have been developed, and machine thinning times have been further reduced from figures shown here.

Variable*	Automated thinning (± SE)	Manual thinning (± SE)
Average time required for thinning (person-hours/ac)†	2.03 (0.5)b	7.31 (0.5)a
Average number of lettuce after thinning (plants/ac)	33,612 (1,328)a	32,914 (1,026)a
Average number of doubles after thinning (plants/ac)	2,042 (413)a	402 (140)b
Average spacing between lettuce within a row after thinning (in)	11.0 (0.4)a	11.2 (0.3)a

* Means within a row with different letters are significantly different at a 0.05 level.
† Does not include time to thin doubles.

and we did not consider net profits to growers for the two weed management techniques.

The automated thinners evaluated in this study traveled at speeds greater than 2 miles per hour (mph) and thinned as many as eight seedlines per pass. Hand crews thin at less than 1 mph and thin one seedline at a time. However, automated thinners can be hampered by wet soil and windy conditions. Automated thinners are often operated in the morning, when wind velocity is lower, to reduce the risk of the thinning chemicals drifting onto keeper plants.

Crop stand, number of doubles

The final crop stand was similar in the automated and manual thinning treatments (table 2). On average, there were 33,662 plants per acre and 32,913 plants per acre, respectively, in the automated and manual thinning plots. However, automated thinning left five times more doubles than did manual thinning (table 2). A key factor in the number of doubles was the accuracy of the seeding operation. If seedlings were very close, an automated thinner could not separate them due to the tolerance programmed into the machine that ensured that it did not spray too near the keeper plants and damage them. Given the level of technical development in the automated thinners we used in the studies, manual thinning crews were better able to distinguish two closely spaced lettuce plants and therefore left fewer doubles.

Where lettuce plantings were not accurately spaced, automated thinners left more doubles.

Automated thinners leave doubles in cases where plants are very closely spaced; the machine's plant spacing settings are designed to avoid spraying too close to the regularly spaced keeper plants.

In this case, an automated thinner mistook a burning nettle (*Urtica urens*) for a lettuce, left it unsprayed and instead sprayed lettuce plants on either side of it.

Weed control

After thinning, the number of weeds left behind in the 1-inch band on either side of the seedline was similar in the automated and manual thinning plots, an average of 750 and 650 weeds per acre, respectively. As mentioned earlier, the difference was not significant at 0.05 level. Therefore, it was concluded that the automated thinners were as efficient as the thinning crew in removing weeds in the thinning operation.

Both systems tended to leave behind weeds that were in close proximity to lettuce plants. In the manual thinning plots, this could have been because crew members missed the very small weed seedlings or the seedlings may have been concealed by the lettuce plant canopy. Crew members were also careful during thinning to avoid stand losses; they hoed delicately around the lettuce plants and may have missed weeds. In automated thinning plots, weeds survived in the buffer area around keeper plants. If a weed was close to a lettuce plant, the camera recognized it as a large lettuce plant and did not spray it. Occasionally, a weed was left behind in the space where a lettuce plant should have been, because the machines in our trials could not distinguish between weed and crop plants.

Weed species counted included burning nettle (*Urtica urens*), common purslane (*Portulaca oleracea*), hairy nightshade (*Solanum physalifolium*), shepherd's purse (*Capsella bursa-pastoris*), common groundsel (*Senecio vulgaris*), common mallow (*Malva neglecta*) and annual sowthistle (*Sonchus oleraceus*). There was no difference between the two thinning systems in the number of weeds, by species, left behind (data not shown).

Doubles and weed removal

Weeding crews removed doubles, weeds left behind after thinning and recently emerged weeds faster in the manual thinning plots than in the automated thinning plots. Automated thinning plots had five times more doubles than manual thinning plots, and it took crews 1.5 person-hours per acre longer, 6.9 (± 0.8) person-hours per acre compared with 5.4 (± 0.6) person-hours per acre, to remove them and the weeds.

Labor costs for doubles and weed removal was $111.09 per acre for automated thinning and $86.94 per acre for manual thinning (using a general labor rate of $16.10 per hour, including 40% benefits, Tourte et al. 2016). However, these time and cost results for doubles and weed removal seemed to be influenced by differences in the accuracy in planting, as some sites had more doubles than others.

Plant spacing, *S. minor*, yields

The average spacing between lettuce plants within a crop row was similar in the automated and manual thinning plots, approximately 11 inches and 11.2 inches, respectively (table 2). Desired spacing is 9 to 11 inches, and these results indicate that automated thinners can provide equivalent accuracy to manual thinning.

There were no differences between the incidences of *S. minor* in the automated and manual thinning plots (data not shown). The average weight of 24 lettuce plants was similar in the automated and manual thinning plots, approximately 52 pounds. The average weight of 24 marketable lettuce heads, approximately 37 pounds, also did not differ between the two systems.

The number of unharvested lettuce plants at the end of the study was similar in the automated and manual thinning plots, approximately 1,200 plants per acre. This was an important result, verifying that automated thinning did not produce a greater number of smaller plants at harvest because of inadequate plant spacing during thinning.

Automated thinning compares well

Automated lettuce thinners were as accurate in thinning lettuce as manual thinning and produced comparable stands and yield. Automated thinning was more rapid than and removed weeds at the same rate as manual thinning. However, in situations where lettuce plantings were not accurately spaced, they left more doubles, which necessitated greater time being spent to remove them in a subsequent weeding operation.

There was no significant difference in lettuce yield at harvest between fields that used automated thinners and those that were manually thinned.

The comparable results of automated thinning and manual thinning suggest that growers could direct labor from thinning to other jobs such as irrigation and harvest. We did not evaluate the economics of automated thinning, but a cursory comparison of labor costs shows that automated thinners can be more cost effective, and given the adoption of automated thinning already, it is evident that growers see the benefits of it on their bottom line.

Already available since our study are wider machines capable of thinning 18 seedlines in one pass, which undoubtedly increases efficiency and speed. In the future, improvements in machine vision may allow better recognition of crops and weeds, and improvement in spray systems may reduce the number of doubles and improve weed removal. Future studies of this technology may be more multifaceted (e.g., ability to recognize doubles, capability of applying insecticides and fungicides to the keeper plants) and include their impact on overall efficiency and economic benefit that they bring to the farm given labor shortages faced by growers. CA

A. Shrestha is Professor, Weed Science, at California State University, Fresno; E. Mosqueda is Former Graduate Student at California State University, Fresno; R. Smith is UC Cooperative Extension Farm Advisor in Monterey, San Benito and Santa Cruz counties; D. Goorahoo is Associate Professor, Vegetable Science, at California State University, Fresno.

References

Bell CE. 1995. Broccoli (Brassica oleracea var. botrytis) yield loss from Italian ryegrass (*Lolium perenne*) interference. Weed Sci 43:117–20.

Bell CE, Fennimore SA, McGiffen Jr ME, et al. 2000. My view. Weed Sci 48:1.

Cahn MD. 2014. UC IPM Pest Management Guidelines: Lettuce. Irrigation of Head and Romaine Lettuce. http://ipm.ucdavis.edu/PMG/r441311511.html.

Chu Q, Liu J, Bali K, et al. 2016. Automated thinning increases uniformity of in-row spacing and plant size in Romaine lettuce. HortTechnology 26:12–9.

Fennimore SA, Smith RF, Tourte L, et al. 2014. Evaluation and economics of a rotating cultivator in bok choy, celery, lettuce, and radicchio. Weed Technol 28:176–88.

Fennimore S, Tourte L, Rachuy J, et al. 2010. Evaluation and economics of a machine-vision guided cultivation program in broccoli and lettuce. Weed Technol 24:33–8.

Haar MJ, Fennimore SA. 2003. Evaluation of integrated practices for common purslane (*Portulaca oleracea*) management in lettuce (*Lactuca sativa*). Weed Technol 17:229– 33.

Smith R. 2014. Evaluation of Spray Materials for Thinning/Weeding Lettuce. http://cemonterey.ucanr.edu/files/201678.pdf.

Smith R, Cahn M, Daugovish O, et al. 2011. *Leaf Lettuce Production in California*. UC ANR Pub 7216. Oakland, CA.

Taylor JE, Charlton D, Yúnez-Naude A. 2012. The end of farm labor abundance. Appl Econ Perspect P 34(4):587–98.

Tourte LJ, Smith RF, Klonsky K, et al. 2016. Sample costs to produce and harvest romaine hearts. UC Davis Cost and Returns Study. http://coststudyfiles.ucdavis.edu/uploads/cs_public/50/a0/50a0bad6-1cf0-4d61-a632-78b6fe2ff538/2015romaineheartsfinaldraft_1-27-2016-1.pdf.

Turini T, Cahn M, Cantwell M, et al. 2011. *Iceberg Lettuce Production in California*. UC ANR Pub 7215. Oakland, CA.

RESEARCH ARTICLE

Wild pigs breach farm fence through harvest time in southern San Joaquin Valley

Camera traps recorded 860 wild pig encounters at Laval Farms during the harvest season for grapes and pistachios, most of them at night.

by Michael D. White, Kayla M. Kauffman, Jesse S. Lewis and Ryan S. Miller

Abstract

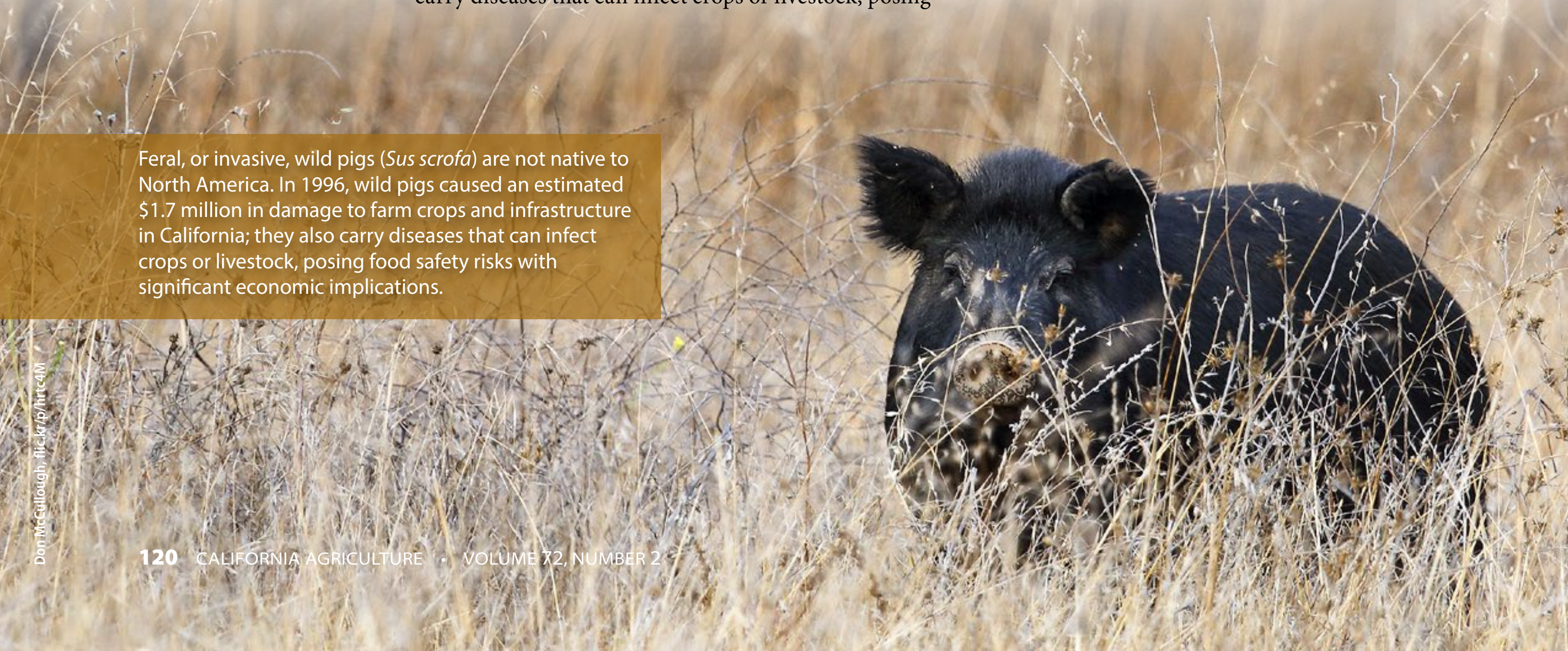
Wild pigs cause around $1 billion of damage to agriculture in the United States each year — foraging on crops, breaking branches and vines, and damaging irrigation lines and fences — but little is known about how and when they access agricultural fields. We used wildlife camera traps to document and describe wild pig access to two fenced southern San Joaquin Valley farms. Pigs breached fences around agricultural fields, especially during the harvest period when crops were ripe, and almost exclusively at night, outside of the regulated, daytime recreational pig hunting period. GPS data from an adult boar revealed that pigs may travel long distances from wildlands to reach crops. The results of our case study suggest that increasing monitoring and maintenance of fences during the harvest season and removing pigs that have learned to access farms may help reduce pig damage to agricultural fields. The results also suggest a formal scientific investigation of risk factors and strategies to reduce wild pig damage is warranted.

Online: https://doi.org/10.3733/ca.2018a0017

Wild pigs are conservatively estimated to cause $800.5 million to $1.5 billion in damage each year in the United States (Anderson et al. 2016; Pimentel et al. 2000; Pimentel et al. 2005; Seward et al. 2004). In 1996, wild pigs caused an estimated $1.7 million in damage in 40 California counties (Frederick 1998), and they are known to occupy 56 of 58 California counties (Christie et al. 2014). In addition to damaging farm crops and infrastructure, wild pigs carry diseases that can infect crops or livestock, posing food safety risks with significant economic implications (Jay-Russell et al. 2012; Kreith 2007, Miller et al. 2017; Seward et al. 2004). For example, an incident of *Escherichia coli* O157:H7 spinach contamination in San Benito County, California, in 2006 was linked to wild pigs (Jay et al. 2007).

Feral, or invasive, wild pigs (*Sus scrofa*) are not native to North America; introduced wild boar were released intentionally or escaped domestication, resulting in self-sustaining populations of wild pigs in many parts of the United States. The abundance of wild pigs can be higher near agriculture, especially in landscapes with a mix of farm and natural land cover (Lewis et al. 2017). Wild pigs consume a wide variety of plants, including crop plants, and animals, including livestock such as new-born lambs and calves. They also damage soils by rooting, wallowing and trampling; break tree branches; and damage irrigation systems and fences (Pimentel et al. 2000; Pimentel et al. 2005; Lombardini et al. 2016).

Nonlethal pig control methods rely largely on fences to prevent access. Small-scale studies of fence designs show that a pig-proof fence can be constructed from woven wire mesh 2.5 to 4 feet (0.8 to 1.2 meters) tall with a ground-level and a top strand of barbed wire (Hone and Atkinson 1983; Lavelle et al. 2011). However, exclusion is feasible only for small areas (Barrett and Birmingham 1994), and ongoing maintenance is essential.



Feral, or invasive, wild pigs (*Sus scrofa*) are not native to North America. In 1996, wild pigs caused an estimated $1.7 million in damage to farm crops and infrastructure in California; they also carry diseases that can infect crops or livestock, posing food safety risks with significant economic implications.

Don McCullough, flic.kr/p/hrrc4M

There is little empirical information on wild pig activity and the effectiveness of pig control measures in agricultural fields and ranches in California, so we are participating in a collaborative project studying wild pig ecology and potential pig-related agricultural damages at Tejon Ranch (fig. 1). The 270,000-acre (109,000-hectare) Tejon Ranch, located in the southern San Joaquin Valley and Tehachapi Mountains of California, supports extensive natural wildlands as well as farms. Wild pigs were first recorded on Tejon Ranch in the early 1990s, as the result of an accidental release from a high-fenced hunting ranch in the Tehachapi Mountains. Several thousand pigs are now distributed throughout Tejon Ranch (Lewis et al., unpublished data). We undertook a case study of the activity patterns of wild pigs and factors that may regulate their access at two farms on the ranch to determine if a more formal investigation of wild pigs and California agriculture is warranted.

Two fenced farms assessed

This study assessed two fenced farms: Laval Farms, approximately 950 acres (384 hectares) with 35,300 feet (10,800 meters) of perimeter fence; and Old Headquarters, approximately 270 acres (109 hectares) with 17,300 feet (5,270 meters) of perimeter fence (fig. 1). Both farms are surrounded by natural lands occupied by pigs, with the highest-quality pig habitat to the south of the fields in the Tehachapi Mountains (fig. 1). These farms support wine grapes and pistachios. In 2016, the harvest period for grapes was early September to end of October, and for pistachios it was Sept. 1 to 20 (Dennis Atkinson, Tejon Ranch Company, personal communication).

On July 14, 2016, we walked the perimeter fence of each farm to identify holes, weak spots or structures such as ladders or gates that pigs could use to enter the fields. If in good repair, the perimeter fences would be considered pig-proof based on small-scale fence trials (Hone and Atkinson 1983; Lavelle et al. 2011): They were approximately 3.2 to 3.6 feet (0.9 to 1.1 meters) tall and made of 2.5-inch (6.4-centimeter) mesh chain link with horizontal barbed wire strands. Single or double strands of barbed wire typically extended above the top of the chain link. A steel cable woven through the bottom of the fence was buried 6 to 8 inches (15 to 20 centimeters) deep. In places the steel cable lay on the ground surface, particularly at Laval Farms.

