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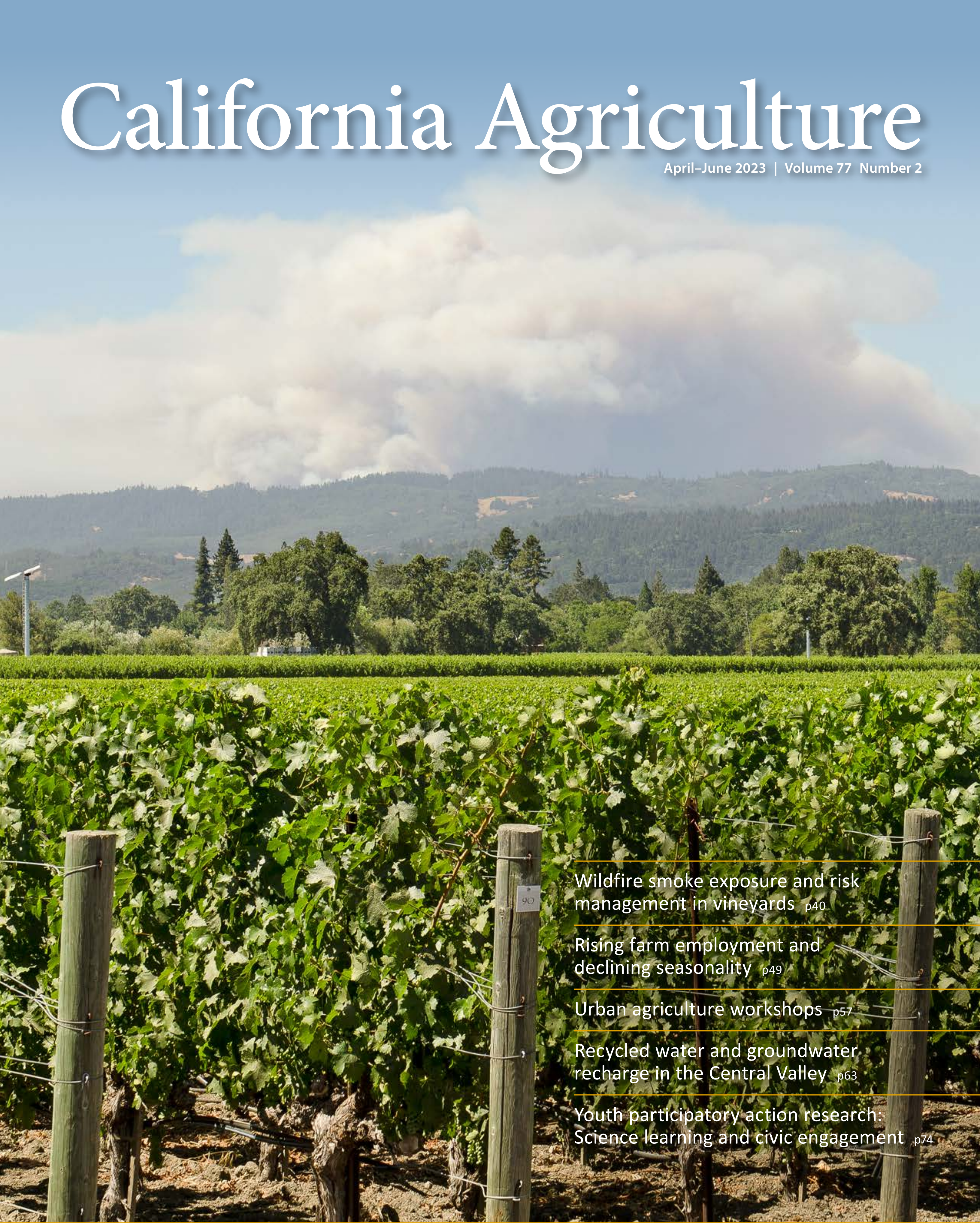

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EDITORIAL

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Research and review articles

COVER: Smoke from the 2014 Butts Fire hovers over vineyards in Napa Valley. In recent years, wildfires in California have had far-reaching impacts on viticulture and the wine industry at large. Researchers surveyed wine grape growers and producers across the state to better understand how wildfires have affected viticulture and operational management decisions (see Zakowski et al., page 40). Photo: tfoxfoto, iStock.com.

RESEARCH ARTICLE

California wine grape growers need support to manage risks from wildfire and smoke

Wildfire smoke exposure presents a unique challenge for viticulture as it can result in mild to severe degradation in wine grapes.

by Emily Zakowski, Lauren E. Parker, Devon Johnson, John Aguirre and Steven M. Ostoja

Online: https://doi.org/10.3733/ca.2023a0006

Abstract

California has experienced an increase in the size and severity of wildfires in recent years, with wide-ranging impacts to agriculture. The 2020 wildfire season was particularly catastrophic, causing billions of dollars in damage to the state's world-renowned wine industry. Wine grape growers and wine producers statewide were recently surveyed to better understand the wildfire informational resources available to producers, as well as the role wildfire risk plays in operational management decisions. The survey results show that the negative impacts of wildfires on wine production may be the result of wildfire smoke more than of the actual wildfires. We also show that managers do not always make operational changes, even when they perceive increased wildfire risk. Despite diverse sources of wildfire-related information and operational guidance, there is not enough information to effectively manage fire risk.

Like other California specialty crops, wine grape production has faced challenges, including market shifts, regulatory pressure, and climate change. The effects of climate change, such as drought, extreme heat, and frost/freeze, have resulted in millions of dollars of crop losses (Reyes and Elias 2019), with additional impacts from changed conditions, including worsened pest and disease pressure (Pathak et al. 2018). However, the most notable climate-related disturbance has been wildfires, which has had far-reaching impacts on viticulture and the wine industry at large. The 2020 wildfire season burned more than 4 million acres and produced extensive smoke that harmed California agriculture. Some of these wildfires were particularly harmful to the wine industry, as many fires were within or near important wine grape growing areas, and vineyards across the state were affected by smoke (fig. 1).

A wildfire burns near a Northern California vineyard. The majority of respondents to the authors' survey believe wildfire risk to wine grape growing or wine-making operations is greater today than 5 years ago. *Photo*: Ordinary Mario, iStock.com.

While a small number of vineyards and wineries actually burned, widespread smoke affected vineyards statewide. Wildfire smoke exposure presents a unique challenge for viticulture because it can result in mild to severe degradation in wine grapes. Quality loss is a widely recognized risk of wildfire smoke exposure in wine grapes. When wildfire smoke is present in vineyards, wine grapes may absorb a variety of chemicals such as volatile phenols, which are aromatic compounds that can give wine an unpleasant smoky taste or other objectionable aromas (Fryer et al. 2021; Osborne and Tomasino 2019). Some of these harmful phenols can bind to the sugars in the grapes and release during fermentation, creating an ashy taste in the wine (Fryer et al. 2021). But, because the severity of smoke taint depends on multiple physiological and chemical processes (Fryer et al. 2021; Kennison et al. 2011; Osborne and Tomasino 2019), it can be difficult to determine in advance whether smoke-exposed grapes will produce smoke taint in wine. This means that smoke exposure can undercut the salability of grapes to the cautious buyer and can leave winemakers who do purchase smoke-exposed grapes with unsalable products (Madhusoodanan 2021).

Additional costs to California's wine industry resulting from the 2020 wildfire season alone included equipment and structure loss, insurance costs (e.g., loss of coverage, increased premiums), loss of tourism revenue, labor challenges (e.g., health/safety, lost wages), and impacts from resultant power shutoffs (e.g., inability to operate water pumps, irrigation equipment, and cold storage). In all, these impacts contributed to damage estimates topping $3 billion, including tens of millions in lost structures and equipment, $576 million in lost grape tonnage following vineyard destruction, and more than $600 million in lost tonnage resulting from smoke exposure (J. Moramarco, bw166, personal communication).

Where fire presents a direct threat, viticulturalists and wineries are limited in their ability to actively manage the threat in real time, because they are often required to evacuate. Efforts to reduce the potential for damage as part of a regular maintenance schedule may include clearing brush and creating defensible space within and around vineyards and structures, developing fire preparedness and response plans, or installing remote-controlled sprinkler systems (Vyenielo 2021). When trying to reduce the potential damages from smoke taint, viticulturalists may monitor online resources such as in-depth weather and smoke reports (Parsons 2021) and respond to the threat by preemptively harvesting grapes. However, there is no way to accurately measure or predict whether grapes will produce tainted wine, meaning that winemakers must analyze grape and wine samples after the fact in order to determine the presence of taint (Madhusoodanan 2021). To our knowledge, no prior work has explored and quantified the degree to which these management actions are employed or their potential efficacy.

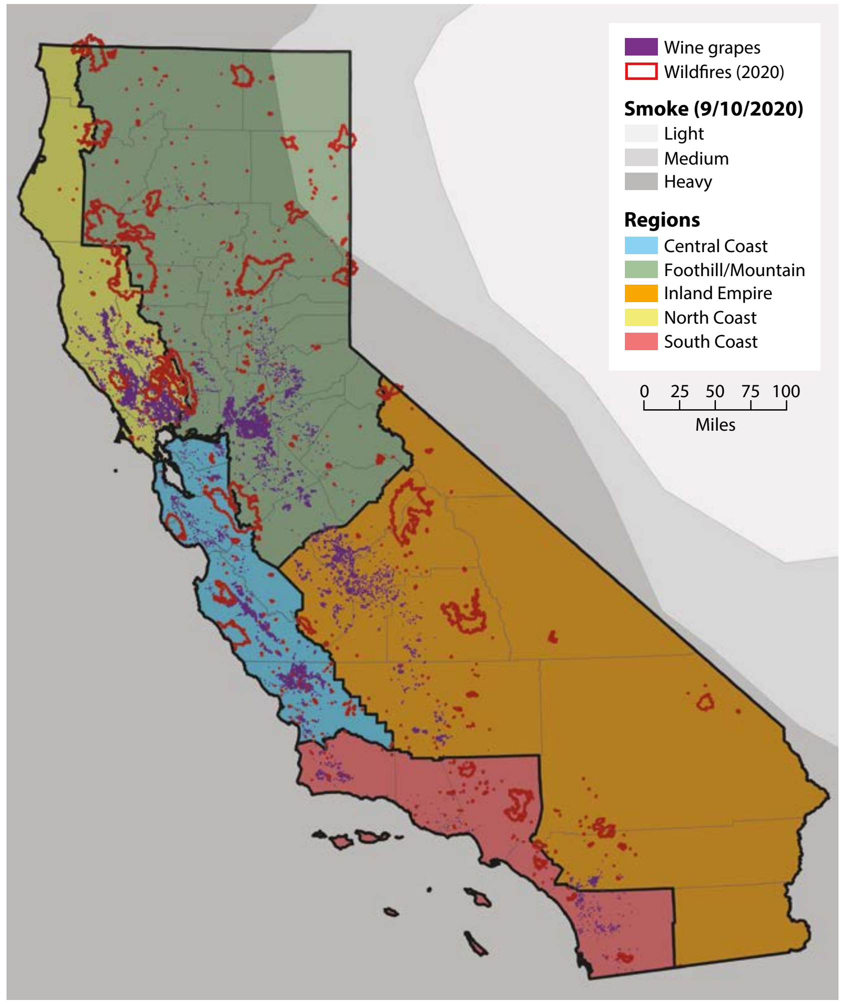

FIG. 1. The spatial distribution of 2020 wildfires (red polygons; Cal Fire 2021) relative to wine grape vineyards (purple points; CACASA 2019) across five geographic regions in California. Smoke density data (gray shading; NOAA 2021) illustrates the extent of fire-mediated risks beyond fire boundaries. Smoke data are daily; here we display smoke extent from September 10, 2020, which falls during a period when many wine grape varieties are particularly vulnerable to smoke effects (Kennison et al. 2011; Summerson et al. 2021).