Only two holes at Laval Farms had signs of pig use at the beginning of the study, but many repairs of previous breaches by pigs were obvious, consisting of one or more t-posts blocking holes dug under fences or the wiring together of loose chain link that pigs had bent, and the fence was slack in many places. The Old Headquarters fence was newer and generally in good condition, with few unrepaired holes, its bottom mostly buried and no signs of current pig use.

Camera traps along the fences

We assessed wild pig use of the farms in summer and fall 2016 using remotely triggered wildlife cameras located along the farms' perimeter fences. We placed wildlife camera traps at all holes and selected weak spots in the fences (fig. 2) and oriented the cameras to photograph animals inside the fences. Cameras were secured with plastic zip ties to t-posts positioned next

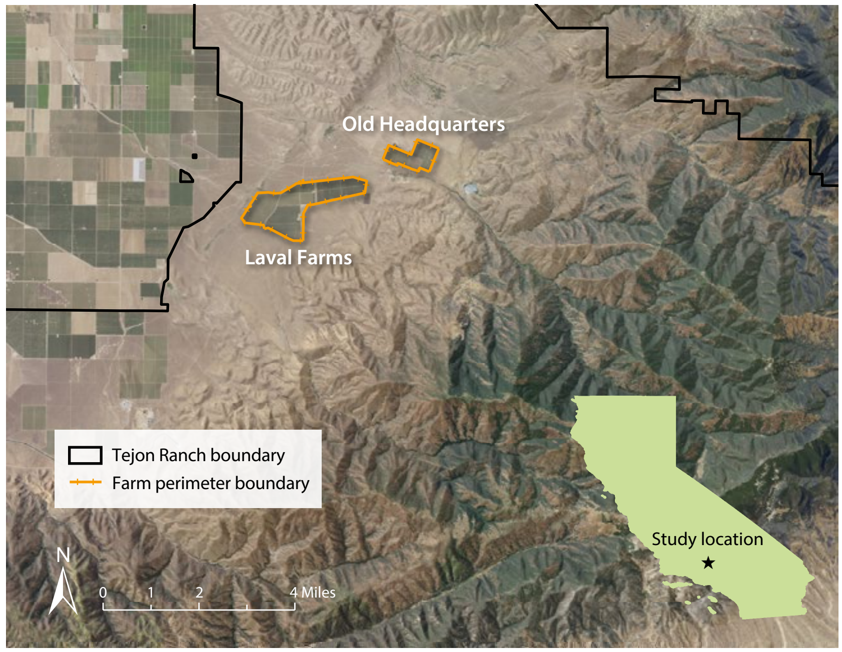


FIG. 1. Location of the two farms on Tejon Ranch where we studied wild pig activity. The agricultural land visible to the west of Laval Farms and Old Headquarters is in the southern San Joaquin Valley. Highest-quality, year-round wild pig habitat lies in the Tehachapi Mountains south of the farms.

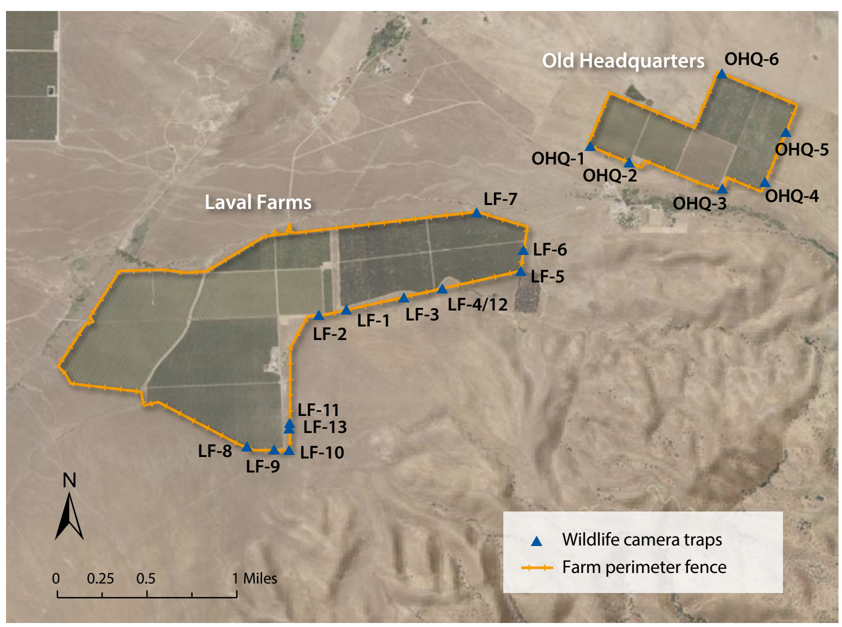


FIG. 2. Location of wildlife camera traps at the study sites. Laval Farms, 950 acres, has a 35,300-foot perimeter fence; Old Headquarters, 270 acres, has a 17,300-foot perimeter fence. We placed camera traps along the perimeter at locations where there were existing holes or weak spots in the fences.

to each hole or weak spot, at an angle greater than 45 degrees to the fence line and pointed slightly downward. Cameras were spaced a minimum of 50 feet (15 meters) apart, so that a single camera could capture activity at multiple holes or weak spots. During the study, pigs created a hole adjacent to camera trap LF-4, and the camera was repositioned to a new location (LF-12) less than 50 feet (15 meters) from LF-4 to better cover that section of fence. We present the combined results for these two cameras (LF-4/12). Camera LF-2 was dropped from the study because of problems with tall grass continually triggering the camera. Camera trapping duration was July 14 to Dec. 14, 2016 (22 weeks).

We used Spypoint model IR-7 (infrared flash) and BF-10 (black flash) wildlife cameras, with distance sensitivity and photo quality set to the highest settings. The cameras took bursts of three photos, with a 10-second delay between each photo in a burst and a 1-minute minimum delay between bursts. We checked cameras every 2 weeks and changed low batteries and replaced memory cards. If a camera stopped functioning or the memory card was full, the date and time of the last photo taken were recorded, and the day it was restarted was counted as a half-day in quantifying the number of days each camera operated (camera-days). At the completion of camera trapping, fences were resurveyed, all weak spots were mapped and pictures were taken to assess any changes.

Photo analysis

We reviewed all photos and recorded any image containing a wild pig, along with the date, time and number of pigs in the image. The same animals may trigger a camera repeatedly within a brief period; therefore, photos of pigs for each camera were grouped into what we termed “encounters.” An encounter documents the contact of pigs with a camera trap and was defined as a series of one or more photos of pigs separated by a period of at least 30 minutes from the next series of pig photos comprising the next encounter. Thus, an encounter could be a single animal or a group of pigs and might be comprised of a single photo or multiple photos.

As individual cameras operated for different lengths of time, we standardized the camera trap data as number of encounters per camera-day. We grouped encounters across wildlife cameras into 7-day periods (called weeks but not corresponding to the calendar week) or hours of the day as appropriate for display of seasonal or daily patterns. We assessed seasonal changes in activity by comparing total weekly encounter rates across all cameras within three crop harvesttime periods: preharvest (July 14 to Aug. 31), harvest (Sept. 1 to Nov. 2) and postharvest (Nov. 3 to Dec. 14). Statistical differences in encounters between the harvest periods were tested with ANOVA and *t*-tests after rank-transforming the 22 weeks of encounter data (Conover and Iman 1981).

GPS data on pig M302

In a separate USDA-funded project at Tejon Ranch, we are trapping and collaring wild pigs using GPS-enabled tracking collars to estimate pig population abundance and space use patterns. One of the GPS-collared male pigs (M302) in that project, estimated to be 5 years old

The fences at Laval Farms and Old Headquarters farm were chain link with a strand of barbed wire at the top of the fence and a steel cable through the bottom buried in the ground. (A) The Old Headquarters fence was newer and generally in better condition than the fence at Laval Farms; this section was tight and snug to the ground but had a displaced top wire and bent chain link from animals climbing over it. The wildlife camera trap (left), like all the other five cameras on the Old Headquarters perimeter fence, caught no evidence of pig activity. (B) Laval Farms fence had existing holes at the start of the study and developed many new holes over the course of the study. This section was bent at the top and had a hole at the bottom partially blocked with a t-post that was enlarged over the course of the study. Camera traps at Laval Farms (at right in this photo) recorded high levels of pig activity.

and 200 pounds (90.7 kilograms), visited Laval Farms extensively during our study. While derived from only a single individual, the space use data from this pig supplemented our camera trap data by allowing estimates of movement patterns and time budgets.

A Lotek Iridium GPS collar (Newmarket, Ontario, Canada) was programmed to record a location every 30 minutes on pig M302 from Aug. 2 to Nov. 28, 2016, and the data were mapped using an ESRI ArcMap Geographic Information System. For the purposes of this study, we considered M302 to have entered the farm once he crossed the fence, whether his location was in an agricultural field or, for example, on an adjacent access road (see fig. 2). We determined, by week, the number of hours that M302 spent on-farm. We assessed seasonal changes by comparing total time spent on-farm each week within three time periods: preharvest (Aug. 3 to Aug. 30), harvest (Aug. 31 to Nov. 1) and postharvest (Nov. 2 to Nov. 27). Statistical differences in time spent on-farm between the harvest periods were tested with ANOVA and *t*-tests after rank-transforming the 17 weeks of time-spent-on-farm data (Conover and Iman 1981).

Laval Farms fences breached

Wild pigs accessed Old Headquarters and Laval Farms differently during this study. No pigs were captured by the six camera traps at the Old Headquarters farm over the course of the 760 total camera-days (table 1). Old Headquarters farmworkers reported seeing no pigs or pig damage during 2016. Therefore, we are reporting only the results for Laval Farms.

The 11 cameras at Laval Farms ran for 1,530 camera-days over 22 weeks. Wild pigs were detected every week and appeared to have preferred entry points to the farm (table 1). Two camera traps placed at the two existing holes in the fence with signs of pig use at the start of the study (LF-11, LF-13) captured pigs repeatedly over the course of the study, yielding on average more than two encounters every day that the cameras were active (2.04 and 2.49 encounters per day, respectively). Three other camera traps (LF-3, LF-4/12 and LF-5) placed at existing weak spots also captured pigs repeatedly over the course of the study, with an encounter every 1.5 to 2.5 days (0.37 to 0.67 encounters per day).

There were 860 total encounters on 394 (26%) of the 1,530 camera-days (table 1). Each encounter averaged 3.11 photos (95% CI = ± 0.19), and an average of 1.16 individuals (95% CI = ± 0.03) were seen in each photo (a maximum of seven pigs was seen in a single photo). The average encounter rate across all cameras was 0.56 (95% CI = ± 0.59) encounter per camera-day. Two cameras (LF-11 and LF-13) accounted for 73% of the encounters, and another three cameras (LF-3, LF-4/12 and LF-5) accounted for an additional 25% of the encounters. Only two of the 11 cameras (LF-6 and LF-7) never detected pigs.

Pigs clearly damaged the Laval Farms fence during the study. Fences were generally maintained during fall and winter months, and at the beginning of the study in July there were only two holes in the fence that showed recent pig signs. By the end of the study, however, there were at least 24 holes of sufficient size for a pig to pass through and several areas where the top of the fence was bent from animals climbing over it. Fifteen of the holes showed signs of pig use. Seven of these used holes did not have cameras, so it is likely


Tejon Ranch Conservancy

This sow was one of the many wild pigs that entered Laval Farms during the study. Cameras recorded 58.7 encounters per week during harvest; additionally, there was evidence of pig use at many fence holes where there were no cameras. The pigs came always at night, most often between midnight and 2 a.m. One boar fitted with a tracking collar (M302 — see text) spent an average of over 3 hours each week on the farm, and a maximum of 7 hours in one night.

TABLE 1. Wildlife camera trap results of pig activity on Laval Farms (LF)

Camera	Camera-days	Encounters	Encounters per camera-day	Percentage of total encounters
	no.			*%*
LF-1	147.5	4	0.03	0.5
LF-3	145.5	54	0.37	6.3
LF-4/12	139.5	94	0.67	11.0
LF-5	148.5	71	0.48	8.3
LF-6	153.5	0	0.00	0.0
LF-7	93.0	0	0.00	0.0
LF-8	152.5	1	0.01	0.1
LF-9	119.5	5	0.04	0.6
LF-10	152.5	5	0.03	0.6
LF-11	152.5	311	2.04	36.3
LF-13	125.5	312	2.49	36.4
Total	**1,530**	**860**		**100.00**

that camera traps underestimated the activity of pigs at Laval Farms.

While field trials have produced fence designs that will contain pigs (Lavelle et al. 2011), Hone and Atkinson (1983) found that pigs can breach many types of fences and learn where they are most easily breached. Previous studies found that wild pigs tend to access fields closest to a wildland edge (Geisser and Reyer 2004; Thurfjell et al. 2009). Our case study supports these findings.

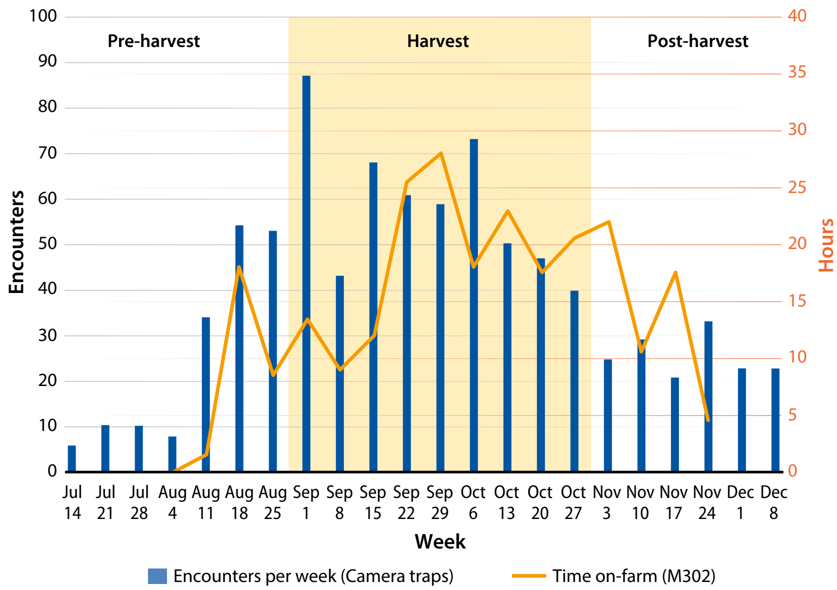


FIG. 3. Total number of wild pig encounters from camera trap photos at Laval Farms and time spent (hours per week) there by pig M302 by week (dates are the first day of each 7-day period). There were statistically greater numbers of encounters ($P = 0.0004$) and time spent ($P = 0.002$) during the harvest period than during preharvest or postharvest periods.

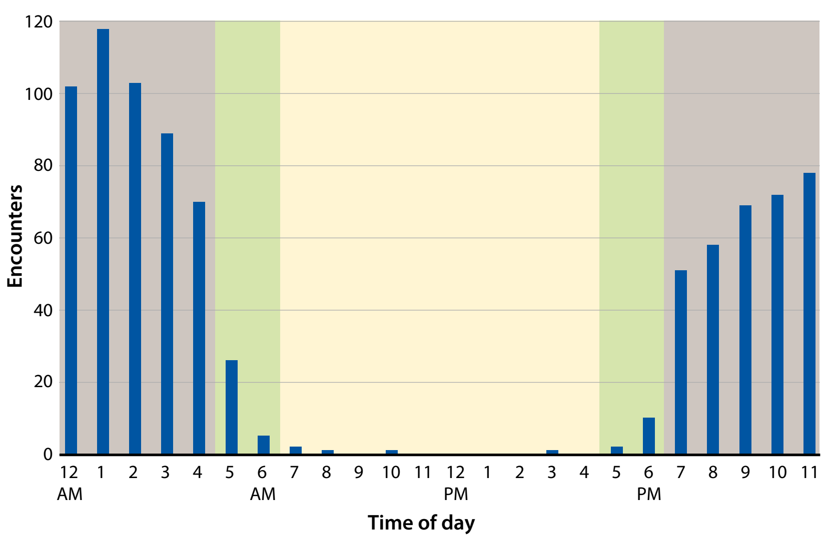


FIG. 4. Frequency of wild pig encounters from camera trap data by time of day for the length of the 22-week study. Grey indicates nighttime hours, yellow indicates daylight hours and green indicates sunset/sunrise hours. Virtually all encounters were before sunrise or after sunset.

Pig activity highest at harvest time

Consistent with the finding of Lombardini and colleagues (2016), wild pig use of Laval Farms followed crop ripening, with encounter rates ($P = 0.0004$) and time spent on-farm by M302 ($P = 0.002$) significantly higher during the harvest period than the pre- or postharvest periods (fig. 3). Encounters averaged 25.0 per week during the preharvest period, increased to 58.7 encounters per week during harvest and tapered off to 25.7 encounters per week in the postharvest period. M302 spent an average of 171 minutes per week on-farm during the preharvest period (Aug. 3 to Aug. 30), increasing to 1,133 minutes per week during the harvest period (Aug. 31 to Nov. 1) and falling to 817 minutes per week in the postharvest period.

Interestingly, pig activity remained at or above preharvest levels well after all crops were harvested. Postharvest period encounter rates were higher, but not significantly so, than preharvest encounters, while time spent on-farm by M302 was significantly greater postharvest than preharvest ($P = 0.01$). It may be that pigs were seeking blank pistachios remaining on the ground after harvest (Dennis Atkinson, Tejon Ranch Company, personal communication) or other food resources and cover associated with the crops. Crops can provide a supplemental food source for pigs when there is less food in wildland areas (Thurfjell et al. 2009), and wildland food resources were likely relatively low during the dry summer and early fall months at Tejon Ranch.

Virtually all encounters were before sunrise or after sunset (fig. 4). Only 3% of encounters (26 of 860) occurred between 30 minutes prior to sunrise and 30 minutes after sunset. Pig activity quickly increased after sunset and fell rapidly after sunrise, with the greatest activity observed between 12 a.m. and 2 a.m. (38% of encounters). M302 was never recorded on-farm during daylight hours. Wild pigs accessing the farm primarily during nighttime hours is consistent with previous research. For example, Andrzejewski and Jeziersk (1978) found that pig activity at feeding stations was greatest between sunset and sunrise.

It is difficult to determine from camera trap data how much time pigs spent in the Laval Farm fields. However, one adult boar, M302, entered Laval Farms 116 times between Aug. 2 and Nov. 28 (a 231-day period, fig. 3) and spent a total of 236 hours on-farm over the 17 weeks that he was collared, including spending 7 hours on-farm in 1 night. Only considering the days he visited the farm, the average time M302 spent on-farm was 194 minutes per day (95% CI = ± 51 minutes per day).

M302 traveled long distances

M302 traveled 3 to 5 miles (4.8 to 8.0 kilometers) each way (straight-line distance) from wildland areas in the Tehachapis to Laval Farms and adjacent agricultural fields to the west nearly every day during the harvest period (fig. 5). He alternated visiting Laval Farms and fields to the west. He appeared to generally use the same travel routes and points of access to the agricultural fields, and only came to them at night.

Effects of human activity, crops

Human activity and crop maturity may have been reasons why wild pigs regularly accessed Laval Farms during this study but not Old Headquarters. Although crop types were the same on the two farms (grapes and pistachios), the vineyards at Laval Farms were more mature than at Old Headquarters, and Laval Farms is three times larger. Also, due to its size and configuration, the southern portion of Laval Farms most used by pigs had little regular human activity (Dennis Atkinson, Tejon Ranch Company, personal communication), whereas Old Headquarters had more human activity over its entire area. The grapes at Old Headquarters were harvested for the first time in 2016, and there may have been a difference in productivity between the two farms that pigs detected. However, it is more likely that there was greater pig activity at Laval Farms because of the poorer condition of the fences and less human activity.

Controlling pig access to farms

The California Department of Fish and Wildlife regulates pigs as a big game species, selling over 50,000 pig tags each year (Christie et al. 2014), but current California big game regulations limit pig harvest to daylight hours (½ hour before sunrise to ½ hour after sunset). While high hunting pressure can reduce wild pig densities (Sweitzer et al. 2000), daytime hunting causes pigs to shift to a nocturnal activity pattern (Barrett and Birmingham 1994). A nocturnal activity pattern was apparent at Tejon Ranch, which supports a year-round recreational pig hunting program.

When pigs are nocturnally active, recreational hunting would only be an effective pig control strategy in agricultural fields, as some have suggested (Geisser and Reyer 2004; Hone and Atkinson 1983), if regulations allowed hunting at night. Only 3% of wild pig encounters in this study were recorded during the legal hunting hours.

Although not used at Laval Farms, depredation permits issued by the California Department of Fish and Wildlife allow culling of pigs at night by authorized individuals (Christie et al. 2014), a potentially useful tool available to farmers to reduce nocturnal pig damage. This approach specifically targets individual pigs that

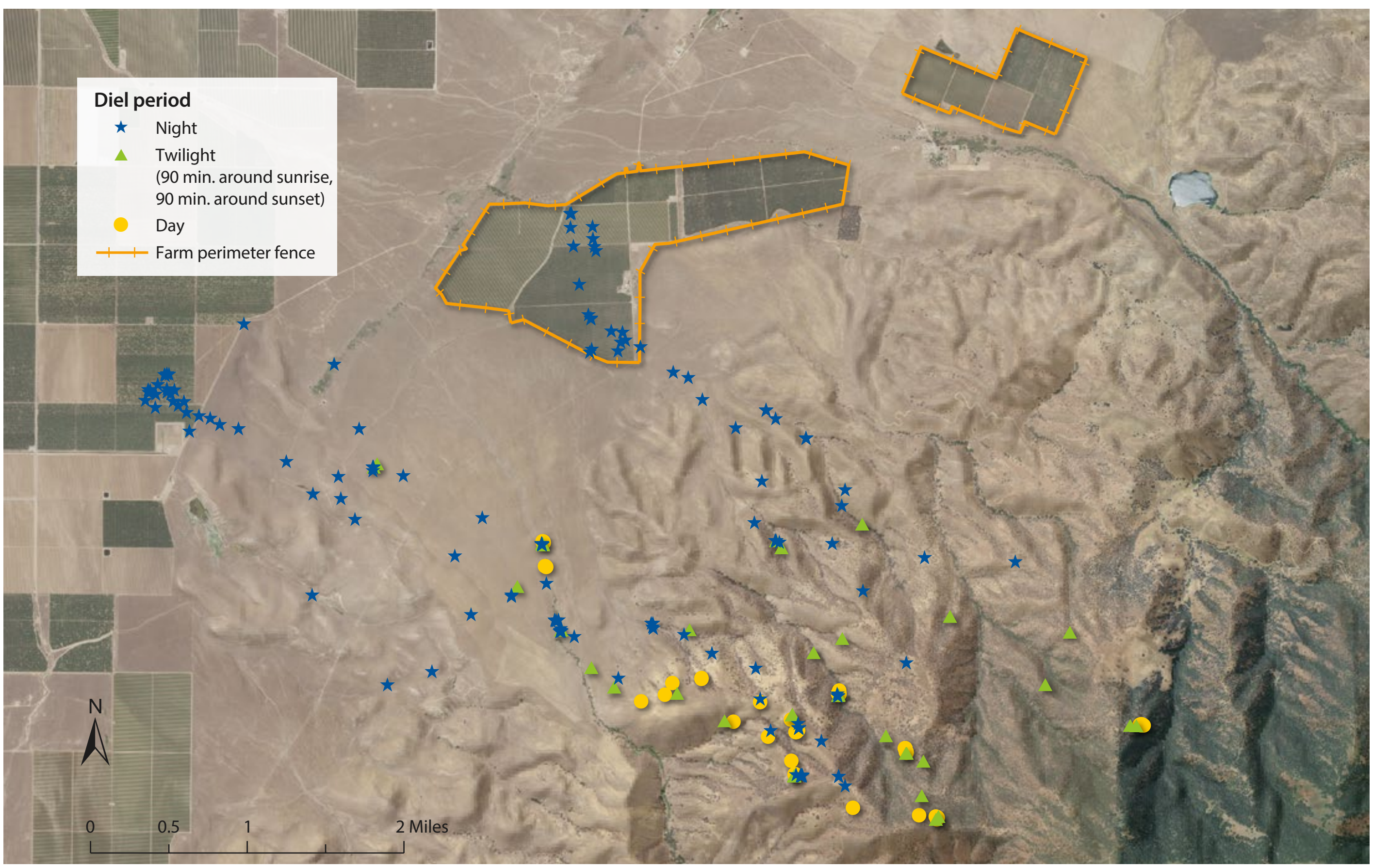


FIG. 5. Locations of GPS-collared wild pig M302 recorded every half hour from Oct. 27 to Nov. 2, symbolized by the time of day. He alternated visiting Laval Farms and fields to the west. He appeared to generally use the same travel routes and points of access to the agricultural fields, and only went to them at night. The same pattern of space use occurred in weeks not shown. Note that some points may obscure other points.

have learned where farms are in the landscape and how to access them. Alternatively, because wild pigs retreat to wildland habitat during daylight hours, depressing pig populations in wildland areas could also reduce the number of pigs accessing agricultural fields. However, long-term population control through a sustained harvest program may be challenging since pigs can increase their reproductive rates as their population densities decline and immigrate to unoccupied areas (Beiber and Ruff 2005).

Formal research needed

Although our research did not quantify the impacts of pigs frequently accessing Laval Farms in significant numbers, it was clear that the pigs damaged fences and irrigation systems, consumed and damaged fruit, and rooted around vines and trees. Our findings demonstrate the potential risks and damages to California agriculture posed by wild pigs, which are consistent with the agricultural damages caused by pigs across the United States (Pimentel et al. 2005). They also demonstrate the need for a formal research effort to better understand the magnitude of the problem, the factors that increase risks of damage and methods to reduce damage.

Our study suggests factors that increase the risks of pig damage to agriculture include proximity to wildland areas supporting pigs, poorly maintained or no fencing, and areas with low human activity. However, we still have a poor understanding of how wild pigs move through heterogeneous landscapes to find and exploit agricultural versus wild food resources, levels of agricultural damage caused by pigs in various locations, and farms and crops most at risk of pig damage. Our findings suggest that damage may be mitigated by regular monitoring and maintenance of fences, culling pigs that have learned to breach fences, and, potentially, recreational hunting or professional culling to reduce wildland pig populations adjacent to agriculture. But structured research is needed to assess and quantify the relative efficacy and costs of these and other strategies in reducing damages in different crops and geographic regions of California. CA

M.D. White is Visiting Scholar, Department of Environmental Policy, Science and Management, University of California Berkeley; K.M. Kauffman is Veterinary Science Masters Student, Wyoming State Veterinary Lab, University of Wyoming; J.S. Lewis is Assistant Professor, College of Integrative Sciences and Arts, Arizona State University; and R.S. Miller is Senior Ecologist, Center for Epidemiology and Animal Health, Veterinary Services, USDA Animal and Plant Health Inspection Service.

This study was conducted while MDW and KMK were on the staff of the Tejon Ranch Conservancy, and JSL was a Postdoctoral Researcher with Conservation Science Partners. We acknowledge the contributions and support of those organizations. We thank Dr. Kurt VerCauteren for advice on study design and implementation. Jerre Stallcup provided valuable comments and edits to the manuscript. Ben Teton assisted with fieldwork. We thank the Tejon Ranch Company for providing access to the farms described in this study.

References

Anderson, A, Slootmaker C, Harper E, et al. 2016. Economic estimates of feral swine damage and control in 11 US states. Crop Prot 89:89–94.

Andrzejewski R, Jeziersk W. 1978. Management of a wild boar population and its effects on commercial land. Acta Theriol 23(19):309–39. http://rcin.org.pl/Content/10505/BI002_11474_Cz-40-2_Acta-T23-nr19-309-339_o.pdf

Barrett RH, Birmingham GH. 1994. Wild pigs. In: *The Handbook: Prevention and Control of Wildlife Damage*. http://digitalcommons.unl.edu/icwdmhandbook/51

Bieber C, Ruff T. 2005. Population dynamics in wild boar *Sus scrofa*: Ecology, elasticity of growth rate, and implications for the management of pulsed resource consumers. J Appl Ecol 42:1203–13.

Christie J, DeMarco E, Hiroyasu E, et al. 2014. Wild Pig Management at Tejon Ranch. Bren School Group Project 2014. Bren School of Environmental Science and Management, UC Santa Barbara.

Conover WJ, Iman RL. 1981. Rank transformation as a bridge between parametric and non-parametric statistics. Am Stat 35(3):124–9.

Frederick JM. 1998. Overview of wild pig damage in California. In: Baker RO, Crabb AC (eds.). Proc 18th Vertebrate Pest Conf. UC Davis. p 82–6.

Geisser H, Reyer HU. 2004. Efficacy of hunting, feeding, and fencing to reduce crop damage by wild boars. J Wildlife Manage 68(4):939–46.

Hone J, Atkinson B. 1983. Evaluation of fencing to control feral pig movement. Wildlife Res 10(3):499–505.

Jay MT, Cooley M, Carychao D, et al. 2007. Escherichia coli O157:H7 in feral swine near spinach fields and cattle, Central California Coast. Emerg Infect Dis 13(12):1908–11.

Jay-Russell MT, Bates A, Harden L, et al. 2012. Isolation of Campylobacter from feral swine (Sus scrofa) on the ranch associated with the 2006 Escherichia coli O157: H7 spinach outbreak investigation in California. Zoonoses Public Hlth 59(5):314–9. www.ncbi.nlm.nih.gov/pubmed/22405465

Kreith M. 2007. Wild Pigs in California: The Issues. UC Agricultural Issues Center. AIC Issues Brief 33. www.agmrc.org/media/cms/AgMRC_IB33v3_13C1D662ADDAE.pdf

Lavelle MJ, Vercauteren KC, Hefley TJ, et al. 2011. Evaluation of fences for containing feral swine under simulated depopulation conditions. J Wildlife Manage 75(5):1200–8.

Lewis JS, Farnsworth ML, Burdett CL, et al. 2017. Biotic and abiotic factors predicting the global distribution and population density of an invasive large mammal. Sci Rep 7, no. 44152. doi:10.1038/srep44152

Lombardini M, Meriggi A, Fozzi A. 2016. Factors influencing wild boar damage to agricultural crops in Sardinia (Italy). Curr Zool 63(5):507–14. doi:10.1093/cz/zow099. http://cz.oxfordjournals.org/content/czoolo/early/2016/10/01/cz.zow099.full.pdf

Miller RS, Sweeney S, Slootmaker C, et al. 2017. Cross-species transmission potential between wild pigs, livestock, poultry, wildlife, and humans: Implications for disease risk management in North America. Sci Rep 7, no. 7821.

Pimentel D, Lach L, Zuniga R, Morrison D. 2000. Environmental and economic costs associated with non-indigenous species in the United States. BioScience 50(1):53–65.

Pimentel D, Zuniga R, Morrison D. 2005. Update on the environmental and economic costs associated with alien-invasive species in the United States. Ecol Econ 52(3):273–88. www.sciencedirect.com/science/article/pii/S0921800904003027

Seward NW, VerCauteren KC, Witmer GW, Engeman RM. 2004. Feral swine impacts on agriculture and the environment. Sheep Goat Res J 12. http://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1011&context=icwdmsheepgoat

Sweitzer RA, Van Vuren D, Garder I, et al. 2000. Estimating sizes of wild pig populations in the north and central regions of California. J Wildlife Manage 64(2):531–43.

Thurfjell H, Ball JP, Åhlén PA, et al. 2009. Habitat use and spatial patterns of wild boar Sus scrofa (L.): Agricultural fields and edges. Eur J Wildlife Res 55(5):517–23. www.researchgate.net/profile/John_Ball7/publication/225512960_Habitat_use_and_spatial_patterns_of_wild_boar_Sus_scrofa_(L.)_agricultural_fields_and_edges/links/54b2791e0cf2318f0f948c75.pdf

RESEARCH ARTICLE

Central Coast growers' trust in water quality regulatory process needs rebuilding

A 2015 survey of growers showed their trust of the regional water board had decreased since 2006, even though there had been more frequent communication.

by Ann Drevno

Abstract

Growing evidence of agricultural water pollution in California's Central Coast even after the implementation of tough water quality regulations has increased the pressure on regional stakeholders. Previous research has shown that collaborative relationships between growers and regulators can motivate growers to make management decisions that benefit the environment. However, informal evidence suggested trust might have been eroding between growers and the Central Coast Regional Water Quality Control Board (CCRWQCB, the regulator) since 2004, the year the first legislation went into effect. Using a survey conducted in 2015, interviews and in-depth document review, this study assesses growers' trust of and communication with other agricultural groups and water quality regulatory agencies, specifically CCRWQCB. Survey results were compared to results of the same survey sent out in 2006. Results corroborate other research — growers' trust of most regional agricultural groups was closely correlated with frequency of communication. However, growers' trust of CCRWQCB did not correspond to the relatively high contact frequency and had declined since 2006. The literature on rebuilding trust suggests ways forward for CCRWQCB.

Many, if not most, water bodies in Central Coast agricultural areas are severely degraded due to chemical inputs. Nitrates have become a critical problem for groundwater contamination and drinking water supplies (Harter et al. 2012). Additionally, agricultural pesticides (e.g., historically organophosphates, currently pyrethroids) are a major source of regional toxicity (Anderson et al. 2003; Anderson et al. 2006; Anderson et al. 2010; Anderson et al. 2011; Hunt et al. 1999; Phillips et al. 2012; Phillips et al. 2006). Sediments are another top water pollutant in the area.

Improving water quality in agricultural areas is contingent on a variety of factors, including landowners' and growers' decisions on land use and farming practices. The choice to adopt protection measures on farms can be influenced by real estate markets, government policies, and individual motivations (Ryan et al. 2003), as well as by the existence of trusting relationships between growers and regulatory agencies (Leach and Sabatier 2005; Lubell 2007).

Anecdotal evidence suggests that issues of trust and communication are especially germane in the Central Coast region. Regulatory relationships there appear to be at a critical juncture. Local farming organizations have voiced their concerns over the decreasing collaboration between regulators and growers over the past decade.