While California's wine industry, and the state's agriculture sector more broadly, may be resilient to a single challenging year, multiple difficult years over a short time frame could prove detrimental to individual operations (Cooley et al. 2015). Research suggests that California can expect increasingly frequent and severe climatic stressors to agricultural production in the coming decades (Pathak et al. 2018), including an increase in wildfire activity (Goss et al. 2020; Westerling 2018). Given the marked increase in wildfire activity in recent years (Goss et al. 2020; Williams et al. 2019) and the additional wildfires expected under climate change, it is important to understand the full set of effects of wildfire on wine grape production and growers.

In this light, we surveyed viticulturists and wine producers to assess how wildfires have impacted the industry in recent years, with a focus on the 2020 wildfire season. This work reports on survey responses to characterize the varied nature of wildfire impacts

Smoke from the 2020 Walbridge Fire near a vineyard in Sonoma County. Wildfire smoke exposure was a key impact reported by most (82%) survey respondents. Smoke exposure can result in quality and financial loss. *Photo*: s_gibson, iStock.com.

on wine grape and wine producers. Additionally, we report on survey responses that provide insight into the various management decisions made in light of fire impacts in recent years, and highlight the information sources being used by producers to respond to wildfire risk and impacts. The objectives of this research are to improve the understanding of the effects of wildfire on viticulture and address the knowledge gaps around management responses and resources used by producers to mitigate losses. More broadly, we wanted to help identify the informational needs of technical assistance providers (e.g., Cooperative Extension, agriculture commissions, industry groups, etc.) in wine grape–growing regions, to support them as they aid producers in preparing for and recovering from today's fires and adapting to and improving resilience for the fires of the future (Johnson et al. 2023).

Growers and producers surveyed

To address these objectives, we distributed a 22-question survey comprised of multiple choice, "select all that apply," and short-answer prompts (online technical appendix). These were sent electronically via newsletters and emails to 14 regional and statewide agricultural association listservs (e.g., California Department of Food and Agriculture Pierce's Disease Control Program, Sonoma County Winegrape Commission, Lodi Winegrape Commission, California Association of Winegrape Growers), with organizations selected for e-distribution based on audience relevance, broad geographic representation, and the potential for wide reach. In order to extend our outreach, we also distributed 93 postcards with a QR code for the online survey and an additional 93 print surveys by U.S. Mail to estate wineries across the state. These 182 vineyards and wineries were identified through the California Wine Institute online database (California Wine Institute 2022) and were assigned to receive a QR postcard or print survey at random, with a post-hoc review to ensure that the randomized assignments did not result in a heavy regional bias in one outreach method or the other.

Electronic survey responses were automatically collected by and housed in the online Qualtrics survey system, and U.S. Mail responses were manually recorded and entered into the survey system. A total of 202 responses were received and recorded for analysis. The response rate for mailed surveys was 37%; however, we were not able to track the number of individuals who received survey solicitation via our electronic outreach and cannot differentiate those who received solicitation via email versus QR postcard. Therefore, a complete response rate is not knowable.

In order to understand survey responses within the context of respondent demographics, the survey asked three questions to ascertain respondents' professional role within the wine industry (i.e., grower, vineyard manager, wine producer with a winegrower license), level of experience, and geographic location by county (technical appendix, Questions 1–3). Respondents could select more than one professional role but could only select one experience level and county location. For those who operate across multiple counties, survey wording requested that they select the production county for which they are most concerned about wildfire risk. County locations were spatially aggregated to five geographic regions modified from Rilla et al. (2011) (fig. 1).

Non-demographic survey questions pertained to fire impacts (direct and indirect), management responses related to the impacts realized, and information or resources accessed by the respondent. Though our survey focused on the 2020 wildfire season, questions about impact and response for years prior to 2020 were also included, allowing us to explore perceived changes in risk and resulting effects on management decisions. Survey questions were crafted to identify resources used by producers to manage for or respond to wildfires but were not specific as to time period (i.e., 2020 or years prior). Using the geographic regions defined above, we took a regionally focused approach to assess survey responses. Given that technical service providers (TSPs) typically serve at the county or regional level, we present our results through a regional lens, which provides locationally relevant results for the TSP community.

Grapes damaged by smoke

Of the 202 survey responses, 149 identified as growers (59%), 117 identified as commercial wine producers

(32%), 24 identified as vineyard managers (9%), and two gave no response to professional identity. In terms of the regional distribution of respondents, 141 (70%) were from North Coast counties, while 31 (15%) were from Central Coast counties, 18 (9%) were from the Foothill/Mountain counties, 7 (4%) were from South Coast counties, and 5 (3%) were from Inland Empire counties. Of the 196 survey respondents who provided their experience level, 87% had more than 10 years of experience, with 46% having 11–30 years and 41% having more than 30 years of experience, respectively (table 1).

Survey respondents were asked about the severity of impact of the 2020 wildfire season on their operations (technical appendix, Q 15), with 199 of 202 respondents answering this question. Of these 199, 13 (six Central Coast, two Inland Empire, two North Coast, two South Coast, and one Foothill/Mountain) indicated no impact. In our assessments of survey responses regarding the 2020 wildfire season, we only considered responses from the 186 individuals who indicated some degree of impact. Of these, 20% reported a slight impact, 35% a great impact, 37% a severe impact, and 7% irreversible damage. Some of the largest acreage fires during the 2020 season occurred in the North Coast region in Napa and Sonoma counties, which typically receive the highest county-average prices paid for wine grapes (CDFA 2022a). Vineyards burned in these two counties in 2020 (fig. 1). This is reflected in the responses to the survey question on the severity of 2020 wildfire impacts, in which only North Coast respondents reported irreversible damage (fig. 2A), with 77% of those reporting irreversible damage coming from Napa County.

We next considered the nature of impacts in conjunction with the severity of the impact for the 13 individuals who reported irreversible damage (technical appendix, Q 12). While all types of impacts were incurred, the inability to access vineyards (60%) and the inability of the winery buyer to receive and process grapes for non-smoke-related reasons (100%) were more frequently associated with irreversible damage than with lower levels of severity (fig. 2B). Moreover, those experiencing irreversible damage were the only ones who selected all potential options in response to the survey question about the nature of wildfire impacts; these responses indicate that the "irreversible" nature of damage may not only be related to the proximity to wildfire, but also to the compounding challenges of experiencing numerous impacts.

Most respondents (82%), regardless of their severity response, indicated that wildfire smoke was a key impact. For the 37 respondents who selected only slight impact, smoke exposure was the most prevalent (63%). In comparison, for the 70 individuals who indicated severe impact, 71% identified a disruption of harvest activities due to smoke-related human health concerns as one of the specific types of impacts suffered (fig. 2B). This highlights that wildfire smoke can have differing degrees of severity of perceived and actual impact, depending on how the smoke specifically affects an operation.

To better understand the nature of wine grapes' exposure to smoke, respondents who incurred the impact "grapes exposed to wildfire smoke" were asked to characterize the outcomes of that impact (technical appendix, Q 14). The percentage of respondents who noted "grapes exposed to wildfire smoke" varied

TABLE 1. Survey respondent demographics showing the number of regional respondents, the number of respondents identifying with each professional role, and years of experience

Region	Number of respondents	Professional role		Years of experience	
Central Coast	31	Grower	18 (40%)	0–10	4 (14%)
		Vineyard manager	3 (7%)	11–30	17 (59%)
		Comm. winegrower	24 (53%)	>30	8 (28%)
Foothill/ Mountain	18	Grower	14 (42%)	0–10	2 (11%)
		Vineyard manager	5 (15%)	11–30	8 (44%)
		Comm. winegrower	14 (42%)	>30	8 (44%)
Inland Empire	5	Grower	5 (63%)	0–10	0
		Vineyard manager	1 (13%)	11–30	4 (80%)
		Comm. winegrower	2 (25%)	>30	1 (20%)
North Coast	141	Grower	105 (55%)	0–10	17 (12%)
		Vineyard manager	14 (7%)	11–30	58 (42%)
		Comm. winegrower	71 (37%)	>30	62 (45%)
South Coast	7	Grower	7 (50%)	0–10	2 (29%)
		Vineyard manager	1 (7%)	11–30	4 (57%)
		Comm. winegrower	6 (43%)	>30	1 (14%)

Note that respondents could select more than one professional role and all of the 202 survey respondents provided their experience level. Percentages reported in the table are relative to the number of respondents by region and may not add to 100% due to rounding.