In discussions leading up to the California Legislature's 2002 decision to end agriculture's exemptions from waste discharge requirements, agricultural interests recognized that the water quality problem was not going to fade. That recognition motivated the Farm Bureau, a trusted agricultural organization, to become part of the conversations and solutions (farm advisor, personal communication, February 2013). The political context at the time — mounting

Online: https://doi.org/10.3733/ca.2018a0015

Agricultural pollution affects many water bodies on California's Central Coast and has prompted regulatory action. This article examines the perspectives of Central Coast growers on water quality issues and on the many groups involved in water quality regulation and management, including agricultural groups and the Central Coast Regional Water Quality Control Board.

John Chacon, California Department of Water Resources

The Central Coast Regional Water Quality Control Board is one of nine statewide; each water quality control board issues permits and enforces requirements at the local level. Map of California regional water quality control boards adapted from California Water Boards brochure (revised May 2013).

cases of polluted drinking water, the passage of Senate Bill 390, which reasserted pressure on regional water boards to take more responsibility for comprehensive water control, and public frustration with polluted waterways — set the stage for a unique regulatory process in which agricultural interests sought to support water regulations and become more involved (Kranz 2004).

As one UC Cooperative Extension (UCCE) advisor described the situation (personal communication, February 2013), the Farm Bureau "became instrumental in calming [the growers] down, deciding to be proactive, and working with others to convince the farming community that [water quality control measures] were worth investing in."

In 2004, the Farm Bureau reiterated these collaborative sentiments, stating that although "the [new water quality mandates] weren't perfect," the Central Coast Regional Water Quality Control Board (CCRWQCB) had taken a "constructive approach" (Kranz 2004). Eight years later, the extent of perceived collaboration among agricultural stakeholders leading up to the 2012 Agricultural Waiver dramatically shifted. Instead of the Farm Bureau lauding the regulatory process as "constructive," it called it "flawed" and lacking in collaboration and participation (Campbell 2012).

Although the Farm Bureau's perspective may shed light on an important trend occurring in the Central Coast regulatory process, no research has yet examined growers' opinions on trust, water quality issues and the regulatory process over time and the resultant policy implications. My goal was to survey hundreds of growers and ground-truth the reported changes in opinions and relationship patterns over a 9-year period, from 2006 to 2015.

Rigorous regulatory changes

Each of California's nine regional water quality control boards (or regional boards) has the authority to regulate water quality at a local level. Included in a regional board's jurisdiction is the right to waive the discharge permits so that an industry that releases pollutants into state waters, including agriculture, need not apply for a permit. After the passage of Senate Bill 390 in 1999, however, regional boards issuing waivers to agriculture had to attach conditions (e.g., any mandated requirements, best management practices, monitoring requirements) to the waivers and renew or update those mandates at least every 5 years.

In 2004, CCRWQCB passed its first Conditional Waiver of Waste Discharge from Irrigated Lands (the 2004 Agricultural Waiver). The conditions required growers to enroll in the agricultural waiver, complete 15 hours of water quality education, prepare a farm management plan, implement water quality improvement practices and complete individual or cooperative water quality monitoring. When the 2004 Agricultural Waiver expired in July 2009, substantial data from the cooperative monitoring program and scientific studies demonstrated that water bodies in the region continued to be severely impaired from agricultural runoff. Because the Central Coast Water Board did not have a quorum to adopt a new agricultural waiver, the order was extended with some modifications until July 2010. With the board still at an impasse, the 2004 waiver was extended three more times (July 2010, March 2011 and September 2011).

After nearly 3 years of negotiation, on Mar. 15, 2012, CCRWQCB passed a new waiver. The updated and more comprehensive 2012 Agricultural Waiver placed farms in one of three tiers, based on their risk to water quality (Tier 1 being the lowest risk and Tier 3 the highest), and imposed requirements for each tier. For Tier 1 and 2 farms, the requirements were similar to those in the 2004 order with two notable additions: groundwater monitoring (all tiers) and total nitrogen application reporting (for some Tier 2 and Tier 3 farms). Tier 3 farms, on the other hand, had to comply with several new rigorous provisions, including individual discharge monitoring and reporting.

A third agricultural waiver (or Ag Order 3.0) was adopted on

Mar. 8, 2017, and will be in effect for only 3 years, as it was intended to be an interim order. The most significant changes are more extensive groundwater monitoring and nitrogen application reporting.

Across the region, a variety of third-party organizations have arisen to assist CCRWQCB in controlling water pollution and to help growers comply with the conditions of the agricultural waivers. These organizations have become deeply embedded in the regional governance and agricultural support networks. For example, Central Coast Water Quality Preservation, Inc., or Preservation, Inc., manages the cooperative monitoring program for growers enrolled in the agricultural waiver; the California Department of Pesticide Regulation (DPR) delivers statewide pesticide regulatory programs, and county agricultural commissioners' offices regulate pesticide use on a local level, among other duties; local Farm Bureau offices collaborate with other agricultural organizations to advocate and provide services for local growers; and UCCE, U.S. Department of Agriculture (USDA) Natural Resources Conservation Service, and local California resource conservation districts have established programs that provide technical and financial assistance to help growers integrate best management practices into farming systems.

Each organization has different relationships with regional growers, colored by historical interactions and its institutional goals. My study tracked growers' trust with these organizations, how much they valued the information and communication with the organizations, as well as how their views of them changed over time and in response to the first two agricultural waivers.

Motivations to change behavior

Growers' behavioral decisions to alter farming practices in favor of the environment have been widely researched (Beedell and Rehman 2000; Knowler and Bradshaw 2007 Prokopy et al. 2008). Prior studies in the field of agricultural economics have developed models to predict growers' decision-making, many of which assume that they will maximize profits over other objectives (Willock et al. 1999). However, behavioral economists, political scientists, social psychologists and other social scientists have demonstrated how cultural and psychological concerns can also heavily motivate growers' decisions to change their behavior (Chouinard et al. 2008; Leach and Sabatier 2005; Mzoughi 2011). Dozens of case studies and several meta-analyses synthesizing these works (Knowler and Bradshaw 2007; Prokopy et al. 2008) cite a wide range of environmental factors influencing growers' choice to adopt best management practices. These include a motivation to show others their environmental commitment (Mzoughi 2011), a desire to protect the environment (Greiner and Gregg 2011), a strong attachment to the land (Ryan et al. 2003) and good stewardship (Brodt et al. 2004; Ryan et al. 2003).

Of interest to my research is a growing body of work in the fields of political science and environmental policy that demonstrates how trust between stakeholders, including regulators and regulated groups, can impact growers' decisions, and change their views over time. Trust has been reported as a pivotal factor in solving natural resource conflicts, especially common resources (Cox et al. 2009; Ostrom et al. 1999; Ostrom and Walker 2003; Rudeen et al. 2012). Given its weight in environmental policy processes, researchers have endeavored to uncover ways in which trusting relationships are cultivated as well as how they degrade.

Communication can greatly influence trust. According to Leach and Sabatier (2005), "The strength of each interpersonal relationship ought to increase with the frequency of contact and with the cumulative number of interactions over time." Research also shows that it is not only the contact frequency but also the type of contact that matters. For example, the history of interactions (Lubell 2007) and of agreements or disagreements (Leach and Sabatier 2005) can inform trust.

Whether the communication is in-person or long distance also plays a role. Ostrom and her colleagues (1994) found that face-to-face communication is a promising means of fostering trust. Others have found that a lack of face-to-face contact could be disadvantageous; for example, institutional distance between growers and regulatory agencies, could hinder trust building (Lubell 2007). Communication among growers is also important: Lubell and Fulton (2008) showed that growers' relationships with their agricultural community, or "diffusion networks," such as with other growers, local outreach and education agencies, and neighbors, were pivotal in growers' decisions to adopt best management practices for water quality.

Agricultural water quality regulation in California's Central Coast is laden with contentious issues of trust, collaboration and stakeholder involvement (Drevno 2016).

Two grower surveys

This study uses data from two public opinion surveys. The first survey was conducted by UC Davis Professor Mark Lubell and UCCE agent Mary Bianchi in 2006, which was 2 years after the first agricultural waiver was adopted. The survey was mailed to 1,994 growers in Santa Barbara and southern San Luis Obispo counties. The list of growers was assembled from UCCE educational classes. A total of 454 completed surveys were received. This first survey employed Dillman's (2000) total design method, which includes an introduction letter followed by two waves of survey packages and reminder postcards.

I sent out the second survey in 2015, which was 2 years after the second agricultural waiver was implemented. (The second waiver was passed in 2012, but because of a deferral, or stay, it was not put into effect until 2013.) The second survey was approved for exemption from IRB review by UC Santa Cruz. To make accurate comparisons, the 2015 survey used the same survey techniques and prompts as the 2006 survey.

Because the list of 2006 survey recipients was not publicly available, the second survey was sent to all growers enrolled in the 2012 Agricultural Waiver available through the electronic Notice of Intent. The second survey was conducted through an email survey portal. After duplicate email addresses, erroneous email addresses, and email addresses of growers no longer farming were removed, the survey distribution list was comprised of 1,089 growers across the Central Coast region. A total of 230 completed surveys were received. While the respondents in the 2015 survey were not the same set of growers as in the 2006 survey, all respondents were growers in the region under the same regulatory system.

A paired *t*-test was used to examine the differences in attitudes between 2006 and 2015 survey responses, as well as other factors that may have changed over time. Pearson's correlation tests were employed in hypothesizing a close relationship between trust of a water quality agency and the information value received from that agency.

To complement the results from the surveys and further trace the evolution of agricultural stakeholder narratives between 2006 and 2015, I completed a detailed set of qualitative interviews with key actors (growers and agency officials) knowledgeable about the agricultural water quality regulatory process. I also analyzed secondary data — CCRWQCB meeting minutes, policy reports, newspaper and magazine articles and judicial proceedings.

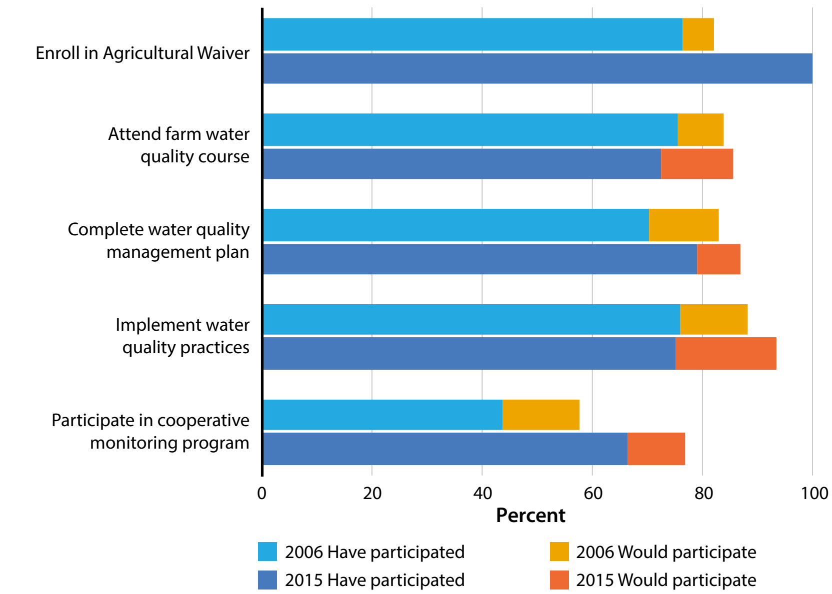


FIG. 1. Types of water quality management activities growers in the Central Coast had already adopted or would be interested in adopting, as self-reported in 2006 and 2015 surveys.

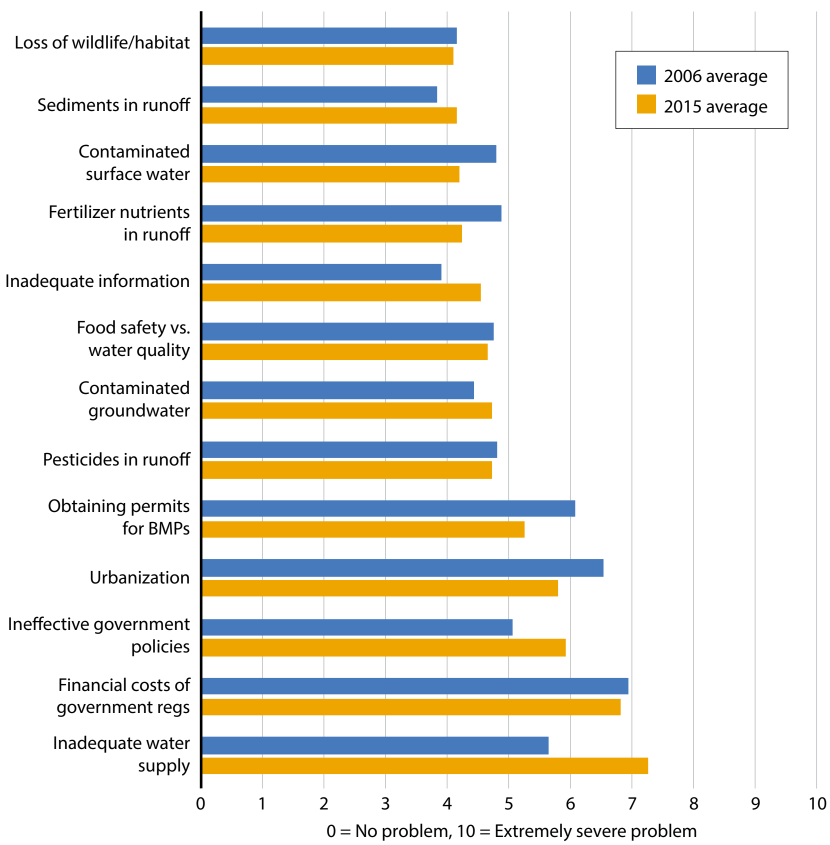


FIG. 2. Growers' opinions on the seriousness of various water quality issues, in 2006 and 2015.

Growers self-report high scores

The first set of questions in the survey asked growers what types of water quality management activities they had already participated in or would be interested in participating in. Growers self-reported very high scores (fig. 1). One interesting result was the discrepancy in reported participation in the cooperative monitoring program compared to the actual participation numbers recorded by the program (found as part of the review of secondary data). The reported participation of over 95% of all growers was substantially lower than the program documentation numbers. The most plausible explanation is that enrolled growers simply forgot that they had enrolled or did not realize they had done so, especially in 2006, when the cooperative monitoring program and monitoring provisions were new to growers.

Pollution not the biggest issue

A second set of questions asked survey participants to share their opinions of water quality issues (fig. 2). Eight issues placed an average score of 5 or less, meaning growers thought these issues ranked closer to being "no problem" than "an extremely severe problem." These included pollution from pesticides, fertilizers and sediments and contamination of groundwater and surface water. Of these, surface water pollution and fertilizer pollution significantly dropped in importance to growers over the 9-year period.

Despite participants perceiving these five water quality issues to be less severe than other problems, academics, scientists and regulators often cite these issues as the most problematic sources of water quality contamination (Anderson et al. 2003; Anderson et al. 2010; CCRWQCB 2011a; Harter et al. 2012). For example, in a review of scientific data, CCRWQCB staff "found that many of the same areas that showed serious contamination from agricultural pollutants 5 years ago are still seriously contaminated" and that "staff does not believe there is improvement in nitrate concentrations in areas that are most heavily impacted" (CCRWQCB 2011a). Additionally, scientific studies published during this period showed increasing evidence of ambient toxicity in the Central Coast region due to pesticides (Anderson et al. 2006; Anderson et al. 2011; Hunt et al. 1999).

Growers identified as the most serious regional water quality problems the issues more directly impacting their farm viability and management practices. In 2015, during a historic 4-year drought, inadequate water supply was unsurprisingly growers' top concern; in the 2006 survey it ranked as the fourth most serious concern. Three of the five water quality issues most worrying growers were related to the regulatory process — the financial costs of regulations, ineffective government policies and obtaining permits for best management practices. Ineffective government regulations rose from being the fifth greatest concern in 2006 to the third greatest concern in 2015, which supports the Farm Bureau's account of amplified frustration over the regulatory process.

Ecological issues and fairness matter

The third set of questions aimed to assess growers' motivations and cultural values in their water quality decision-making (fig. 3). More than 75% of respondents from both surveys agreed with the following statements:

- Growers have a duty to protect the land.
- Growers' knowledge is important for policymaking.
- I am complying with water quality regulations.
- Protecting the environment is as important as economic viability.
- Most growers are implementing water quality practices.
- Government decisions should consider as many different interests as possible.

These results indicate that growers generally believe they are protecting water quality, that they have a duty to do so and that environmental goals are just as important as profitability. They corroborate the results of previous studies that demonstrated ecological and moral concerns mattered in growers' decision-making and motivations were not exclusively profit driven (Chouinard et al. 2008; Mzoughi 2011).

One issue that more growers disagreed with in 2015 was that "the management practices requirements of the Ag Waiver are fair to agricultural producers." As Drevno (2016) states in her paper on the Central Coast agricultural water quality regulatory process, fairness was a hotly contested issue in the 2012 Agricultural Waiver negotiations. The issue of equity arose in several areas of the negotiations, spanning the types of best management practices required to the cost and unequal burdens of tiered mandates.

Trust and communication

The final series of questions asked growers about their trust of and communication with other agricultural groups and water quality agencies and about the value of information they received from those organizations (fig. 4). In both years, environmental groups were the least trusted and least communicated with; other growers were the most communicated with but not necessarily the most trusted.

Survey data show a very close relationship between information value and trust. Results from a Pearson's correlation test found a strong positive relationship between the two variables; the coefficients (*r* score) were close to a perfect positive relationship ($r = 1$), varying only between 0.80 and 0.99.

There also appeared to be a close positive relationship between amount of communication, trust and information value (fig. 4). These results support the body of literature on the connection between trust and contact frequency, but they show a few exceptions. Despite more communication, growers reported a dip in trust of a few organizations, including CCRWQCB and Preservation, Inc. The regional board is located at a sufficient physical distance from growers in the northern part of the region: over 170 miles for growers in southern Santa Clara County and northern Santa Cruz County, which could hinder face-to-face communication. Another possible explanation might be that the values and interests of growers are different than those of regulatory agencies (Leach and Sabatier 2005; Lubell 2007).

Growers generally believe they are protecting water quality, that they have a duty to do so and that environmental goals are just as important as profitability.

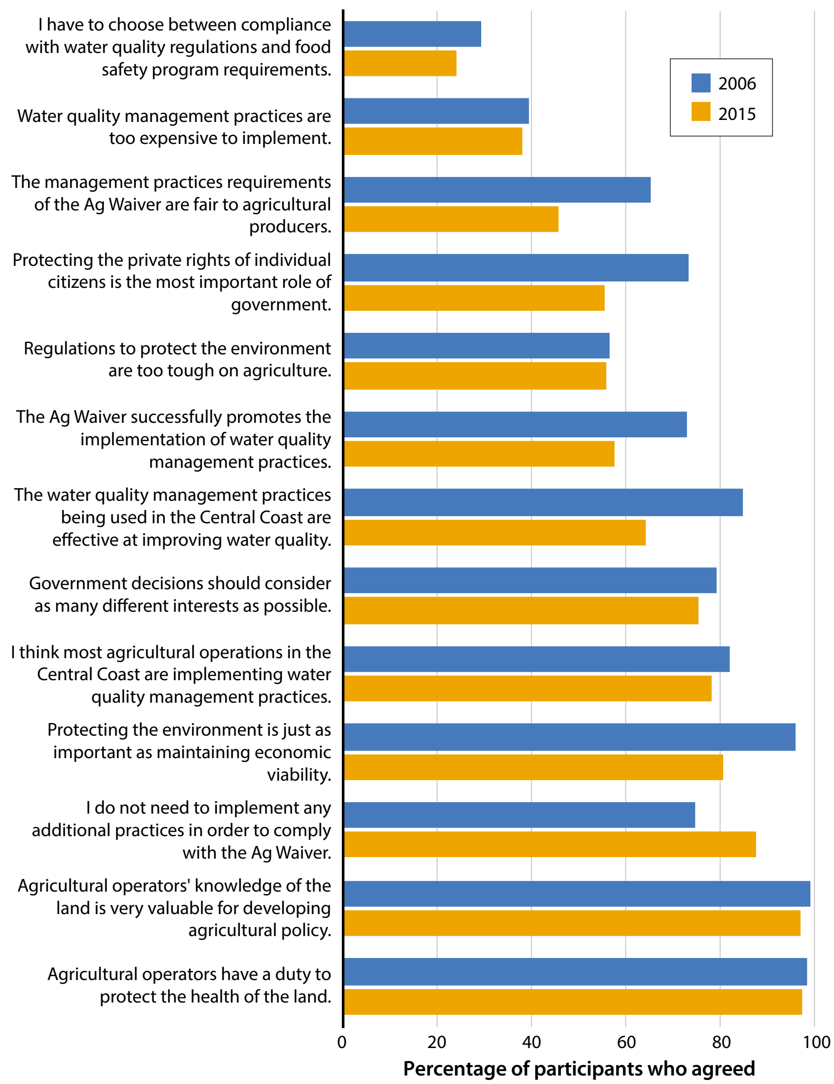


FIG. 3. Growers' opinions on land stewardship and water quality regulation issues.

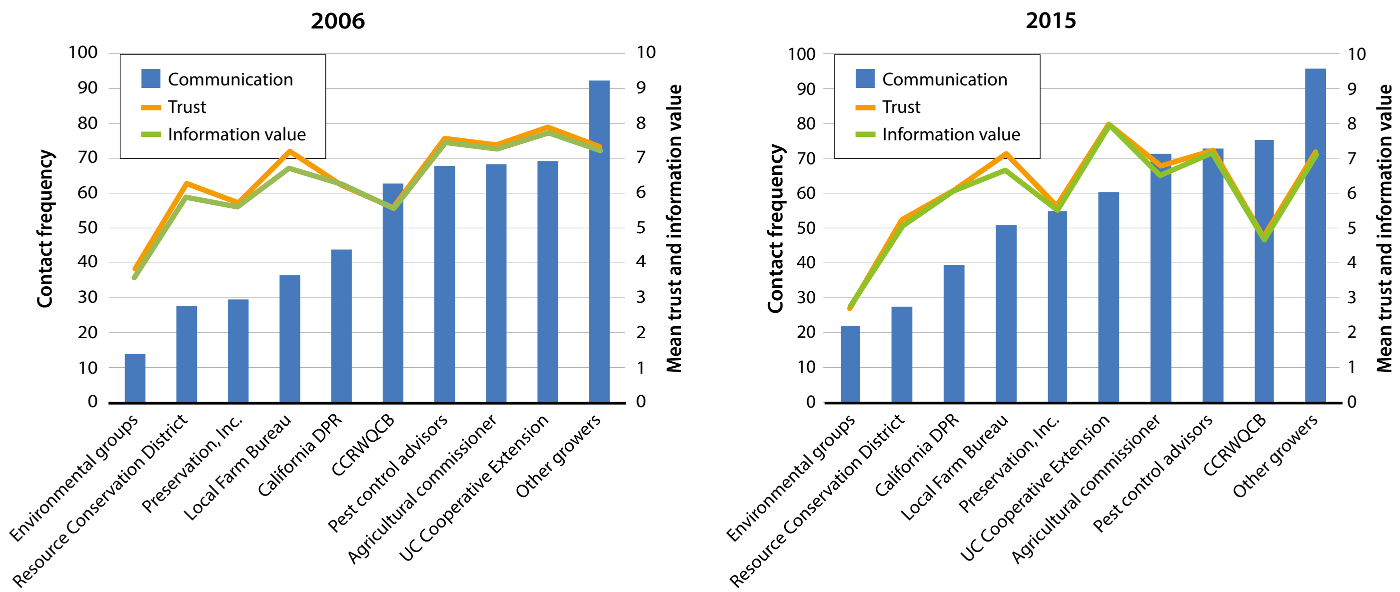


FIG. 4. Growers' trust of, contact frequency with, and perceived value of the information from water quality management organizations in the Central Coast Region, 2006 and 2015.

The biggest dip in trust despite more frequent communication was with CCRWQCB, the main regulatory agency in the region. Lubell (2007) explains the phenomenon of distrust that may occur between their perceived adversaries: "Farmers tend to categorize policy organizations according to their perceived policy interests: regulatory agencies are viewed as serving environmentalists, while local agricultural agencies and private agricultural organizations are seen as serving the farmer. Thus, growers view regulatory agencies as less trustworthy and local agricultural agencies as more trustworthy."

Different policy interests could also help explain the low scores on trust of environmental groups; growers scored their trust of those groups at 3.6 out of 10 in 2006, and 2.8 in 2015.

The survey results on trust of and contact with nonregulatory agencies confirm a strong relationship between the two variables. The 2015 results generally show that there was a significant improvement in the amount of trust when a grower had contact with an organization compared to when a grower had no contact (fig. 5). But with CCRWQCB, as described earlier, and with other growers, trust did not significantly improve with contact.

To test the observation of trust decreasing the study compared mean trust of the various organizations for the two surveyed years (fig. 6). The decrease in trust of CCRWQCB between 2006 and 2015 was significant (*t* score = 0.002); mean scores were 5.60 in 2006 and 4.75 in 2015.

Finally, the study assessed for correlation a subset of 2015 responses regarding opinions on required water quality management practices and a subset of 2015 responses related to trust of CCRWQCB. Findings suggest that growers' trust of CCRWQCB is associated with their opinions on required water quality practices (fig. 7). Trust of CCRWQCB was greater among growers who agreed or strongly agreed with statements related to the fairness, effectiveness and success of water management practices mandated in the agricultural waivers. Trust of CCRWQCB was lower among growers who disagreed with those statements.

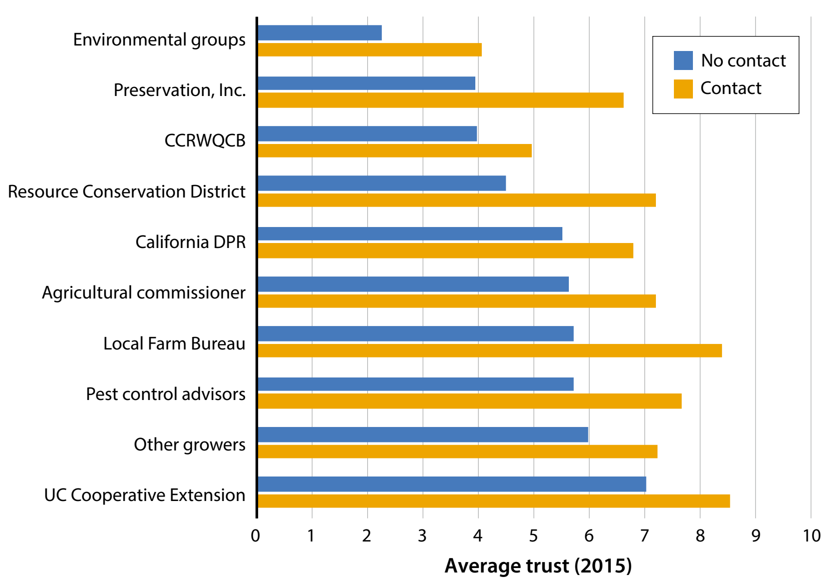


FIG. 5. Growers' trust of various water quality management organizations and contacts with those organizations, 2015.

Eroding trust, future fix

Although growers' frequency of contact with CCRWQCB did not increase their trust of it, it does not follow that growers' communication with or the information they receive from regulatory agencies is disadvantageous. Rather, more research is needed into the types of communication used by CCRWQCB, how their communication has changed over time and how the CCRWQCB's communication might influence relationships with the regulated group.

That there was a correlation between growers' trust of CCRWQCB in 2015 and their opinions on its water quality management decisons cannot confirm causation — that trust leads to a convergence of beliefs, or a convergence of beliefs leads to trust; however, prior studies suggest the latter (Leach and Sabatier 2005). To build trust between two rival political actors is complicated, especially because core beliefs can be culturally embedded or shaped by historical events. However, it is possible.

The trust process is best begun by achieving agreement on, at very least, empirical issues with sound evidence. Leach and Sabatier (2005) offer a few ways to undertake the process: (1) a "professional forum" exposing scientific evidence from competing coalitions mediated by a neutral facilitator (p. 464), (2) starting negotiations with a period of joint fact-finding and consensus building on the basic dimensions of the problems (p. 499) or (3) pursuing empathy-building exercises such as field trips (p. 499).

While encouraging accounts of a collaborative relationship between growers and CCRWQCB during the 2004 Agricultural Waiver negotiations are difficult to substantiate from the 2006 survey responses, results from the 2015 survey and agriculture testimonies confirm that what rapport remained after 2004 was markedly soured during subsequent negotiations. There was a significant drop in trust by 2015, and in the survey growers reported that they were increasingly frustrated by the policy process, the majority agreeing that regulations were "unfair" and "too tough."

"Trust ought to be correlated with the length, depth, and recency of past collaboration" (Leach and Sabatier 2005), and only 9 years prior, growers and CCRWQCB had joined efforts to pen the first ever regulatory program for agricultural water quality in the Central Coast. So why did trust degrade after 2004, and what lessons might be learned for future agricultural waiver negotiations?

A fatalistic explanation is that the decline in trust was inevitable. Comfortable with the 2004 provisions that they had collaboratively designed, growers became frustrated by increasing mandates. Unavoidably, the 2004 Agricultural Waiver was going to be made tougher — scientists, the state, and the public demanded that CCRWQCB act on the growing evidence that water quality was not improving.

A second explanation is that the approach CCRWQCB staff took during the drafting of the second agricultural waiver tainted relations. During the drafting of the 2004 Agricultural Waiver, staff took a collaborative and educational approach, slowly easing the agricultural industry into water quality regulations. Whereas for the second agricultural waiver, CCRWQCB negotiators took a more centralized approach and came out of the gates strong, proposing the very tough 2010 Draft Order that categorized farms into tiers with coupled mandates, brought individual monitoring into the fold for the first time and required certain blanket provisions for all farms. Several agricultural interests claimed the new regulatory program was "the most rigorous in the state" (CCRWQCB 2011b). Although the new waiver was significantly watered down by the time it was ratified, the process leading up to it had greatly strained rapport, and opened a rift between growers and CCRWQCB that would be difficult to restore.

Many growers and agricultural stakeholders highlighted above all else their disappointment in how the negotiations were handled, emphasizing the process itself more than particular mandates. The Santa Barbara Farm Bureau wrote that its members supported the 2004 Agricultural Waiver because it "focused on collaboration" and was "based on a good faith effort from both the agricultural community as well as [the Regional] Board"; however, they were "extremely disappointed" by the stakeholder participation process for the updated

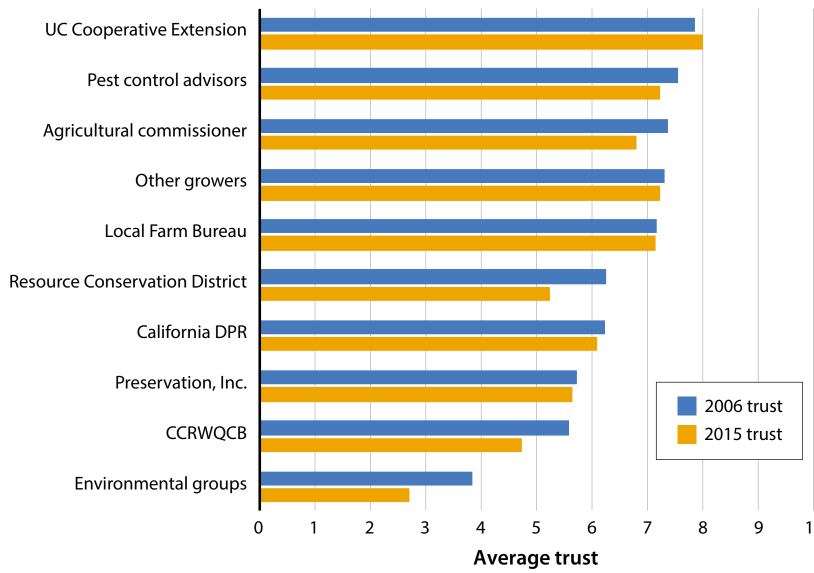


FIG. 6. Growers' trust of different water quality organizations in 2006 and 2015.

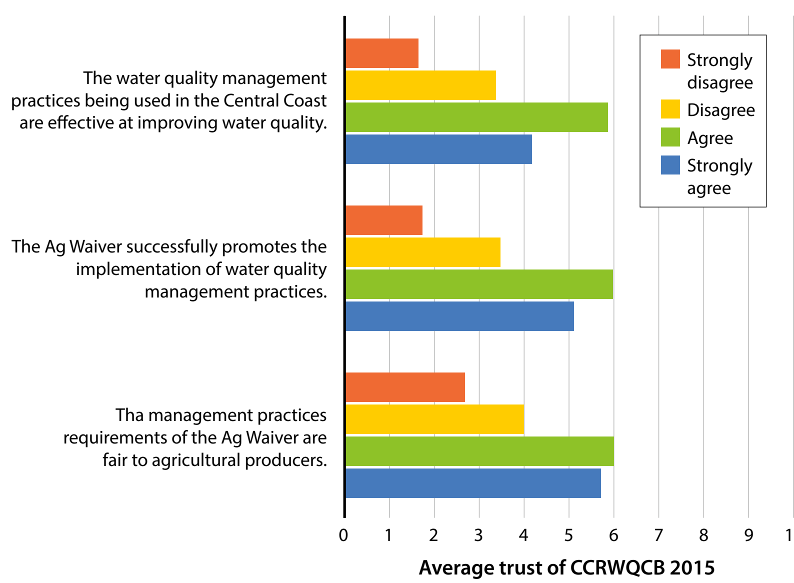


FIG. 7. Correlation of growers' 2015 responses regarding opinions on required water quality management practices and their trust of CCRWQCB.

waiver, calling it a "failed" attempt due to staff members' "reluctance to collaborate."

Another statement that more pointedly aimed at issues of declining trust and collaboration between growers and CCRWQCB came from the Santa Barbara County Flower and Nursery Growers Association: "It appears that [CCRWQCB] staff is proposing to squander the spirit of cooperation that has been so assiduously developed over the years, and to destroy the degree of trust between the private and public sector that has been diligently promoted over these same years. This arrogant, and heavy-handed, jack-boot approach will utterly destroy any hope of cooperation or trust from the private sector."

Sacramento County Superior Judge Frawley recently (Superior Court of California 2015) ruled that the 2012 Agricultural Waiver did little more than the 2004 Agricultural Waiver in improving water quality and needed to be greatly strengthened. If CCRWQCB did not improve water quality through its new structure and mandates and it soured relationships with growers along the way, what can be learned from that? Could the CCRWQCB have generated a more collaborative negotiation process while improving water quality?