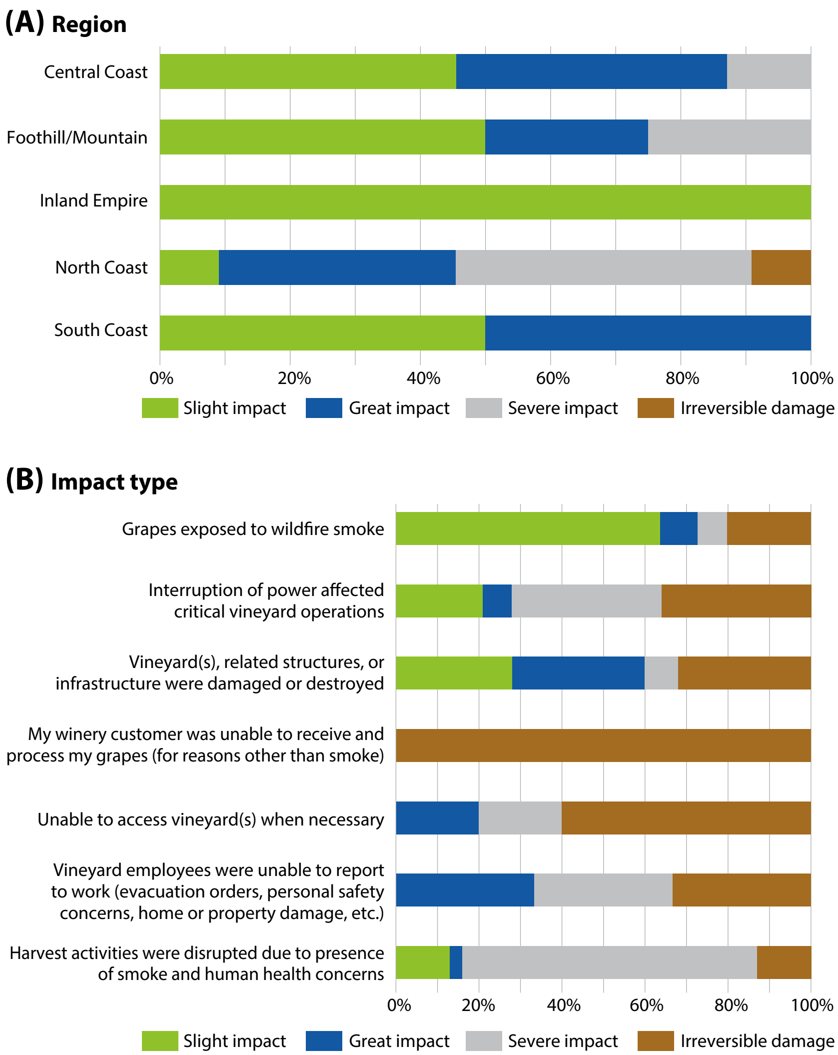

FIG. 2. Severity of wildfire impact. (A) Percent of respondents in each region that incurred a slight (green), great (blue), severe (gray), or irreversible (brown) degree of impact from the 2020 wildfires. (B) For each severity level, the percent of respondents who indicated a given type of impact. Note that respondents could select more than one type of impact.

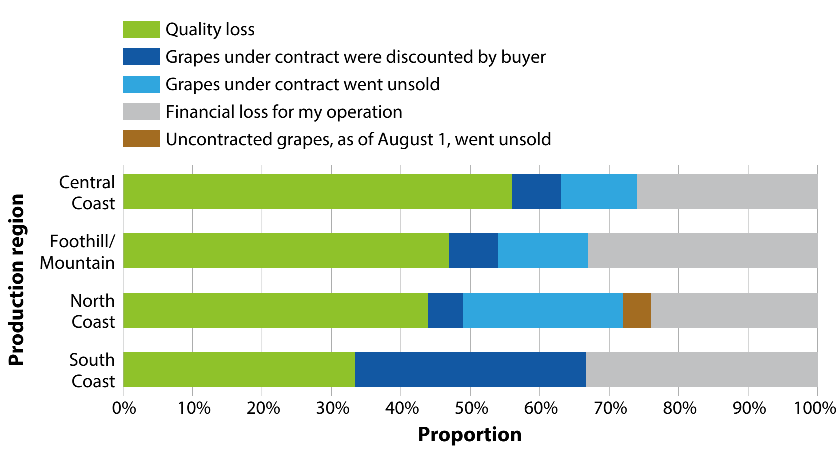

FIG. 3. The percent of respondents from each region that reported experiencing a given type of impact as a result of grape smoke exposure. Only those who indicated they were impacted by wildfire in 2020 and identified grape smoke exposure as among the impacts they incurred were included here. Note that respondents could select more than one type of impact.

by region, with 92% of North Coast, 61% of Foothill/Mountain, 58% of Central Coast, 29% of South Coast, and 0% of Inland Empire respondents indicating grape exposure to smoke. Of those who did incur this impact, quality loss was the most frequently reported issue across regions, ranging from 33% to 56% of responses depending on region (fig. 3). Quality loss may be the principal cause of other impacts, which include unsold contracted grapes, unsold uncontracted grapes, and discounted grapes. Collectively, these smoke-exposure-specific impacts resulted in financial losses, which were reported by 25% of respondents, at a relatively consistent rate across regions.

Laboratory testing for smoke taint is a primary means of quantifying the degree of potential damage to wine (Farella, Braun, and Martel LLP 2021) and mitigating losses from smoke exposure. Given the widespread wildfire smoke events that occurred in 2020, there was significant demand for smoke taint testing, which is reflected in our survey responses (technical appendix, Q 16–18). More than 75% of survey respondents reported a need for rapid laboratory testing services as a result of smoke exposure in 2020. Survey responses indicated that adequate testing can be difficult to come by: Of the 157 respondents in need of testing, a large majority (72%) were unable to access testing results in a timely manner. This adversely affected harvest decisions and likely contributed to unharvested tonnage and subsequent economic losses.

Concerns over worsening wildfire risks

In order to understand whether and how wildfire risk has influenced vineyard management decisions, we asked respondents whether they have considered or implemented any operational changes in light of perceived wildfire risks (technical appendix, Q 5–6). While these questions were not limited to a specified timeframe, respondents were first asked whether they perceived wildfire risks to their operation to be greater today than five years ago (technical appendix, Q 4). This may have primed their responses (Minton et al. 2017) to reflect the risks and events that occurred since 2016. A majority of respondents across regions believes the wildfire risks to their wine grape growing or wine-making operation is greater today than five years ago, with the North Coast having the highest proportion of respondents (96%) responding that risks today are greater — an unsurprising response rate considering the recent impacts of the 2020 wildfire season in that region.

Despite the perception of increased risk, relatively fewer respondents have considered and/or implemented changes to their operation in response to wildfire risk (fig. 4; technical appendix, Q 5–6), and 22% of those who believe risks to be greater did not consider or implement operational changes. For the 114 respondents who *have* implemented operational changes in response to wildfire, 84 (74%) changed management practices or adopted new practices (e.g., monitoring weather and fire conditions or developing new practices to collect and sample grapes). Further, 90 (79%) changed or improved the physical aspects of their operation (e.g., removed vegetation or purchased new equipment to harvest more quickly in the event of wildfire). The majority (68%) noted that these changes or improvements required a cash outlay, and 49% indicated that the changes decreased operational efficiency (technical appendix, Q 7–8). Six survey respondents (most of whom were from the North Coast and/or had more than 30 years of experience) did not believe wildfire risk is greater today than five years ago, yet still considered and implemented management changes in response to wildfires.

Wildfire information lacking

Recognizing the role that knowledge may play in risk management, we asked respondents whether they believe they have the information needed to effectively manage the risk of wildfires to vineyard operations (technical appendix, Q 9). Of the 198 respondents to this question, 43% said that they did not have the information they needed, while only 26% believed they did have sufficient information and 31% were not sure. Regionally, the majority of respondents in the Foothill/Mountain region were unsure of whether they had sufficient information to mitigate wildfire risk, while South Coast producers were the most likely (43%) to believe they had the information they needed to manage risk (fig. 5). Moreover, survey results suggest that the more experience a grower has, the more likely they are to say that they have the information they need to manage wildfire risk. For growers with more than 30 years of experience, 38% said they had the information they needed, compared with 21% of growers with 11–30 years of experience and only 8% of growers with 10 or fewer years of experience. However, 34% of growers with more than 30 years of experience still reported a lack of sufficient information, along with 49% and 48% of growers with 11–30 years and 10 or fewer years of experience, respectively.

Finally, to further home in on how TSPs and TSP organizations can better serve the informational needs of wine grape growers and wine producers, respondents were asked about their primary information source(s) for wildfire-related information and/or guidance for their agricultural operation (technical appendix, Q 10). Multiple resources were used across regions, with strong regional preferences for an information source among respondents from the South Coast (trade/commodity organizations) and the Inland Empire (other growers) (fig. 6). Across regions, fewer than 15% of respondents reported using Cooperative Extension as a wildfire information resource, preferring instead to turn to other growers, commodity organizations, and government agencies.

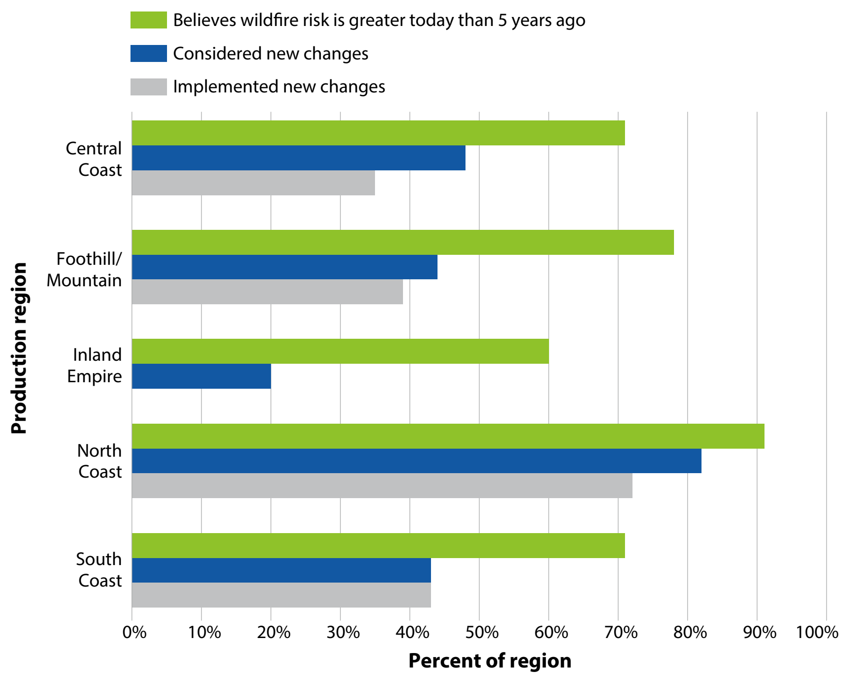

FIG. 4. The percent of respondents from each region that believes wildfire risk is greater today than five years ago (green bar), considered making adaptive management changes to their operation in response to wildfire risk (blue bar), and implemented change to their operation due to wildfire risk (gray bar).

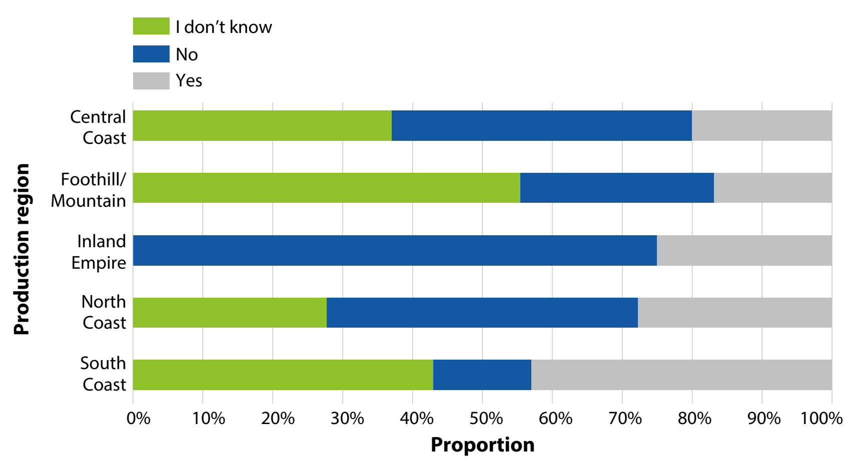

FIG. 5. The percent of respondents from each region that believes they do (gray), do not (blue), or are not sure (green) they have sufficient information to manage wildfire risk.

Harm from smoke exposure

The geographic distribution of responses is not reflective of vineyard acreage, as the Foothill/Mountain and Inland Empire regions (which contain the northern and southern Central Valley, respectively) collectively account for about 50% of wine grape acreage in the state (CDFA 2022b). While the North Coast has only 25% of California wine grape acreage, it is home to nearly half of the state's wineries (California Wine Institute 2022). We suggest that the high number of respondents from the North Coast region may be reflective of the recent wildfire activity in this region and that the occurrence of a fire in or near vineyards

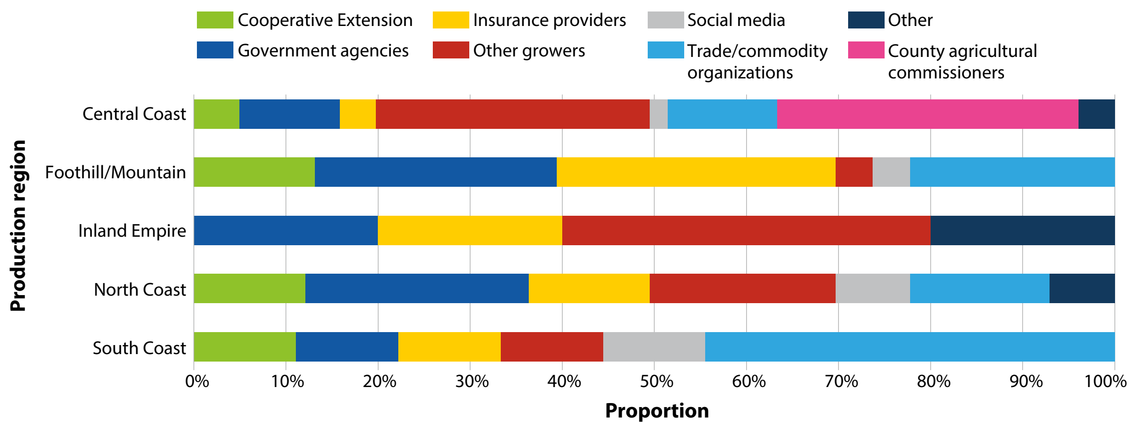

FIG. 6. The percent of respondents from each region that reports they receive wildfire information from different information sources. Note that respondents could select more than one information source.

(fig. 1; Cal Fire 2021) is a more influential driving factor behind the geography of respondents than simply production numbers. The spatial pattern of impact severity supports this idea and is borne out in insurance data showing North Coast counties receiving the highest indemnity payments in the state due to fire losses (CA DOI 2021). North Coast counties incurred more than 36% of statewide wildfire losses for commercial agriculture and farm owners in 2020, despite representing only 8% of the insurance market (CA DOI 2021).

Smoke exposure was the most widely cited impact of wildfire across the state, followed by quality and monetary losses. Survey responses align with industry research documenting between 165,000 and 325,000 tons of unharvested grapes statewide due to "actual or perceived concerns of quality loss" from wildfire smoke exposure in 2020 and subsequent financial losses of more than $600 million (J. Moramarco, bw166, personal communication). These losses — combined with the high demand for laboratory testing for smoke taint during the 2020 wildfire season — make clear the urgent need for testing services. In response, the California Department of Food and Agriculture's Center for Analytical Chemistry initiated efforts in 2021 establishing a response team to respond to emergency-related requests for analytical testing (CDFA 2021). However, test results by themselves often cannot deliver a definitive determination regarding the significance of quality loss from smoke exposure, and can be a costly and time-consuming process, requiring resources growers may not have (Quackenbush 2021).

Improving risk management

Previous research has shown that risk perception can — but does not necessarily — increase after experiencing a natural hazard (Champ and Brenkert-Smith 2016; McGee et al. 2009). Barriers such as time, money, policy, and culture (Gosnell et al. 2019) may prevent producers from adopting adaptive management changes despite perceived risk. Our survey results suggest an explanation, in that nearly half of producers who implemented operational change in response to wildfire risk suffered a reduction in operational efficiency. This highlights the types of tradeoffs that producers must weigh when making adaptive management decisions (Birgé et al. 2016). Moreover, factors beyond risk perception (e.g., management style, past experience, access to information) may drive management actions (Niles et al. 2015) even in the absence of a perceived increase in risk.

Beyond weighing tradeoffs, many producers report they lack sufficient knowledge to make informed decisions in the face of new or worsening environmental stressors (Mase and Prokopy 2014). Although we did not ask whether this perceived knowledge gap is a function of availability (i.e., the information does not exist), access (i.e., producers cannot or do not know where to access pertinent information), or accessibility/applicability (i.e., producers struggle to understand or apply the available information in the context of their operation), the regional and experience-level breakdown in the responses may provide some guidance for TSP networks in prioritizing their efforts to address wildfire risk management for viticulture.

However, we note that relatively few respondents get information from local technical service providers. Respondents may see Cooperative Extension as being solely local TSPs. This understates the value of extension specialists who generate substantive research and science-based information (e.g., Caffrey et al. 2019; Osborne and Tomasino 2019), which may reach the wine industry via means other than local extension agents. Still, the pattern of information sources among California wine grape growers is similar to results seen elsewhere, showing a propensity of producers turning to private consultants, industry publications, or other growers for information on a variety of non-fire farm management practices (Brodt et al. 2009; Ohmart 2008). However, we do not think these results suggest that Cooperative Extension needs to do more as an informational resource. Rather, extension TSPs

A vineyard sign in Sonoma County burned by the October 2019 Kincade Fire. Survey results underscore the need for increased support for wine grape growers and producers to better adapt to a future with larger and more severe wildfires. *Photo*: Anne Belden, iStock.com.

may facilitate information sharing across the diverse network of resources to which producers actually turn. For example, peer-to-peer information exchange can serve as a complementary and reinforcing method for technical learning and adaptation (Garbach and Long 2017). Such efforts need resources and individuals to organize and champion them.

Wine producers need more support

Our survey results underscore the need for increased support for wine grape growers and producers at the state, county, and industry levels. Needed support includes increasing the availability of smoke taint testing in order to provide support for timely harvest and processing decisions. This is critical to mitigating economic losses during future large-scale wildfires, since, in the absence of adequate testing capacity, undamaged or lightly affected grapes may go unharvested, or damaged grapes may be processed into wine that is unfit for its intended use. Similarly, there may be benefits in securing safe access to vineyards and wineries in areas under wildfire evacuation orders, as a strategy for limiting the most significant, irreversible causes of economic damage to individual operations. Cash outlays and operational efficiency challenges can represent potentially significant barriers to better managing wildfire risks, which suggests that financial support for growers and producers can help them adapt to a future with more fire. In addition, the implementation of strategies to address wildfire risks may be influenced by a lack of available information. This highlights a need for more research, particularly in prevention or remediation tactics for smoke damage. However, lack of confidence around the availability of information to manage risks is likely to hinder the adoption of effective risk management strategies, even when research results deliver useful information. This should prompt government agencies, industry organizations, researchers, and extension specialists to consider how they disseminate information. An overall strategy for organizing, updating, and distributing available information quickly and effectively to wine grape industry members is an essential component in bolstering the wine industry's ability to adapt to and manage wildfire risks in the future. CA

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RESEARCH ARTICLE

More jobs and less seasonal employment in California agriculture since 1990

Agricultural employment rose 10% from 1990 to 2020, with less seasonality but more use of contract labor.

by Zachariah Rutledge and Philip Martin

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Abstract

Employment in California agriculture has increased over the past 30 years and has become less seasonal. There were an average of 404,000 farm jobs in California in 2020, 10% more than average employment of 367,000 in 1990. Meanwhile, seasonality, as measured by peak month employment divided by trough month employment, fell 22% over three decades, from 1.8 in 1990 to 1.4 in 2020. Most farmworkers have one farm employer a year, although that employer may be a labor contractor who moves workers from one farm to another. Most new workers in the California farm workforce are H-2A guest workers, the young and flexible Mexican workers who are legally authorized to work in the United States and who are often brought to farms by labor contractors. In the future, rising employment and declining seasonality, combined with an aging and settled farm workforce, may reduce farmworker migration and flexibility.

Over the past decade, the number of H-2A guest workers employed on California farms increased more than tenfold, so that almost 44,000 farm jobs were certified to be filled by H-2A workers in fiscal year (FY) 2022 (DOL 2022). During FY2020, two-thirds of the H-2A jobs certified in California were in crop support services. Most crop support jobs were with farm labor contractors (FLCs), but one-sixth were hired directly by fruit producers. Almost 10% of the H-2A workers were hired directly by vegetable producers (Castillo et al. 2022). Until the 2008–2009 recession, most H-2A workers were in southeastern states such as Florida. However, the slowdown in migration of undocumented individuals after 2008–2009, combined with a stable demand for farmworkers and the aging and settling of undocumented workers who arrived before 2008–2009, contributed to the rapid growth in the H-2A program in the three Pacific Coast states that employ half of U.S. farmworkers, a third of whom work in California.

Farmworkers pick strawberries in Southern California. Strawberries and other berries are among the most labor-intensive commodities grown in California. Farm employment has increased over the past three decades, and the gap between peak and trough employment has declined. *Photo*: Joshua Rainey Photography, iStock.com.

This paper analyzes agricultural employment data from the California Employment Development Department (EDD 2022a) and the Quarterly Census of Employment and Wages (EDD 2022b) to understand changing patterns of farmworker employment in the 21st century. The data show that seasonality is declining in most regions and commodities, primarily because of higher employment during the winter months, which may reflect more winter pruning jobs and fewer summer harvesting jobs. Second, the data emphasize the increasing importance of nonfarm crop support employers, mostly labor contractors, who bring workers to farms to perform specific tasks. More farms appear to be developing a year-round workforce that is hired directly and supplemented when needed with workers brought to farms by labor contractors, including H-2A guest workers (Rutledge and Mérel 2022).