These questions are beyond the scope of this article; however, what is clear is that water quality must improve. Consequently, CCRWQCB should invest in rebuilding its important relationships with growers as it proceeds through the stakeholder collaboration processes for the next agricultural waiver. To begin to rebuild trust, agricultural representatives and CCRWQCB members might sit down and review together existing empirical, scientific studies on Central Coast water pollution, and, at the very least, come to a consensus regarding the state of regional water quality and the sources of pollution.

CCRWQCB may find it useful to have a third-party agency review how it has previously communicated with growers and suggest strategies to restructure future negotiation techniques. The third-party agency should be respected by growers, scientists and regulators. Growers' perception of unfairness in the water quality regulations needs to be addressed, but that's the most difficult task of all — to weigh growers' perceived fairness with more effective pollution control measures. CA

A. Drevno is National Science Foundation Postdoctoral Fellow, Santa Clara University.

I would like to thank survey respondents and interviewees, and Dr. Mark Lubell and UCCE agent Mary Bianchi for their 2006 survey on which this research is based. The second round of surveys for this study received nonfinancial endorsements from four regional agricultural organizations — the Monterey County Farm Bureau, the Agriculture and Land Based Training Association (ALBA), University of California Cooperative Extension (UCCE), and Agricultural Water Quality Alliance — and many people from these organizations provided valuable feedback. I would like to thank my dissertation advisor, Daniel Press, whose insights and guidance greatly enhanced this research. My thanks to Executive Editor Jim Downing and Associate Editor Mark Lubell, and to the two anonymous reviewers for their comments and critiques on my manuscript. This project was supported by the National Science Foundation's Graduate Research Fellowship Program and Career-Life Balance Grant. Any opinions, findings and recommendations expressed in this material are those of the author and do not necessarily reflect the views of the National Science Foundation.

References

Anderson BS, Hunt JW, Phillips BM, et al. 2003. Integrated assessment of the impacts of agricultural drainwater in the Salinas River (California, USA). Environ Pollut 124(3):523–32.

Anderson BS, Phillips BM, Hunt JW, et al. 2006. Evidence of pesticide impacts in the Santa Maria River watershed, California, USA. Environ Toxicol Chem 25(4):1160–70.

Anderson BS, Phillips BM, Hunt JW, et al. 2010. Watershed-Scale Evaluation of Agricultural BMP Effectiveness in Protecting Critical Coastal Habitats: Final Report on the Status of Three Central California Estuaries. UC Davis, Granite Canyon and US Geological Survey. Grant Report for the Central Coast Water Board.

Anderson B, Phillips B, Hunt J, et al. 2011. Pesticide and toxicity reduction using an integrated vegetated treatment system. Environ Toxicol Chem 30(5):1036–43.

Beedell JDC, Rehman T. 2000. Explaining farmers' conservation behaviour: Why do farmers behave the way they do? J Environ Manage 57(3):165–76.

Brodt S, Klonsky K, Tourte L, et al. 2004. Influence of farm management style on adoption of biologically integrated farming practices in California. Renew Agr Food Syst 19(04):237–47.

Campbell K. 2012. Central Coast: State Water Board issues partial stay of new regulation. AgAlert, Sept 5.

CCRWQCB. 2011a. Water Quality Conditions in the Central Coast Region Related to Agricultural Discharges.

CCRWQCB. 2011b. March 17 Meeting Minutes. www.waterboards.ca.gov/centralcoast//board_info/agendas/2011/march/Item_14/march_17_transcript_condensed.pdf

Chouinard HH, Paterson T, Wandschneider PR, Ohler AM. 2008. Will farmers trade profits for stewardship? Heterogeneous motivations for farm practice selection. Land Econ 84(1):66–82.

Cox JC, Ostrom E, Walker JM, et al. 2009. Trust in private and common property experiments. Southern Econ J 75(4):957–75.

Dillman DA. 2000. *Mail and Internet Surveys: The Tailored Design Method* (vol 2). New York: Wiley.

Drevno A. 2016. Governing water quality in California's Central Coast: The case of the conditional agricultural waiver. J Sci Policy Governance 8(1).

Greiner R, Gregg D. 2011. Farmers' intrinsic motivations, barriers to the adoption of conservation practices and effectiveness of policy instruments: Empirical evidence from northern Australia. Land Use Policy 28(1):257–65.

Harter T, Lund J, Darber J, et al. 2012. Addressing Nitrate in California's Drinking Water. Center for Watershed Sciences, UC Davis.

Hunt JW, Anderson BS, Phillips BM, et al. 1999. Patterns of aquatic toxicity in an agriculturally dominated coastal watershed in California. Agr Ecosyst Environ 75(1):75–91.

Knowler D, Bradshaw B. 2007. Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32(1):25–48.

Kranz D. 2004. Environmental recommendations gain FB support. AgAlert, Sept 22.

Leach WD, Sabatier PA. 2005. To trust an adversary: Integrating rational and psychological models of collaborative policymaking. Am Polit Sci Rev 99(04):491–503.

Lubell M. 2007. Familiarity breeds trust: Collective action in a policy domain. J Polit 69(1):237–50.

Lubell M, Fulton A. 2008. Local policy networks and agricultural watershed management. J Publ Adm Res Theor 18(4):673–96.

Mzoughi N. 2011. Farmers' adoption of integrated crop protection and organic farming: Do moral and social concerns matter? Ecol Econ 70(8):1536–45.

Ostrom E, Burger J, Field CB, et al. 1999. Revisiting the commons: Local lessons, global challenges. Science 284(5412):278–82.

Ostrom E, Gardner R, Walker J. 1994. *Rules, Games, and Common-Pool Resources*. Ann Arbor: University of Michigan Press.

Ostrom E, Walker J (eds.). 2003. *Trust and Reciprocity: Interdisciplinary Lessons for Experimental Research*. New York: Russell Sage Foundation.

Phillips BM, Anderson BS, Hunt JW, et al. 2006. Solid-phase sediment toxicity identification evaluation in an agricultural stream. Environ Toxicol Chem 25(6):1671–6.

Phillips BM, Anderson BS, Hunt JW, et al. 2012. Pyrethroid and organophosphate pesticide-associated toxicity in two coastal watersheds (California, USA). Environ Toxicol Chem 31(7):1595–603.

Prokopy LS, Floress K, Klotthor-Weinkauf D, Baumgart-Getz A. 2008. Determinants of agricultural best management practice adoption: Evidence from the literature. J Soil Water Conserv 63(5):300–11.

Rudeen AK, Fernandez-Gimenez ME, Thompson JL, Meiman P. 2012. Perceptions of success and the question of consensus in natural resource collaboration: Lessons from an inactive collaborative group. Soc Natur Resour 25(10):1012–27.

Ryan RL, Erickson DL, De Young R. 2003. Farmers' motivations for adopting conservation practices along riparian zones in a Midwestern agricultural watershed. J Environ Plann Man 46(1):19–37.

Superior Court of California, County of Sacramento. 2015. Monterey Coastkeeper, The Otter Project, PCFFA, Environmental Justice Coalition for Water, Santa Barbara Channelkeeper, Sportfishing Protection Alliance v. California State Water Resources Control Board (SWRCB). Case Number: 34-2012-80001324.

Willock J, Deary IJ, Edwards-Jones G, et al. 1999. The role of attitudes and objectives in farmer decision-making: Business and environmentally oriented behavior in Scotland. J Agr Econ 50(2):286–303.

RESEARCH ARTICLE

Teens-as-teachers nutrition program increases interest in science among schoolchildren and fosters self-efficacy in teens

An after-school nutrition program increased children's preferences for gardening, cooking and science, and teen teachers reported an increase in health self-efficacy.

by Virginia L.J. Bolshakova, John Gieng and C. Sheena Sidhu

Abstract

The Healthy Living Ambassador Program brings health, teen leadership, and teamwork to California's elementary school gardens through interdisciplinary UC Cooperative Extension collaboration, community-based partnerships and teen teaching. During spring 2015, teen ambassadors trained by Extension educators and volunteers at UC Elkus Ranch in San Mateo County taught nutrition science, food cultivation and healthy living skills in an 8-week, garden-based, after-school nutrition and physical education program for elementary school children in an urban setting. We conducted a pilot study using a mixed-methods approach to measure and explore the program's impact on children's vegetable selection and consumption preferences, as well as perceived self-efficacy in teen healthy living behavior. The children trended toward an increased preference for gardening, cooking and science, and teens displayed an increase in perceived health self-efficacy.

Urban food deserts, built environments and technology advancements (e.g., smart phones and computers) contribute to poorer diets and less physical activity, which tend to increase risks for childhood obesity (Brody 2002). Poor diet quality disproportionately affects our poorest children and ethnic minorities (Hiza et al. 2013; Kirkpatrick et al. 2012). Further, students' academic achievement is directly linked to their nutrition status and health (Glewwe et al. 2001), which includes a healthy mind and a belief in the capability to organize and execute a successful course of healthful action, known as self-efficacy (Bandura 1997). Self-efficacy instigates the adoption, initiation and maintenance of health-promoting behaviors

Online: https://doi.org/10.3733/ca.2018a0016

A pilot study conducted by UC Cooperative Extension showed that the Healthy Living Ambassador Program increased children's interest in science and gardening and that teen teachers developed self-efficacy in healthy behaviors.

Jessica Guild

(Schwarzer and Luszczynska 2006) that ultimately contribute to the overall quality of life. Therefore, healthy living skills woven into educational programs that include healthy eating, physical activity and development of youth self-efficacy in healthy behaviors may improve the health of all youth (both teens and children) regardless of race or income.

A major challenge for nutrition education is how to develop and implement interventions that support vegetable intake while also engaging youth. A garden-enhanced nutrition education program can improve fruit and vegetable intake and promote healthful eating behaviors if educational programs connect children through fun activities (Heim et al. 2009). School and community gardens present considerable potential and have been proposed as a practical and effective tool for connecting youth to nature, food sources and each other, possibly yielding healthier lifestyles and higher academic achievement (Robinson-O'Brien et al. 2009). Additionally, gardening experience may encourage families to grow food in gardens, which can lead to an increase in vegetable consumption as well as greater food security in low-income households (Algert et al. 2016).

Despite these benefits, school garden spaces often lack adequate support for growing food and hosting educational activities. While thousands of school garden beds have been built across California (Eastin 2013), shifts in school administration, local values and educational priorities often determine the support for garden programming (Boyle 2013). Many teachers do not feel they have the experience, interest, time, or appropriate curricula to use the garden as part of their academic instruction (Graham et al. 2005; Graham and Zidenberg-Cherr 2005). Moreover, most schools have no paid staff specifically to manage or teach in the garden. Because teachers are primarily evaluated on classroom instruction, outside garden education remains a low priority and is often unsustainable.

Many schools lack the resources needed to host educational activities in their gardens. The HLA Program aimed to fill that need by training teens to teach the children in their communities about gardening, nutrition, science and fitness. During the program, teens will adopt healthier behaviors themselves.

An HLA teen talks with an elementary school student about growing vegetables. Teens as peer educators can be as effective as adult teachers in prompting healthy behaviors in children.

Teens may be able to help fill this resource gap. In some contexts, teens as peer educators can be as effective (Karcher et al. 2002) as adult teachers in eliciting healthy behavioral changes in children, or even more effective (Smith and Holloman 2013). Furthermore, they can be enthusiastic, nonparent volunteers who contribute to a successful after-school gardening program (Scherr et al. 2013). This positive effect is not surprising because it has been shown that near-peer-assisted learning can improve academic performance in young adults (Williams and Reddy 2016) and in low-income and minority elementary school students who live in urban areas (metropolitan areas with populations > 1 million and cities > 100,000; Rohrbeck et al. 2003).

Teens taking leadership roles in supportive environments may develop self-efficacy in healthy behaviors for themselves, an added benefit of peer-assisted teaching. Efficacy beliefs have been identified as correlates of self-reported healthy behaviors in adolescent populations (Motl et al. 2007; Schwarzer and Luszczynska 2006). It is expected that teens with the opportunity to teach in school gardens will adopt healthier living behaviors by practicing food cultivation, serving as ambassadors for health, and teaching children about nutrition. A further benefit of this near-peer teaching is that it provides teens experiences to develop their own self-efficacy in healthy living that may affect their long-term behavior and, additionally, influence their peers and their community.

The Healthy Living Ambassador (HLA) Program is a collaboration by UC CalFresh, 4-H Youth Development and UC Elkus Ranch in partnership with local schools to organize, connect and grow capacity in resources (e.g., teachers, curriculum, materials) to bring about healthful impacts in local communities.

The UC CalFresh program's goal is to implement policy, system and environmental changes in underserved schools in which more than 50% of students qualify for free and reduced-price meals, and the 4-H program (across the country) seeks to identify urban program models and delivery methods that reach broader audiences, including youth from low-income and ethnic minority backgrounds. The primary purpose of the HLA after-school program is to inform, develop and empower teens by providing a vehicle to positively impact personal, community and planetary health. Using a garden-based curriculum and hands-on activities, teens teach younger children about nutrition, fitness and gardening while presenting a comprehensive and ecological approach to healthy living, agriculture and the environment.

To evaluate the HLA Program's effect on youth (children ages 7 to 8 and adolescents ages 12 to 19), we launched a pilot study during the spring 2015 season and assessed the effectiveness of the HLA Program intervention on children at a subset of San Mateo County school garden sites with (n = 1) and without (n = 1) the HLA Program, and on teen HLA teachers at five sites. We wanted to (1) determine the effects of a garden-based nutrition and physical activity program on youth vegetable selection and consumption preferences, (2) determine the effectiveness and needs of teen teams as teachers and (3) identify any potential benefits of creating an integrated community and Extension partnership, focusing on teen health self-efficacy and teen empowerment.

The HLA Program in San Mateo County

In 2014, the HLA Program was launched in San Mateo County through initial seed funding focused on healthy living from the National 4-H Foundation. Currently, the program is supported locally through San Mateo County's partnership with UC Cooperative Extension and UC CalFresh (2015–18), and it has a blended, coordinated staff support model that includes UC Cooperative Extension, local elementary schools, after-school programs, and teens. The HLA Program completed its fourth season in San Mateo and San Francisco counties in spring 2017 and has a fifth season planned for spring 2018, and there is interest in the program being scaled up to other counties.

From late 2014 into early 2015, UC CalFresh and 4-H Youth Development Program staff recruited 12- to 19-year-old youth from local middle schools, high schools, community colleges and other youth organizations within proximity of elementary school gardens in need (those that were not being used as an education resource and that were fallow or overgrown). For the spring 2015 season, the HLA Program was implemented in five selected elementary schools in Daly City and Redwood City that had existing after-school programs and embraced offering an enrichment activity once per week for 60 to 75 minutes over an 8-week period. At least 50% of the elementary students at these sites qualified for free or reduced-price meals (Ed-Data 2015). The UC Davis Office of Research Institutional Review Board Administration reviewed and approved of the Healthy Living Ambassador Garden Study (IRB #7187551).

School administrators, with support from existing after-school programs, agreed to back implementation of an HLA Program curriculum, as an enrichment activity, delivered by teen teachers (HLAs). The HLA Program curriculum was adapted from the *Health and Nutrition from the Garden* (HNG) curriculum (JMG 2002) and infused with *CATCH* (*Coordinated Approach to Childhood Health for K-5*; catchinfo.org) activities to ensure physical fitness (table 1); the curriculum and activities were approved by the UC CalFresh statewide network.

Before the program commenced, teen HLAs participated in an intensive two-day, overnight training at UC Elkus Ranch in Half Moon Bay to develop their knowledge of and skills and practice in the basics of food cultivation, nutrition, fitness, community leadership, early childhood development and instructional practices for teaching elementary students healthy living skills and how to grow vegetables. Training was provided by UC CalFresh, 4-H, UC Elkus Ranch staff, and UC Master Gardener volunteers.

Upon completion of the training, teen HLAs returned to their communities in San Mateo County, where they taught and mentored young students during after-school hours in a school garden. In addition to planting and nurturing eight to 10 different cultivars

TABLE 1. Curriculum outline for the HLA Program

Activity	Objective
UC Elkus Ranch orientation	Introduce teen HLAs to gardening principles and curriculum.
Site evaluation and introduction	Familiarize teen HLAs with their garden site and site administrators.
Lesson 1: Storytelling of *To Hold a Seed*, the plant life cycle	Understand plant cycle. Plant a seed that students will track over the course of its life cycle.
Lesson 2: Plant spacing in the garden	Create optimal conditions for growth for the garden. Design garden layout based on plant space requirements.
Lesson 3: Garden tasks, journaling and compost	Understand concepts of decomposition and soil creation. Practice mindful-eating exercise. Leaf pressing.
Lesson 4: Edible plant parts, introduction to MyPlate concept	Understand what part of garden plants we will eat. Introduce MyPlate template.
Lesson 5: Insects in the garden	Students log and describe insects.
Lesson 6: Creating habitat for beneficial beasts	Students look for evidence of birds and other vertebrates in the garden.
Lesson 7: Snack day	Students review sanitation and food safety. Students prepare a simple snack from the garden harvest.
Lesson 8: Garden harvest and Lettuce Wrap-Up	Introduce family and faculty to the garden space. Learn how to glean produce from garden and create a healthy snack.
Wrap-up and reflection and training evaluation	Discuss successes and challenges from the HLA perspective. Students take short survey to evaluate training experience.