California requires all employers who pay $100 or more in wages to enroll in the state's unemployment insurance system and pay taxes of 1.5% to 6.2% on the first $7,000 of each employee's wages ($105 to $434) to cover the cost of unemployment benefits for laid-off workers (EDD 2022a). Employers also report their employment for the payroll period that includes the 12th of the month. Summing these monthly employment totals and dividing by 12 months generates average employment, also referred to as year-round equivalent jobs. The monthly employment measures allow us to determine the peak and trough employment months.

Agricultural employment, as defined by the North American Industry Classification System (NAICS 11), peaked at 470,000 in May 2020 and was 346,000 in March 2020, generating a peak-trough ratio of 1.4. More than 470,000 workers are employed on California farms sometime during the year. Workers who are employed only in payroll periods that do not include the 12th of the month, such as those who work only during the first, third, or fourth weeks of the month, are excluded from average employment. In 2016, when California's agricultural employment averaged 425,000, almost a million unique Social Security Numbers were reported by the state's agricultural employers, suggesting 2.3 unique workers for each year-round equivalent job (Martin et al. 2019).

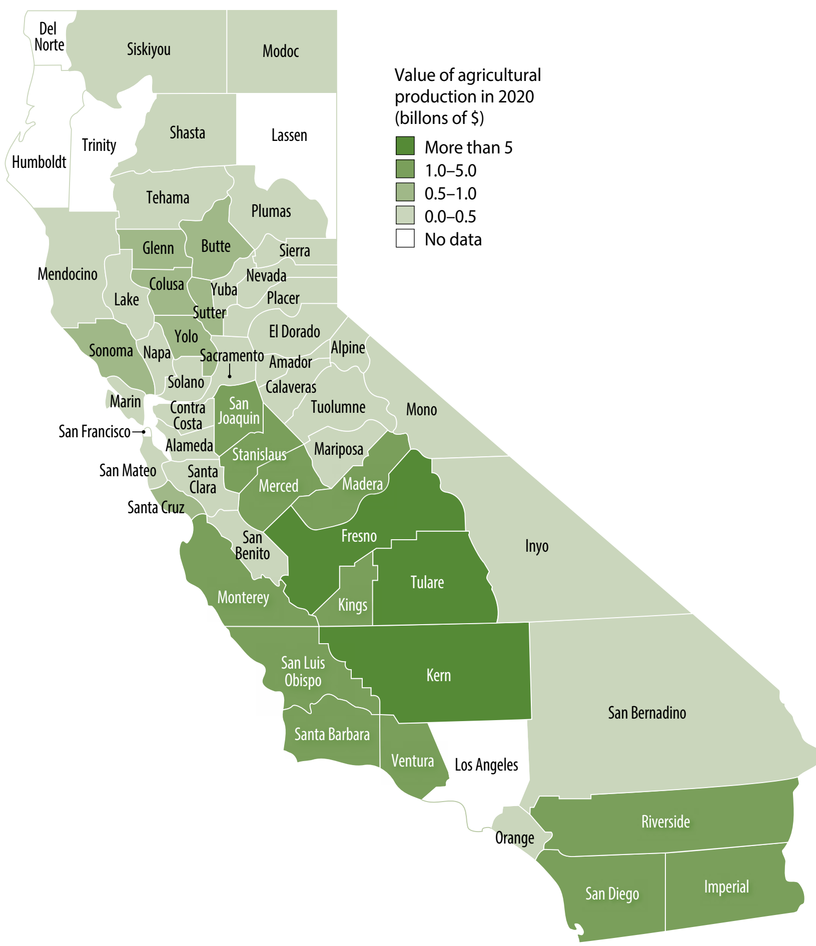

FIG. 1. California farm production value by county, 2020. *Source:* USDA 2023.

An expanding farming economy

California became the leading farm state in terms of sales in 1949, when Los Angeles County led the United States in farm sales (Johnston and McCalla 2004). The state's population doubled between 1950 and 1970, from 10 million to 20 million, and agricultural sales grew fastest in the San Joaquin Valley (SJV) after water projects allowed more acres to be irrigated and suburbanization reduced the availability of farmland in coastal areas.

Citrus and dairy farms in Southern California migrated north to SJV, while tree fruit farms moved from the urbanizing Bay Area to the San Joaquin and Sacramento valleys (Johnston and McCalla 2004). Three SJV counties — Fresno, Kern and Tulare — accounted for 20% of California farm sales in 1949, a third in 2000, and almost half of the state's farm sales in 2020 (fig. 1).

Some crops that were already concentrated in the Sacramento and San Joaquin valleys expanded in acreage. For example, there were 90,000 bearing acres of almonds in 1950, almost 150,000 acres in 1970, 500,000 acres by 2000, and 1.3 million acres in 2022. Most of this additional almond acreage was in the San Joaquin Valley.

New orchards and dairies in the San Joaquin and Sacramento valleys were often larger and more efficient than the coastal farms they replaced, and their higher productivity was reflected in rising yields. Average yields of many fruits and vegetables doubled and tripled over the past three decades; bell peppers and cantaloupes are examples. Yield rose over 50% to 33 tons an acre for strawberries (fig. 2).

The major change in California crop farming over the past half-century has been the rising share of high-value fruits, nuts, vegetables, and melons, as well as horticultural specialties such as flowers and plants, in the state's farm sales. In 1960, the value of fruit,

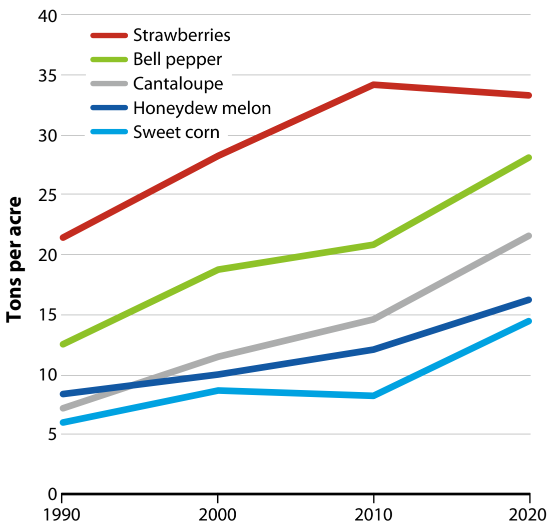

FIG. 2. Yields for selected fruits and vegetables, 1990–2020 (tons per acre). *Source:* USDA 2023.

Farmworkers cut and package lettuce in Salinas. New research shows that yields for fruit and vegetable crops have increased over the past three decades. *Photo*: rightdx, iStock.com.

vegetable, and horticultural (FVH) commodities was two-thirds of the total value of California crops; since 2000, FVH commodities have accounted for over 90% of the value of California crops, reflecting growing consumer demand for fresh produce and nursery plants (Johnston and McCalla 2004). Cotton was California's most valuable crop in 1950; by 2000, cotton was the sixth most valuable crop, and by 2020 cotton was no longer among the state's top 20 crops.

The demand for FVH commodities rises with income, and rising farmland prices encouraged individuals and investors to buy farmland as a hedge against inflation in the 1970s, a decade in which the value of California farmland more than doubled (Johnston and McCalla 2004). Higher interest rates in the 1980s led to a farm financial crisis that was more severe in midwestern states than in California, but encouraged some oil firms and conglomerates to sell their California farmland.

The data in table 1 show that California's farm sales almost tripled in three decades, and that fruit and nut sales almost quintupled. The value of the state's vegetables and melons doubled, as did the value of greenhouse and nursery crops. The state's farm sales were $17.8 billion in 1990, including $4.4 billion worth of fruits and nuts and $3.9 billion worth of vegetables. Farm sales were $27.2 billion in 2000, including $7.3 billion worth of fruits and nuts, $6.2 billion worth of vegetables, and $2.8 billion worth of greenhouse and nursery commodities. This rose to $37.5 billion in 2010, including $13.5 billion worth of fruits and nuts, $6.7 billion worth of vegetables, and $3.8 billion worth of greenhouse and nursery commodities. In 2020, farm sales were $49.1 billion, including $20.6 billion worth of fruits and nuts, $7.8 billion worth of vegetables, and $6.3 billion worth of greenhouse and nursery commodities. In real or inflation-adjusted terms, California farm sales rose by 40% over 30 years, and fruit and nut sales by 140%, while vegetable and nursery sales were little changed.

TABLE 1. California farm sales, 1990–2020

Year(s)	Total	Fruits and nuts	Vegetables and melons	Greenhouse and nursery
		(billions of $)		
1990	17.8	4.4	3.9	—
2000	27.2	7.3	6.2	2.8
2010	37.5	13.5	6.7	3.8
2020	49.1	20.6	7.8	6.3
		(percent increase)		
1990–2000	53%	66%	59%	—
2000–2010	38%	85%	8%	36%
2010–2020	31%	53%	16%	66%
1990–2020	176%	368%	100%	—

Source: CDFA 2023.

An increasing need for labor

Many FVH commodities are labor intensive, so expanding production increases the employment of farmworkers. Rather than hiring workers directly, many farmers are turning to crop support service firms. These are nonfarm businesses that bring workers to farms to accomplish specific tasks. For example, farmers may rely on labor contractors to bring crews of workers for a few weeks to prune, thin, or harvest their crops. Contractors may be the sole employers of the workers they bring to farms under some labor laws, such as unemployment insurance and workers' compensation, and joint employers with farms under others, such as the Agricultural Labor Relations Act.

Combined crop and crop-support employment accounts for over 90% of California's agricultural employment.

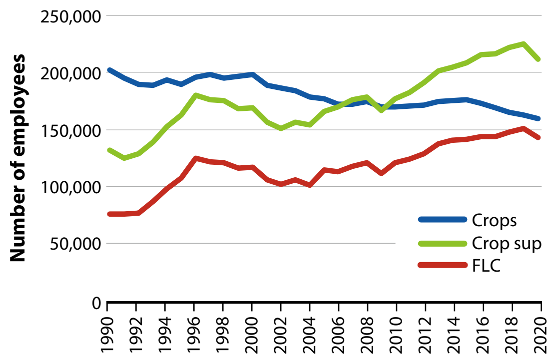

FIG. 3. California crop, crop support, and FLC employment, 1990–2020.

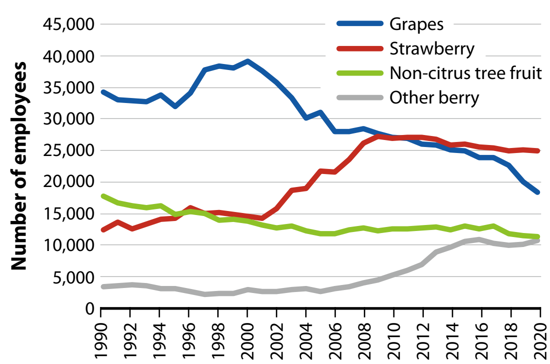

FIG. 4. Average employment in grapes, strawberries, other berries, and tree fruit, 1990–2020.

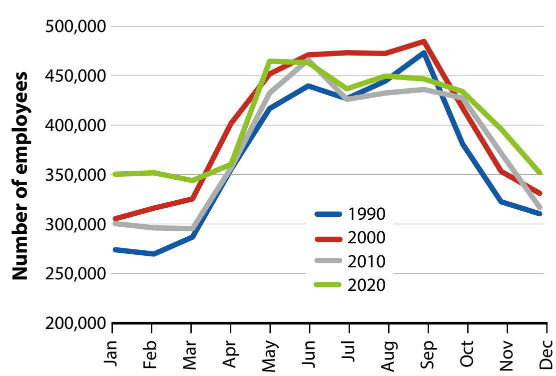

FIG. 5. Employment by month in California agriculture, 1990–2020.

Over the past three decades, California farmers hired 20% fewer workers directly, reducing average direct-hire employment in crops (NAICS 111) from 203,000 to 160,000. Meanwhile, crop-support employment (NAICS 1151) rose by 60%, from an average of 132,000 in 1990 to 212,000 in 2020. Combined crop and crop-support employment accounts for over 90% of California's agricultural employment. Within crop-support employment (NAICS 1151), the farm labor contractor (NAICS 115115) share of average crop-support employment rose from 60% to 67% (fig. 3).

FVH commodities account for 90% of direct-hire crop employment, including 55% for fruits and nuts, 20% for vegetables and melons, and 15% for greenhouses and nurseries.

Employers are assigned to the NAICS code that represents the majority of their sales, so grape vineyards can be distinguished from strawberry, other berry, and non-citrus tree fruit farms. These four types of farms account for almost three-fourths of direct-hire crop employment. Between 1990 and 2020, average direct-hire employment in grapes fell by almost half; strawberry employment doubled; employment in other berries such as blueberries and raspberries tripled; and average employment in non-citrus tree fruits such as peaches, nectarines, and plums fell by a third (fig. 4). Note that there is no commodity information for workers brought to farms by labor contractors.

Longer seasons statewide

The gaps between peak and trough months of agricultural employment are shrinking. Between 1990 and 2000, average agricultural employment rose by almost 10%, from 367,000 to 400,000, and rose especially fast during the winter and spring months, reducing the peak-trough ratio from 1.8 in 1990 to 1.6 in 2000 (fig. 5). Between 2000 and 2010, average employment fell from 400,000 to 380,000, and the peak-trough ratio remained at 1.6. Between 2010 and 2020, average employment rose above 400,000, and the peak-trough employment ratio fell to 1.4. Average employment rose during the winter months and was stable during the summer months.

Declining seasonality was accompanied by a rising share of farm labor contractor employment; the farm labor contractor share of the state's average agricultural employment rose from 20% to 35% between 1990 and 2020 (fig. 6). The largest jump in the FLC share of agricultural employment occurred in the 1990s, when there was an influx of undocumented Mexican workers seeking jobs at a time of low U.S. unemployment.

The FLC share of California agricultural employment was stable between 2000 and 2010, but jumped between 2010 and 2020. The FLC share of the state's

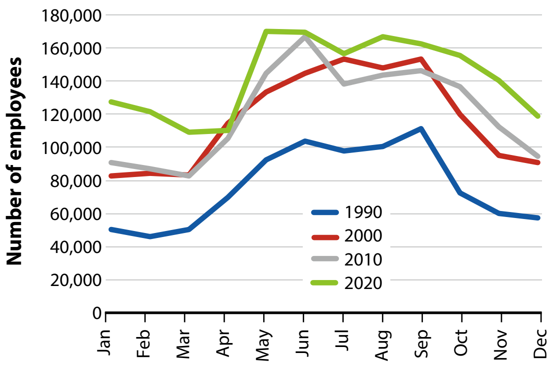

FIG. 6. FLC employment by month, 1990–2020.

average agricultural employment is highest during the summer months of May through August. Three regions account for over 90% of the state's average agricultural employment: the San Joaquin Valley, the Central Coast region centered on Monterey, and the South Coast, which includes Santa Barbara and Ventura counties. Monterey County was the leading producer of hand-harvested fruits and vegetables in 1990, and was joined in 2000 by Fresno, Kern, and Tulare counties (fig. 7). Monterey continued to lead in hand-harvested fruits and vegetables in 2020 with over 4 million tons, but Fresno, Kern, and Tulare also expanded to each produce more than 2 million tons of hand-harvested fruits and vegetables. This helps explain rising farm employment and reduced seasonality.

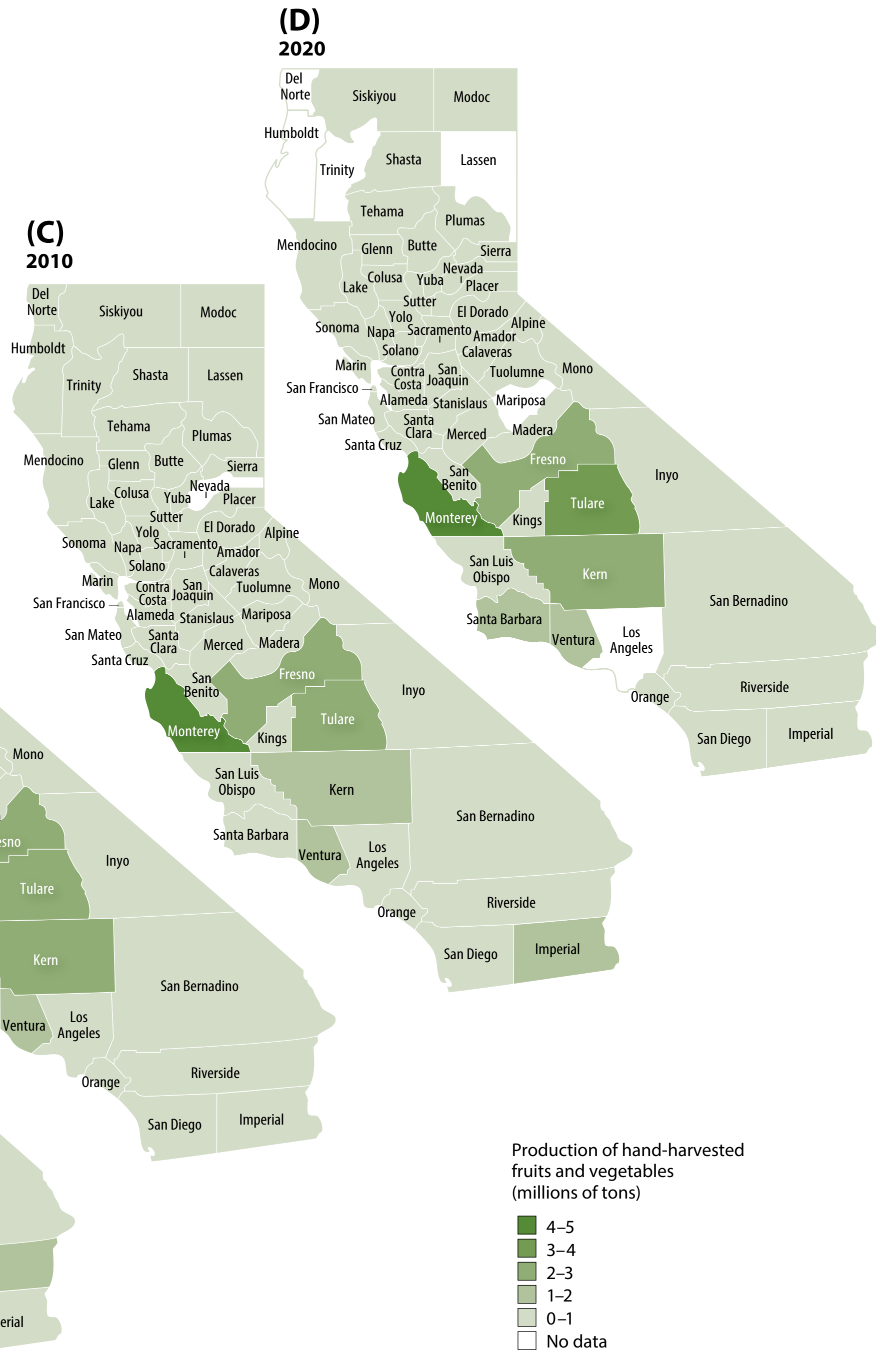

FIG. 7. Hand-harvested fruits and vegetables by county, in millions of tons, in (A) 1990, (B) 2000, (C) 2010, and (D) 2020. *Source:* USDA 2023.

SJV: Longer-term employment

The San Joaquin Valley, from San Joaquin in the north to Kern County in the south, accounts for half of the state's average agricultural employment. SJV average agricultural employment rose from 170,000 in 1990 to 200,000 in 2000, dipped to 185,000 in 2010, and was almost 200,000 in 2020.

Seasonality often increases in smaller geographic areas, but the peak-trough employment ratio fell more in the SJV than it did statewide. The SJV peak-trough ratio fell from 2.2 in 1990 to 1.4 in 2020, more than the drop in the California peak-trough ratio, which fell from 1.8 to 1.4 over these three decades (fig. 8).

Almost half of average agricultural employment in the San Joaquin Valley is with farm labor contractors.

Almost half of average agricultural employment in the San Joaquin Valley is with farm labor contractors, which explains why the SJV has a higher share of the state's FLC employment than of overall agricultural employment. The SJV had over 60% of California's FLC employment in 2020, versus 50% of the state's agricultural employment.

Average FLC employment in the SJV rose sharply between 1990 and 2000, was stable between 2000 and 2010, and rose between 2010 and 2020, when FLC employment was 45% of the SJV's average agricultural employment. The FLC share of SJV agricultural employment is highest during the summer months and lowest in April (fig. 9).

Central Coast: More seasonality

This region includes Monterey County — the U.S. salad and berry bowl. Average employment in Central Coast agriculture rose from 54,000 in 1990 and 2000 to 70,000 by 2020, or a sixth of California's agricultural employment, reflecting more strawberry acreage.

Seasonality is more pronounced in the Central Coast than in the SJV, peaking in July 2020 at 89,000 and reaching a low of 46,000 in January 2020 for a peak-trough ratio of 1.9 (fig. 10). This is significantly higher than the 1.4 peak-trough ratio in the SJV.