(e.g., lettuce, radishes, tomatoes, carrots, beets, parsley, edible flowers, etc.) with the children, teen HLAs built their leadership skills with adult mentors (after-school program partners, UC CalFresh staff, and 4-H staff and volunteers) who provided background support. The 8-week program culminated with Lettuce Wrap-Up, a harvest celebration and feast from the garden that welcomed family and faculty members.

Whenever it was feasible, teams of teen HLAs (three or four youths) served elementary schools within walking distance of their own schools (and, when possible, served elementary schools they had attended as children). The out-of-school (after-school and informal garden space for the HLA Program) setting is conducive to developing personal relationships, as well as nurturing experimentation and relaxation of teens, components that are often lost during the transition from elementary school to middle school (Akos 2002).

Preferences rise for gardening, cooking and science

Two populations of mixed second- and third-grade elementary school children, either participating in the HLA Program (intervention, $n = 71$) or not participating (control, $n = 22$), were evaluated preprogram and postprogram using a paper survey that we adapted from three California 4-H surveys: the Children, Youth, and Families At Risk (CYFAR) Youth Survey, the Self-Efficacy Survey (Baranowski et al. 2000) and the Food Preference Survey (Cullen et al. 2003). Both the intervention site and control site were measured at two time points (approximately 10 weeks apart).

To evaluate changes in preprogram versus postprogram preference for vegetables, gardening, cooking, exercise and science in children, we compared intervention versus control site changes of these parameters using the Mann-Whitney test on the children's preferences (as indicated by the faces they circled — sad, happy or neutral — on the paper survey). The Likert scale we used was based on sad face = 0 and happy face = 5. Comparisons between changes in scores were considered statistically significant when $p \leq 0.05$ (two-tailed).

Compared to the control group, children in the intervention group reported larger increases in their preference for gardening ($p = 0.002$), cooking ($p = 0.044$), and science ($p = 0.002$) after participation in the HLA Program (fig. 1). Reported changes in preferences for vegetables ($p = 0.083$) and exercise ($p = 0.569$) did not significantly differ between the intervention and control sites, though preferences for vegetables leaned in a positive direction. Preference for exercise did not follow this trend, but preference toward cooking increased despite not being included in the program. This could be because neither exercise nor cooking were major components of the teaching of the HNG curriculum, or because "exercise" and "cooking" may have different meanings to a 7- or 8-year-old (which is a limitation of the survey). Additionally, children taking the survey often did not credit physical activity in the garden as exercise, even though it is considered a physical activity by UC CalFresh (V. Bolshakova, personal observation). Further, while the students prepared a lettuce wrap by combining mixed vegetables, the act of cooking (i.e., heating and mixing) was never part of the HNG curriculum or the children's HLA Program experience.

Carrot is the preferred vegetable

Before the HLA Program began, we measured vegetable choice and consumption preferences in the same population of children at the intervention site in the after-school setting ($n = 71$) and, separately, in the group of teen HLAs during their initial day of training before lunchtime ($n = 40$). The intake assay, adapted from the Teacher Taste Testing Process Guide (Kaiser et al. 2012), consisted of approximately 1 ounce (28 grams) each of raw beets, carrots, daikon radish, grape tomato and snap peas — vegetables the youth grew in the garden during the program (fig. 2A). The vegetables were prepared by the research team within 1 day of the assay and the quantity consumed was measured by weighing

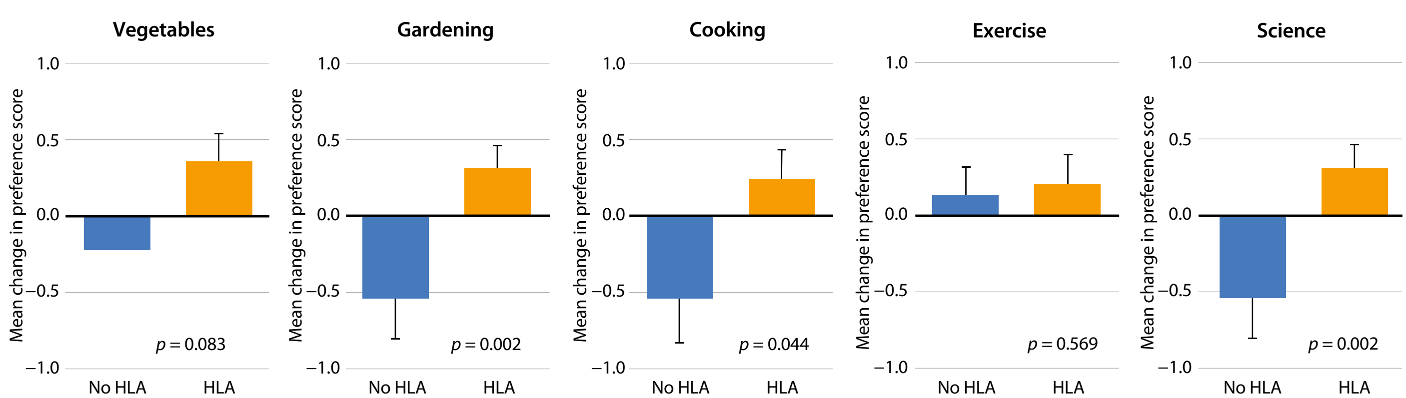


FIG. 1. Increases in elementary school children's preferences toward gardening ($p = 0.002$), cooking ($p = 0.044$), and science ($p = 0.002$) were significantly higher after the HLA program ($n = 71$) compared to controls ($n = 22$). The scale used was based on 0 = sad face and 5 = happy face. A Mann-Whitney test (two-tailed) was performed for these comparisons. Data represents mean and SEM.

the vegetable containers for each child and teen before and after the tastings. Children were encouraged to taste each vegetable and then to eat as much or as little as they wanted.

Of the five vegetables evaluated, carrot was the preferred vegetable consumed by elementary school children (37% of total vegetable consumption) and teens (32%) before the program (fig. 2B). This is not surprising, because carrots are common and accessible; nearly all HLA Program partner schools offered carrots or apples for the supplemental afternoon snack program, and carrot is among the most common vegetables consumed in the United States (USDA ERS 2014).

After the HLA program (10 weeks after the initial vegetable preference measurement), we repeated the assay with the same children. We were not able to collect an adequate number of postprogram vegetable assays from teens to conduct statistical analysis; therefore, post results for teens are not included. To determine the effects that the HLA Program had on preprogram versus postprogram selection and consumption of the five vegetables (beet, carrot, radish, grape tomato and snap pea) or their combined total, we used the Kruskal-Wallis H test to compare these changes to those at the control site. The consumptions were considered statistically significant when $p \leq 0.05$ (two-tailed). Compared to the control, children at the intervention site had a smaller increase in consumption of grape tomato ($p = 0.002$) after participating in the program (fig. 2C). Changes in consumption of beets ($p = 0.890$), carrots ($p = 0.324$), radishes ($p = 0.150$), peas ($p = 0.702$) or total combined ($p = 0.058$) did not differ.

Teen self-efficacy

To understand the potential impact of the HLA Program on developing youth self-efficacy, we looked to our teen stakeholders as "sophisticated observers of their own life" (Corbett and Wilson 2001). Developing successful health interventions requires identification of variables that correlate to healthy behavioral changes (Baranowski et al. 1998). Quantitative studies have found mastery experiences to significantly predict self-efficacy (Britner and Pajares 2006; Usher and Pajares 2008) across behavioral domains, including health-related behaviors. In the HLA Program model, where teens are empowered to become teachers and models of healthy living in their communities, the teen viewpoint is arguably the most critical viewpoint (versus the children receiving instruction and/or adult mentors supporting the teen teachers) in developing and implementing an effective teen-driven health intervention program. Perspectives of teen's perceived self-efficacy in healthy behaviors provide useful insight into their world, where healthy practices may or may not be found. This qualitative investigative approach may provide additional insight into the current research base on health interventions in general. By focusing on teen voices, we hoped to gain perspective about their health efficacy and how that may translate into further developing individual and community health.

We conducted preprogram ($n = 20$) and postprogram ($n = 8$) semi-structured interviews with teen HLAs (demographics, table 2) regarding their views

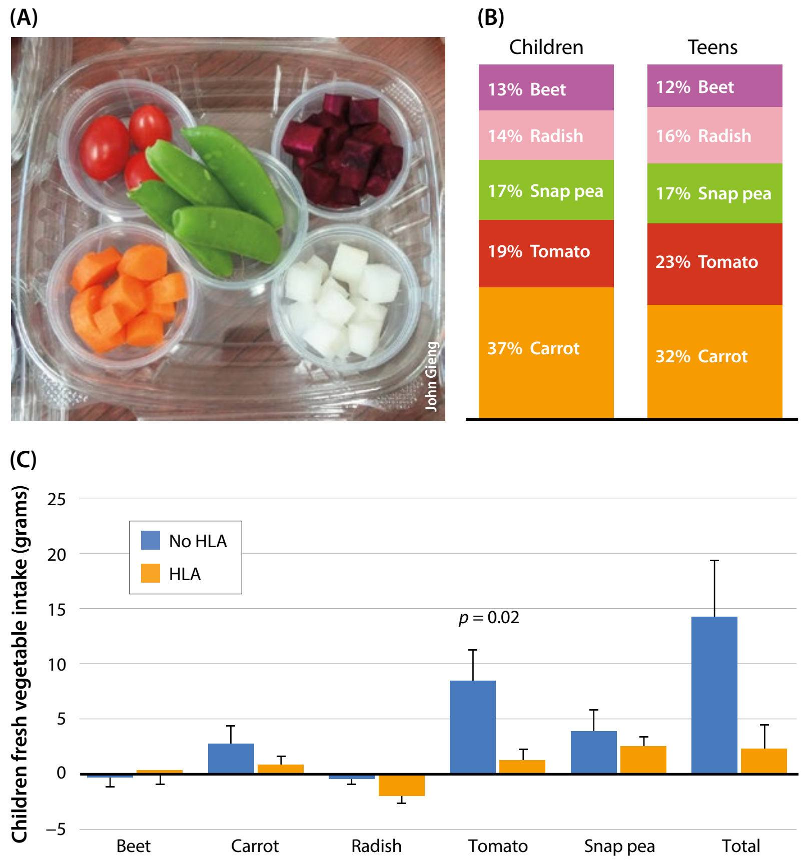
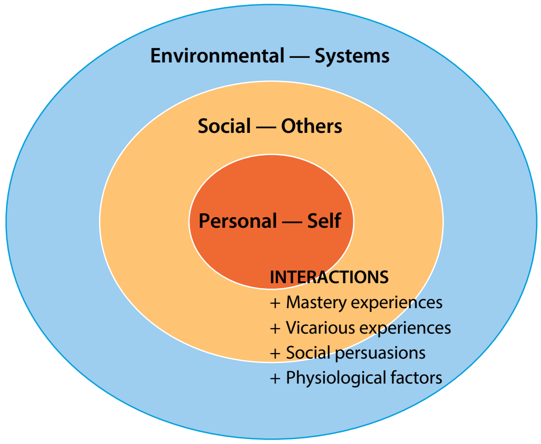


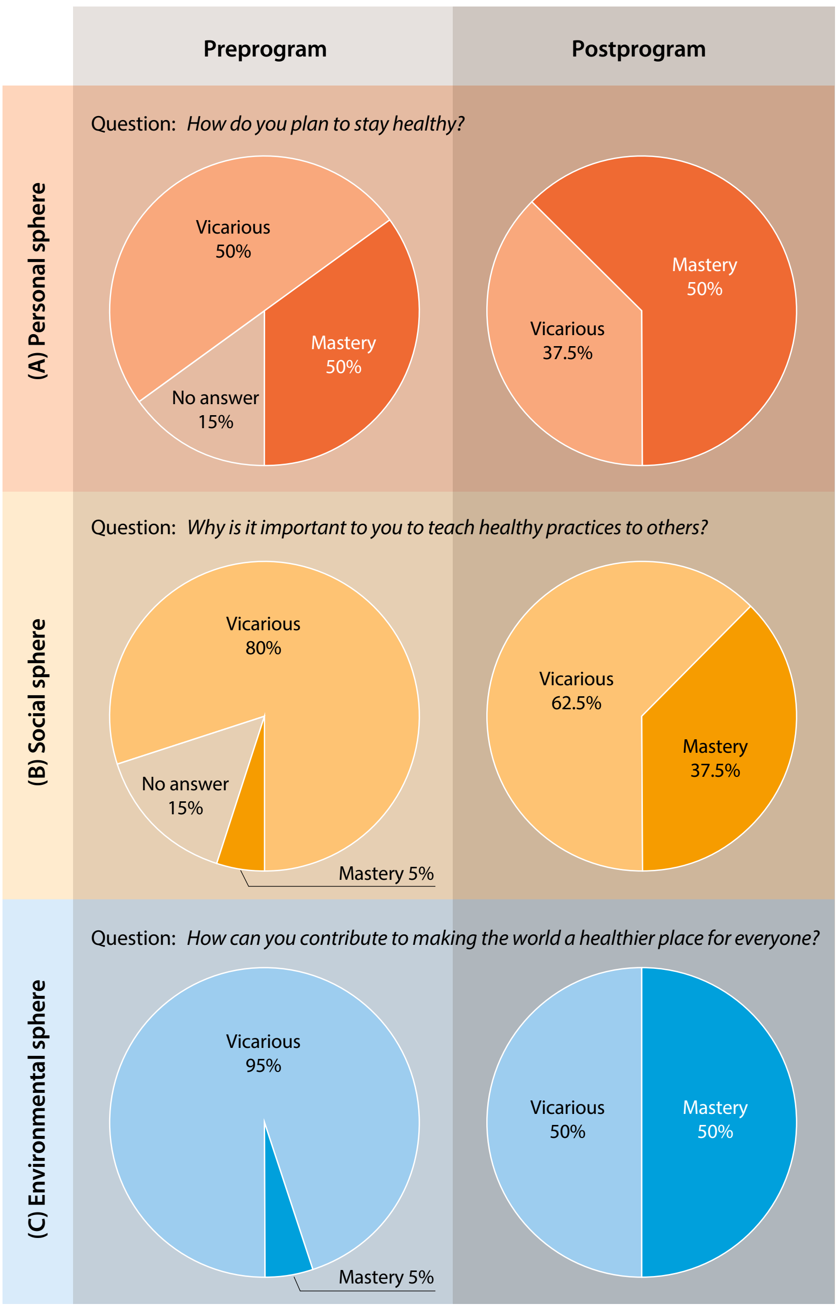
FIG. 2. (A) Example of a vegetable sampling box (beets, carrots, daikon radish, grape tomato and snap peas). (B) Carrot was the preferred vegetable selected and consumed by children ($n = 71$) and teens ($n = 40$) before participating in the HLA Program. (C) Children selected and preferred less grape tomato ($p = 0.02$) after participation in the HLA Program ($n = 71$) compared to controls ($n = 18$). A Kruskal-Wallis H test (two-tailed) was performed with a Dunn's multiple comparison test to compare groups. Data represents mean and SEM.

TABLE 2. Characteristics of HLA teens interviewed preprogram ($n = 20$) and postprogram ($n = 8$)

Characteristics	Pre HLA program ($n = 20$)	Post HLA program ($n = 8$)
Median age	16	14.5
(Range), year	(13–19)	(12–16)
Median grade	11	8
(Range), grade	(8–13)	(7–12)
Participants, *n*		
Female	14	6
Male	6	2
Ethnicity, *n*		
Asian	5	2
Hispanic/Latino	8	1
White	6	5
Two or more	1	0

FIG. 3. Self-efficacy factors and the interactions that construct self-efficacy.





and experiences of, beliefs, and motivations around their own healthy behaviors and their HLA program participation. Preprogram and postprogram populations were selected based on convenience (or availability) to participate in the interviews, and findings do not represent comparisons of distinct individuals. Despite all reasonable efforts to regroup the teen HLAs for postprogram interviews and vegetable assays, coordinating a common time and place to meet proved challenging, despite the fact students were out of school for the summer.

Given the exploratory nature of this study, the convenience sampling technique was effective in helping identify and address shortcomings associated with our questionnaire design. Interviews were conducted in person with individuals or small groups (two or three teens) before the initial training (pre) and after the last garden lesson (post) and were transcribed and independently coded by all three authors. We then regrouped to discuss coding and combined themes into broad categories in Excel (2016).

We interpreted self-efficacy themes through the lens of social cognitive theory (Bandura 1977). Social cognitive theory explains how people learn and develop certain behavioral patterns that are built upon the interplay of personal, social and environmental spheres through interactions of mastery experiences (proficient or insufficient competency or sense of accomplishment), vicarious experiences (modeling or recognizing one's potential or lack thereof by comparison with another person), social persuasions (encouragements or discouragements that may alter one's confidence), and physiological factors (positive or negative interpretation of physiological states often accompanying stressful situations such as nausea or anxiety) (fig. 3). We evaluated teen health self-efficacy by scoring responses to three interview questions relating separately to personal, social and environmental spheres, particularly looking at vicarious and mastery experiences as sources affecting efficacy. Scores were given to answers that represented no answer (score = 0), vicarious experiences (score = 1) and mastery experiences (score = 2).