The farm labor contractor share of Central Coast agricultural employment rose sharply between 1990 and 2020. In 1990, FLC average employment was one-sixth of Central Coast agricultural employment; by 2020, the FLC share was a third. Peak FLC employment in the Central Coast was 31,000 in June and July 2020, while trough employment was 15,000 in December 2020, a FLC peak-trough ratio of 2.1 (fig. 11).

South Coast: Slower growth

The South Coast region, which includes the six coastal counties from San Luis Obispo in the north to San Diego in the south, had average agricultural employment of 70,000 in 2020, the same as the Central Coast.

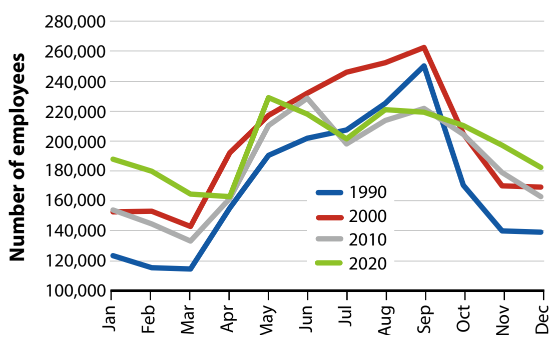

FIG. 8. Agricultural employment in the San Joaquin Valley, 1990–2020.

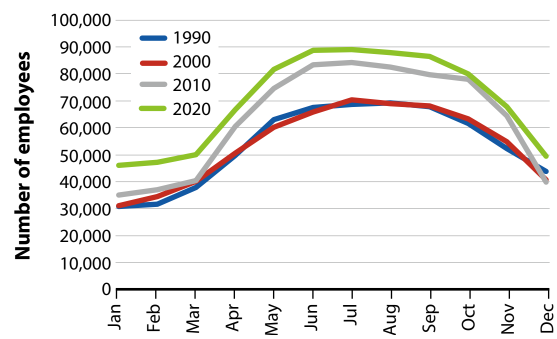

FIG. 10. Agricultural employment in the Central Coast, 1990–2020.

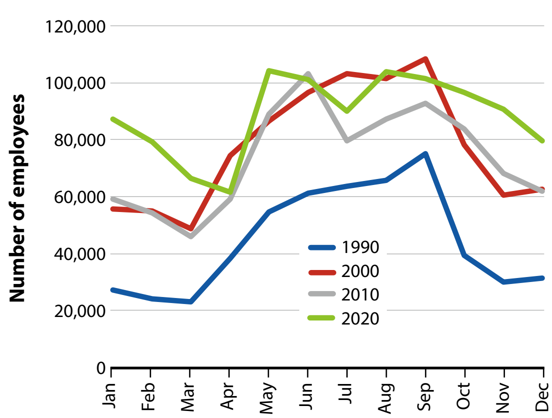

FIG. 9. FLC employment in the San Joaquin Valley, 1990–2020.

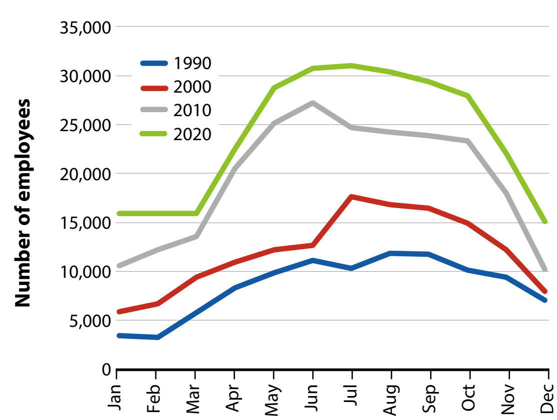

FIG. 11. FLC employment in the Central Coast, 1990–2020.

However, growth in average agricultural employment was slower in the South Coast than in the Central Coast over the past three decades (fig. 12).

Farm labor contractors play a relatively small but growing role in South Coast farm labor markets. The FLC share of average agricultural employment rose from less than 10% in 1990 to almost a quarter by 2020. FLC seasonality in the South Coast is similar to FLC seasonality in other regions. There were 180 workers employed by FLCs in June 2020 for each 100 workers employed by FLCs in December (fig. 13).

Employment in berries doubles

Strawberries (NAICS 111333) and other berries (NAICS 111334) are among the most labor-intensive commodities grown in California. Their production doubled and tripled over the past three decades (Calvin et al. 2022). The state's strawberries were worth $2 billion in 2020, raspberries were worth $405 million, and blueberries were worth $215 million, for total berry sales of over $2.6 billion.

California's average employment in berries more than doubled from 16,000 to 36,000 between 1990 and 2020, while seasonality as measured by employment peak-trough ratios declined from 5.9 to 2.5 (fig. 14). In 1990, berry employment was lowest at 5,000 in January and highest at 28,000 in May. In 2020, January was still the trough month; just under 20,000 workers were employed, compared with 49,000 in June. Berry employment in January tripled between 1990 and 2020 and doubled in May and June.

The upsurge in winter and total berry employment is evident in a comparison of the largest sectors of employment in fruit and nut agriculture. In 1990, California fruit and nut employment peaked at 139,000 in September, including 67,000 in grapes, 34,000 in tree fruit, and 16,000 in berries. By 2020, California fruit and nut employment peaked at 108,000 in June, including 49,000 in berries, 20,000 in grapes, and 19,000 in tree fruit.

There were four workers in grapes for each berry worker in 1990, and 2.5 workers in berries for each grape worker in 2020. Note that some of the decline in grape and tree fruit employment may be due to employers switching from hiring workers directly to hiring them via FLCs; no data are collected on the commodities where FLC employees work.

The Central Coast and South Coast regions accounted for 98% of average berry employment in 2020, including 60% in the South Coast and 38% in the Central Coast. The South Coast share of average berry employment rose from 50% in 1990 to 60%, in 2020, in part due to the expansion of berry production in the Santa Maria area of Santa Barbara County.

Stable farm employment

Over the past three decades, average employment in California agriculture (NAICS 11) rose by 10% to 404,000, while seasonality declined due to more employment during the winter months. The ratio of monthly peak to monthly trough employment fell from 1.8 in 1990 to 1.4 in 2020, reflecting 474,000 workers employed in September 1990 and 270,000 in February 1990, compared with 470,000 workers employed in May 2020 and 346,000 in March 2020.

Many farming operations that hire large numbers of workers have year-round workforces comprised of local workers; they turn to contractors to bring local

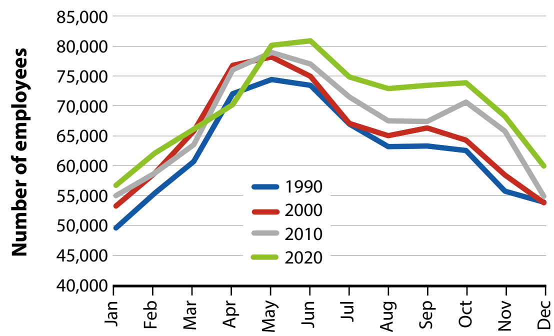

FIG. 12. Agricultural employment in the South Coast, 1990–2020.

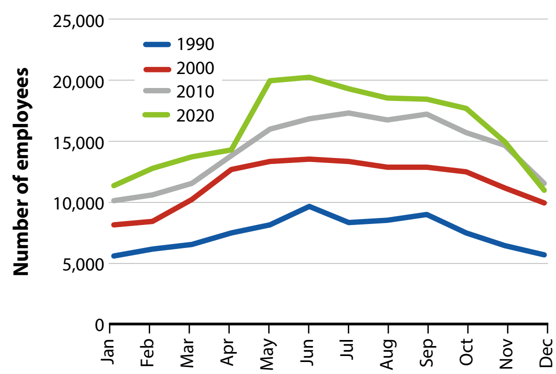

FIG. 13. FLC employment in the South Coast, 1990–2020.

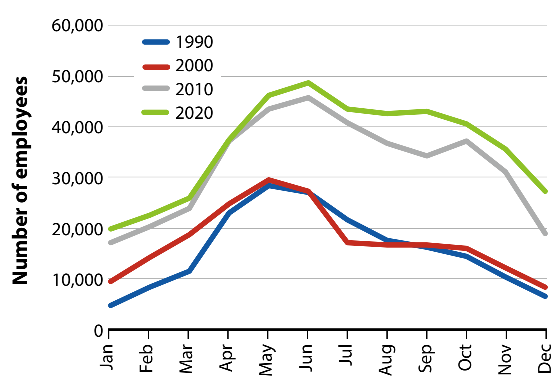

FIG. 14. California berry employment, 1990–2020.

and H-2A workers to their farms to perform specific seasonal tasks. The FLC share of California agricultural employment rose from 20% in 1990 to 35% in 2020. FLC employment is more seasonal, with a statewide peak-trough employment ratio of 1.6 in 2020, higher than the 1.4 employment ratio for all agricultural employment.

The San Joaquin Valley accounts for half of California's agricultural employment, and seasonality in the valley declined faster than statewide. The SJV has over 60% of California's FLC employment, and FLC employment in the SJV is slightly more seasonal than statewide. There were 170 workers employed by FLCs in the SJV in September 2020 for each 100 employed in April 2020.

The Central Coast, centered on Monterey County, accounts for one-sixth of California's agricultural employment, and its farm employment is more seasonal than in the SJV. For each 190 workers employed in June and July 2020 in the Central Coast, 100 were employed in January 2020. FLCs accounted for one-third of the 70,000 average agricultural jobs in the Central Coast in 2020, up from 20% in 1990.

The South Coast region from San Luis Obispo to San Diego has the same average employment as the Central Coast, about 70,000, and experienced less growth between 1990 and 2020, up 12% versus a 30% increase in the Central Coast. The FLC share of agricultural employment in the South Coast more than doubled from 1990 to 2020, reaching almost a quarter of farm employment.

The SJV, Central Coast, and South Coast accounted for 49%, 17%, and 17% of the state's average agricultural employment of 404,000 in 2020, respectively, or a total of 83%. These three regions accounted for 63%, 17%, and 11%, respectively, of the state's average FLC employment of 142,500, or 91% of the state's total FLC employment.

The trends highlighted by this analysis — stable farm employment, decreased seasonality, and more workers brought to farms by labor contractors — seem poised to continue. A growing share of the workers brought to farms by labor contractors are H-2A guest workers (DOL 2022), whose costs are higher because H-2A workers must be provided transportation and housing at no cost and paid an Adverse Effect Wage Rate of $18.65 an hour in 2023, when the minimum wage was $15.50 an hour. A major challenge for the state's agriculture is to ensure that H-2A workers are productive enough to justify their higher costs, which are offset in part by payroll tax savings and by the fact that H-2A workers ensure that farm work is done on time.