Baseline self-efficacy

Before the program began, many teens noted their involvement in sports as a part of their healthy living and wanted to learn more about health and gardening. Others realized that it was a personal challenge to be healthy. When asked "How do you plan to stay healthy?", only about one-third of teens responded with a mastery experience in the personal sphere of the

FIG. 4. Self-efficacy assessments. Teens were interviewed before ($n = 20$) and after ($n = 8$) the implementation of the Healthy Living Ambassador Program. They were asked one question relating to each social cognitive theory sphere: (A) personal, (B) social and (C) environmental, and their responses were categorized according to indications of vicarious, mastery or no related experiences.

social cognitive theory model (fig. 4A). Many of their responses were brief and general vicarious answers (fig. 5A) that identified a process or model that might lead to a healthy outcome, but the youth felt they had not accomplished or mastered it. Several of the students highlighted that they wanted to develop leadership and teamwork skills working with children and fellow teens. Some realized the challenges of understanding the perspectives of other youth and being a positive influence on them.

When asked the questions relating to the social sphere ("Why it is important to you to teach healthy practices to others?") and environmental sphere ("How can you contribute to making the world a healthier place for everyone?"), only 5% of teens answered with mastery experiences, with the remaining teens providing vicarious responses or no response (figs. 4B and 4C). Most teens were not able to provide concrete examples of how they were models of healthy living to others or how they were actively participating in making their communities healthy. Moreover, teens were not sure how they could help others live healthier lives, although some mentioned they could talk to family and friends about healthy eating and be a role model for younger siblings.

Self-efficacy after the HLA Program

From our preprogram and postprogram interviews, we observed shifts in teen responses; broadly, teens focused more on vicarious examples during preprogram interviews and related more mastery experiences after participation in the program (fig. 4). After participating in the program, many teens expressed how much they had learned about and practiced healthy living behaviors as well as how they plan to stay healthy (62.5% mastery responses, fig. 4A). They had not only adopted healthier eating habits, reflected by their evolving diets and food choices, but also had an overall healthier lifestyle, which included sufficient sleep and exercise. Others showed a greater appreciation for the various parts of the food system (fig. 5A). In response to a related question ("How have you changed through participating in this program?"), one youth shared: "[I have] a new perspective on food. I'd have never grown food at a garden before; never really seen it grow. I just went to the market and bought food, plants and everything, but never really [grown and] harvest[ed] food, so that's changed me in a way."

Most teens felt that they became better role models and had some innate ability to teach others, and some learned a lot about their current capabilities for working individually and with others (37.5% mastery responses, fig. 4B). Almost all the teens highlighted the leadership roles they took on in the HLA Program; they felt they had ownership and could modify and work with the curriculum. Most had positive things to say about working with teens as teammates. Some were surprised about how they could positively influence others and be effective teachers of healthy living skills

	Preprogram	Postprogram
(A) Personal sphere — Question: *How do you plan to stay healthy?*	"I try to eat healthily and I try to get exercise, I guess." "Eating the right foods." "I think I needed like more exercise."	". . . before, I wasn't that much of . . . a green person . . . but I actually have changed my diet. I rarely eat . . . bad food now, and I'm always having salads for lunch . . ." ". . . my diet has changed, and also I have a newfound respect for what the adults do when have to lead the younger kids around because sometimes, it's not easy, so I really appreciate that now."
(B) Social sphere — Question: *Why is it important to you to teach healthy practices to others?*	". . . I think everyone deserves to be healthy, like we didn't do anything bad to not be healthy, so you might as well try and help other people stay healthy if they're needing help." ". . . so that other people can feel that way, too." "I feel like staying fit is important."	"I feel like I'm making a difference in my community and others that I meet . . . and it makes me feel proud that I can help change that person's life even if they don't realize it yet." "Eating healthier is really gonna help you in the long run 'cause eating junk food is just so bad for you . . . and I like helping other people out, it makes me feel special."
(C) Environmental sphere — Question: *How can you contribute to making the world a healthier place for everyone?*	"I feel like, to make the world a healthier place, obviously I think you should start with yourself and then start encouraging others to do it too around you and then it's like a domino effect probably." "Help the younger children." "Volunteer work."	". . . planting more gardens because there are so much vegetables and healthy foods . . . at any school or community center, you can just have kids or even adults pick them. They can make salads or they can just eat them whole. Our school has a garden and we do things like that . . . we had a salad bar every Friday."

FIG. 5. Self-efficacy representative quotes. Teens were interviewed before ($n = 20$) and after ($n = 8$) the Healthy Living Ambassador Program. They were asked one question relating to each social cognitive theory sphere — (A) personal, (B) social and (C) environmental — and their responses were categorized according to indications of vicarious, mastery or no related experiences.

(fig. 5B). Others had a different experience — many mentioned the challenge of working with very active children or children not interested in the after-school program.

Almost all of the teens we interviewed mentioned sharing specific information about healthy eating and healthy lifestyles with family and friends. They emphasized being role models for younger siblings and youth, and most provided detailed experiences of encouraging the children they taught to try different foods. Still others saw the bigger picture, of an interconnected system that brought youth, healthy living and community together: "Because it's a chain reaction. If you teach it to a small amount of kids, the small amount of kids will attract other kids and then it will keep on going and going and going. And then the next thing you know, a lot

Children tasted new flavors and developed skills as they prepared fresh treats in the garden. Compared to the control group, children who participated in the HLA program reported larger increases in their preferences for gardening, cooking and science.

of people know about healthy living, and know about what's right and what's wrong, and it will be all good."

When the teens were asked how they might help others live healthier lives, many had ideas or had already initiated community-level changes, such as talking to their teachers or schools about adopting healthy practices at the classroom or school level (figs. 4C and 5C). This engagement as ambassadors at the community level suggests that the training and program promoted teens' self-efficacy in healthy living.

Overall, while youth identified more mastery experiences relating to the personal sphere than the social or environmental spheres during the preprogram interviews (35%), teen mastery experiences grew across all domains over the course of the HLA Program, especially in the environmental sphere, where a 45% gain was observed (preprogram versus postprogram; fig. 4). These results are consistent with the goals of the HLA Program, that in providing mastery opportunities for youth, the program increases self-efficacy and can result in youth creating more complex (even community-level) objectives for themselves.

Study limitations

One limitation of our study is that our non-HLA Program comparison population (control) was from a different school site than the intervention group; however, the school was in the same district and had similar demographics. For the interviews and paper survey, there may have been differences in interpretation of questions and terms as students spoke multiple languages and English fluency varied; we tried to minimize this bias in the paper surveys by reading aloud the questions with text and offering visual interpretations as much as possible (e.g., pictures of vegetables, subject area, etc.).

In evaluating changes in parameters of science, vegetables, gardening, cooking, exercise or physical activity, we only saw a strong statistical increase in gardening, and a slight increase in cooking. While the strong increase in gardening may be attributable directly to gardening activities in the garden program, the other parameters may have been less directly connected to the program from the perspective of the children. Although we did not find strong statistical differences in the other parameters, we did find trends that suggest this program initiates these changes in children, and this should be explored further in a larger study.

We expected the program to increase vegetable consumption among elementary children relative to controls, but found the opposite to be true for grape tomato consumption, where the change was greater in the control group. The program may not be as effective as expected in this area, but may have positive effects in other areas of healthy living as demonstrated by the results of the surveys and interviews. We suggest that future studies focus on examining the program's positive impacts on self-efficacy and behavioral changes.

An additional limitation is the small number of teens we were able to interview and conduct the vegetable intake assay with after the program was completed. Further, these findings are vulnerable to selection bias, and represent only a starting point for hypothesis generation. A more extensive study would require random comparisons of preprogram and postprogram participant interviews from distinct individuals that we were not able to provide in this study. Given that this was a pilot study, the results may be further explored in future studies.

The HLA Program model and beyond

We show with the HLA Program that youth of all ages who cultivate their own vegetables can positively grow healthy behaviors. Teens-as-teachers in the garden can promote interest and preference toward science, gardening and nutrition in elementary children, as well as influence near-peer (elementary children) preference and consumption of vegetables. Providing opportunities for teens to practice, teach and master healthy living habits over an extensive period with the positive support of peers, adult mentors and other near-peer social networks (elementary children) may increase teen self-efficacy. Instead of the traditional model of adults "talking at youth," teen HLAs cultivate youth solutions by taking the lead as catalysts for their own health as well as local action efforts that focus on developing healthier communities starting at the elementary school garden.

Having health knowledge is one thing, but the more that knowledge is put into practice through mastery experiences in a supportive learning environment, the greater the beneficial effect (Murray et al. 1989). Teen HLAs augmented their self-efficacy through knowledge acquisition, skill building, leadership development and applied training. After the HLA spring season experience, empowered HLA teens were compelled to speak and present about their health perspectives to the local and larger community at public agency events and meetings. One team of HLA teens created a YouTube video highlighting the HLA Program for future teen HLA recruitment, and for one senior HLA, a scholarship application (youtu.be/olMWHTXdxmo), because they wanted to ensure that the program continued after they were gone.

Moving forward, teen HLAs may take on the lead of promoting healthy policy, system and environmental changes in their local communities. Such actions may be especially valuable in urban and suburban communities that are becoming more distant from their food sources. CA

For more information about the Healthy Living Ambassador Program, visit http://ucanr.edu/sites/smsf4h/About/HLA/.

V.L.J. Bolshakova is Research Assistant Professor, Purdue University, and Director of Out-of-School Programs for Indiana GEAR UP, and was previously Director of UC Elkus Ranch and Associate Natural Resources and Youth Development Advisor, UC Cooperative Extension San Mateo and San Francisco counties; J. Gieng is Assistant Professor, San Jose State University, and was previously Assistant III, UC Cooperative Extension San Mateo and San Francisco Counties; and C.S. Sidhu is Staff Research Associate, UC Cooperative Extension San Mateo and San Francisco counties.

Special thanks to UC Cooperative Extension staff Mary Vollinger, Mary Carp, Lorena Gimeno, Tammy Arellano, Jessica Guild, Leslie Jensen, Kathleen Stewart and David Ginsburg; many San Mateo community partners including both in-school and out-of-school staff, and Healthy Living Ambassador teens who inspired and encouraged this work daily. The research reported in this manuscript was supported by San Mateo County Measure A Funds to the University of California. The opinions expressed are those of the authors and do not represent the views of the County of San Mateo.

References

Akos P. 2002. Student perceptions of the transition from elementary to middle school. Prof School Couns 5:339–45.

Algert S, Diekmann L, Renvall M, et al. 2016. Community and home gardens increase vegetable intake and food security of residents in San Jose, California. Calif Agr 70(2):77–82. https://doi.org/10.3733/ca.v070n02p77

Bandura A. 1977. Self-efficacy: Toward a unifying theory of behavior change. Psychol Rev 84:191–215.

Bandura A. 1995. Self-Efficacy in Changing Societies. New York, NY: Cambridge University Press.

Bandura A. 1997. Self-Efficacy: The Exercise of Control. New York, NY: WH Freeman.

Baranowski T, Anderson C, Carmack C. 1998. Mediating variable framework in physical activity interventions. How are we doing? How might we do better? Am J Prev Med 15:266–97.

Baranowski T, Davis M, Resnicow K, et al. 2000. Gimme 5 fruit, juice, and vegetables for fun and health: Outcome evaluation. Health Educ Behav 27(1):96–111.

Boyle AM. 2013. School Gardens: Reconnecting Children with Nature and Food. Senior thesis, paper 142, Scripps College. http://scholarship.claremont.edu/scripps_theses/142/ (accessed Oct. 11, 2013).

Britner SL, Pajares F. 2006. Sources of science self-efficacy beliefs of middle school students. J Res Sci Teach 43(5):485–99.

Brody J. 2002. The global epidemic of childhood obesity: Poverty, urbanization, and the nutrition transition. Nutr Bytes 8(2). https://escholarship.org/uc/item/1xb9x54z

Corbett HD, Wilson BL. 2001. Listening to Urban Kids: School Reform and the Teachers They Want. Albany, NY: State University of New York Press.

Cullen KW, Baranowski T, Owens E, et al. 2003. Availability, accessibility, and preferences for fruit, 100% fruit juice, and vegetables influence children's dietary behavior. Health Educ Behav 30(5):615–26.

Eastin D. 2013. UC addresses needs of California youth. Calif Agr 67(1):3–4. https://doi.org/10.3733/ca.v067n01p3

[Ed-Data] Education Data Partnership. 2015. San Mateo County Demographic Data. www.ed-data.org (accessed Nov. 17, 2016).

Glewwe P, Jacoby HG, King EM. 2001. Early childhood nutrition and academic achievement: A longitudinal analysis. J Public Econ 81(3):345–68.

Graham H, Beall DL, Lussier M, et al. 2005. Use of school gardens in academic instruction. J Nutr Educ Behav 37(3):147–51.

Graham H, Zidenberg-Cherr S. 2005. California teachers perceive school gardens as an effective nutritional tool to promote healthful eating habits. J Am Diet Assoc 105(11):1797–1800.

Heim S, Stang J, Ireland M. 2009. A garden pilot project enhances fruit and vegetable consumption among children. J Am Diet Assoc 109(7):1220–6.

Hiza HAB, Casavale KO, Guenther PM, et al. 2013. Diet quality of Americans differs by age, sex, race/ethnicity, income and education level. J Acad Nutr Diet 113:297–306.

Jacobs, GM. 2001. Providing the scaffold: A model for early childhood/primary teacher preparation. E Child Ed J 29(2):125–30.

[JMG] Junior Master Gardener. 2002. Health and Nutrition from the Garden. College Station, TX: Texas Agriculture Extension.

Kaiser L, Schneider C, Mendoza C, et al. 2012. Development and use of an evaluation tool for taste-testing activities by school-aged children. J Acad Nutr Diet 112(12):2028–34.

Karcher M, Davis C, Powell B. 2002. Developmental mentoring in schools: Testing connectedness as a mediating variable in the promotion of academic achievement. School Community J 12:36–52.

Kirkpatrick SI, Dodd KW, Reedy J, et al. 2012. Income and race/ethnicity are associated with adherence to food-based dietary guidance among US adults and children. J Acad Nutr Diet 112:624–35.

Motl RW, Dishman RK, Saunders RP, et al. 2007. Perceptions of physical and social environment variables and self-efficacy as correlates of self-reported physical activity among adolescent girls. J Pediatr Psychol 32(1):6–12.

Murray DM, Pirie P, Luepker RV, et al. 1989. Five- and six-year follow-up results from four seventh-grade smoking prevention strategies. J Behav Med 12:207–18.

Robinson-O'Brien R, Story M, Heim S. 2009. Impact of garden-based youth nutrition intervention programs: A review. J Am Diet Assoc 109(2):273–80.

Rohrbeck CA, Ginsburg-Block MD, Fantuzzo JW, et al. 2003. Peer-assisted learning interventions with elementary school students: A meta-analytic review. J Educ Psychol 95(2):240–57.

Scherr R, Cox R, Feenstra G, et al. 2013. Integrating local agriculture into nutrition programs can benefit children's health. Calif Agr 67(1):30–7. https://doi.org/10.3733/ca.v067n01p30

Schwarzer R, Luszczynska A. 2006. Self-efficacy, adolescents' risk-taking behaviors, and health. In: Pajares F, Urdan T (eds.). Self-Efficacy Beliefs of Adolescents. Scottsdale, AZ: IAP-Information Age Publishing, Inc. p 139–59.

Smith LH, Holloman C. 2013. Comparing the effects of teen mentors to adult teachers on child lifestyle behaviors and health outcomes in Appalachia. J Sch Nurs 29(5):386–96.

[USDA ERS] US Department of Agriculture Economic Research Service. 2014. Potatoes and Tomatoes Are the Most Commonly Consumed Vegetables. www.ers.usda.gov/data-products/chart-gallery/gallery/chart-detail/?chartId=58340 (accessed Nov. 14, 2016).

Usher EL, Pajares F. 2008. Sources of self-efficacy in school: Critical review of the literature and future directions. Rev Educ Res 78(4):751–96.

Williams B, Reddy P. 2016. Does peer-assisted learning improve academic performance? A scoping review. Nurs Educ Today 42:23–9.

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

Visit us online:

calag.ucanr.edu
twitter @Cal_Ag
www.facebook.com/CaliforniaAgriculture

Upcoming UC and UC ANR events

Diagnosing Herbicide Symptoms short course

http://wric.ucdavis.edu/events/diagnosing_herbicide_symptoms_2018.htm

Date: July 10-11, 2018
Time: 8:00 a.m. to 5:00 p.m.
Location: Bowley Plant Science Teaching Facility, UC Davis
Contact: UC Weed Research and Information Center wric@ucdavis.edu or (530) 752-1748

2018 California 4-H State Leadership Conference

http://4h.ucanr.edu/4-H_Events/SLC/

Date: July 26–29, 2018
Time: 9:00 a.m. to 10:00 p.m.
Location: UC Davis
Contact: 4hslc@ucanr.edu or (530) 750-1336

Intermountain Research and Extension Center Field Day

http://ucanr.edu/?calitem=407465

Date: July 26, 2018
Time: 8:00 a.m. to 1:00 p.m.
Location: Intermountain Research and Extension Center, Tulelake
Contact: Rob Wilson (530) 667-5117