Workforce challenges

While a more reliable work force benefits farmers, the division between local and H-2A workers raises some challenges. In the nonfarm economy, the process of creating a core of directly hired workers supplemented by contract workers to perform specific tasks is called hollowing out or fissuring. This can be seen in manufacturers and service firms from banks to hotels. Fissured workplaces raise questions about who is responsible for labor law violations (Weil 2019). They may polarize workforces into high- and low-wage components that limit opportunities for upward mobility (Autor 2019). Workers brought to workplaces by contractors often earn lower wages and have fewer opportunities to climb the job ladder than workers who are directly hired, which may complicate farm labor force management in the future. CA

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RESEARCH ARTICLE

Urban agriculture in California: Lessons learned from an urban farmer workshop series

Evaluation of workshops offered to urban farmers highlights the need for training to achieve economic viability and access to land.

by Rachel A. Surls, Rob Bennaton, Gail W. Feenstra, Ramiro E. Lobo, Alda F. Pires, Jennifer Sowerwine, Julia Van Soelen Kim and Cheryl A. Wilen

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Abstract

Urban farming is an important component of California agriculture, but lack of agricultural census data or common definitions makes it difficult to track and understand. In 2017–2018, a team of University of California Agriculture and Natural Resources (UC ANR) researchers and extension professionals developed a workshop series for urban farmers in California based on results of a prior needs assessment. After conducting 16 workshops in the state's largest urban centers, the team evaluated what participants learned and how they put their knowledge into action. The evaluation highlighted urban farmers' ongoing challenges and found that economic issues such as profitability and land access are some of the greatest barriers for urban farming in California. An unexpected positive outcome was the opportunity for participants to network and meet other farmers. Urban farmers expressed the need for more opportunities for mentoring and building partnerships with other farmers and organizations. Evaluation results suggest that California's urban farmers may be more diverse than California farmers as a whole, and that they are often beginning farmers.

Over the past decade, home and community gardening have been on the upswing, according to the National Gardening Association (2021), with increasing numbers of Americans growing edible crops, from vegetables to herbs to fruit trees. As gardening has increased, so too has a related phenomenon that is often called urban farming or urban agriculture (UA). This term means different things to different people. To some who call themselves urban farmers, it means producing food for their own family in their own backyard. For others, urban farming is a commercial enterprise, either for profit or nonprofit, and often, though not always, at a very small scale.

UA comes in many forms, including backyard growers or community gardeners who are scaling up to sell some of their produce, flowers, honey, or eggs; school gardens where produce is grown not only for in-class lessons, but also for sale; gardens where crops are being grown for donation to food pantries; and high-tech indoor agriculture. In addition, UA encompasses

UCCE Specialist Jennifer Sowerwine teaches workshop participants how to conduct an on-farm food safety assessment. Many participants reported using what they learned to identify and mitigate food safety risks on their farms. *Photo:* Rachel Surls.

Former UCCE Advisor Rob Bennaton discusses soil management with participants at a Los Angeles area workshop. Many workshop participants said their soil management practices improved following their participation. *Photo:* Rachel Surls.

multi-generation family farms that once operated on the edges of cities, but are now surrounded by suburbs. Because UA is emerging and diverse, it has been difficult to quantify, track, and understand. The U.S. Department of Agriculture, which conducts an agricultural census every 5 years, does not distinguish urban farms in its count, so there is no census data for either urban farms or urban farmers.

As UA has evolved in California over the past several years, UC Agriculture and Natural Resources (UC ANR) researchers have worked to understand and address the needs of UA practitioners, including delivery of a multi-region workshop series. The series was designed to provide urban farmers with training and information as well as to identify and assess their needs and challenges.

Assessing urban farmers' needs

Urban farming has sparked attention and action nationwide. Cities, counties, and even state governments around the United States have developed policies to facilitate UA activities (Rangarajan and Riordan 2019). In California, Los Angeles, Sacramento, San Diego, San Francisco and other cities have created policies specifically to promote and facilitate urban farming.

As interest in UA grew, UC ANR researchers and partners teamed up in 2012 to address the needs of urban farmers in California. The team adopted a working definition of UA, a modified version of an American Planning Association definition: "Urban agriculture includes production (beyond that which is strictly for home consumption or educational purposes), distribution and marketing of food and other products within the cores of metropolitan areas and at their edges" (Hodgson et al. 2011).

The team conducted a needs assessment of urban farmers in California in 2013, visiting more than 30 urban farms to learn about their technical assistance needs. They found that urban farms were very small (less than three acres in size on average), were usually led by beginning farmers, and most often operated in a nonprofit rather than for-profit context (Surls et al. 2014). UA was frequently used as a tool for programming around youth development, healthy food access, and social justice. Results also showed that urban farmers had many practical questions about farming, on topics ranging from regulations to marketing to soil and pest management. In response, the UC ANR urban agriculture team created an online resource portal for urban farmers, offering needed resources and information (Surls et al. 2014).

Desire for in-person training

In addition to online resources, the urban farmers interviewed expressed a desire for in-person training. The team embarked on a two-year project to develop and implement a series of workshops for California's urban farmers.

Funded through a UC ANR Competitive Grant, the workshops were geared toward helping urban farmers maximize their success and minimize risks related to operational viability. The 2013 needs assessment highlighted areas where urban farmers needed special training to address soil quality and contamination, water conservation during drought, low yield, economic sustainability, and other issues. These challenges and concerns have been echoed in other UA research and publications nationwide (Diekmann et al. 2017; Pfeiffer et al. 2015; Sowerwine et al. 2020). This project sought to increase urban farmers' understanding of plant growth, animal products, business practices, and regulations in order to promote food safety and minimize the legal risks related to their farming enterprises.

Workshop series topics

The UC Urban Agriculture Workshop Series consisted of four day-long workshops on four different topics. Each workshop series was held in California's largest urban communities: the San Francisco Bay Area, Los Angeles, Sacramento, and San Diego, for a total of 16 workshops conducted between 2017 and 2018. The content for the four topics encompassed:

1. Legal and Regulatory Basics of Urban Agriculture, which included important laws and regulations that urban farmers should understand.
2. Production Issues in Urban Agriculture, which introduced participants to key tenets of crop production, soil management, irrigation and integrated pest management (IPM).
3. Marketing and Business Management for Urban Farmers, which introduced farmers to business planning, marketing, and cash management.
4. Food Safety Basics for Urban Farmers, which covered the basics of food safety, from pre- to post-harvest, and good agricultural practices (GAPs).
5. Most workshops (15 out of 16) were held at urban farms, and featured local urban agricultural practitioners as speakers, along with county agricultural commissioners, environmental health officers, and Cooperative Extension specialists and advisors.

Workshop evaluation method

The team conducted a two-part evaluation to capture information about the workshop participants and how they received and used the information. The first evaluation was administered at the end of each workshop using a "retrospective post-then-pre" evaluation method (Klatt and Taylor-Powell 2005) to assess what participants felt they had learned that day and the overall usefulness of the workshop. In the second evaluation, conducted two to three months after their workshop participation, attendees were asked to respond to an online survey to report whether they had implemented practices or taken specific actions based on what they had learned.

Descriptive analyses of the two surveys were conducted using the Statistical Package for Social Sciences (SPSS). Pearson's Chi-squared and Fisher exact test were used to evaluate demographic differences between the day of event and post-survey respondents ($P < 0.05$). At the end of each workshop, participants were asked to rate their knowledge on a scale of 1 to 5, with 1 meaning no knowledge and 5 meaning extremely knowledgeable, and then to retrospectively rate their knowledge of the same topic before the workshop began. The team conducted paired sample t-tests on the post-then-pre scores to determine the significance of self-reported changes in knowledge over the course of the day ($P < 0.001$). Finally, answers to open-ended questions on both the day-of-event survey and the post-event survey were coded for themes by two reviewers, providing more nuanced information about the benefits of these workshops, as well as the ongoing needs and challenges of urban farmers.

Workshop participants

The 16 workshops were attended by 581 people in four geographic locations. A total of 290 retrospective post-then-pre evaluations (referred to as "day-of" evaluations) were collected over the course of the workshop series. These represented 192 unique attendees, since some people attended more than one workshop. Day-of evaluation respondents most often identified themselves as gardeners, farmers, and students, followed by beginning farmers, educators, and agricultural nonprofit staff (table 1). Of 192 day-of evaluations, 99 respondents (51.6%) identified themselves as farmers (table 2). Among respondents who identified as farmers, 72% identified themselves as new farmers with fewer than 10 years of farming experience. Very small acreages were typical for those who were farming; 74% reported growing crops on one acre or less and 38% said they use a quarter of an acre or less.

Ethnicity of day-of evaluation respondents can be viewed in table 3, with the largest group identifying as white. In regard to gender, 60% of respondents identified as female, 33% as male, and 3% as non-binary. In terms of age, the largest group of day-of evaluation respondents were in the 25–40 age range (43%), with the next largest group in the 41–60 age range (28%).

What participants learned

Participants overwhelmingly found the workshops useful, with 87% of day-of evaluation respondents rating the workshop as either useful or extremely useful. Day-of respondents reported significant increases in knowledge at the end of each workshop compared to their knowledge at the beginning of the workshop, in every topic area. For example, participants in the "Legal and

TABLE 1. Self-identification of workshop participants

Self-identification categories*	Number of respondents (*n* = 192)	Day of workshop survey
Gardener	120	62.5%
Farmer	99	51.6%
Beginning farmer (< 10 years)	71	37.0%
Educator	61	31.8%
Agricultural nonprofit staff	40	20.8%
Student	89	20.3%
Urban agriculture policy advocate	37	19.3%
Researcher	28	14.6%
Other	22	11.5%
Farm employee	15	7.8%
Experienced farmer (10+ years)	11	5.7%
Ag professional/resource agency staff	9	4.7%
Municipal employee involved with urban ag	3	1.6%

* Respondents could choose multiple categories to describe themselves.

TABLE 2. Event participants who self-identified as farmers

Farmer categories	Number of respondents (*n* = 99)	Percent of farmers in each category
Experienced farmer	11	11%
New farmer	71	72%
Farm employee	15	15%
No further designation of farmer type	2	2%

TABLE 3. Ethnicity of day-of-event survey respondents

Respondent ethnicity	Percent of all respondents (*n* = 192)	Percent of farmer respondents (*n* = 99)
White	45.8	53.5
Hispanic/Latino	12.5	10.1
Asian/Pacific Islander	8.9	8.1
Black/African American	4.2	2.0
Native American	0.5	1.0
Other	3.1	3.0
Multi-ethnic	4.7	2.0
No response	20.3	20.3
Total	100.0%	100.0%

Workshops were held at urban farms around the state, including Wild Willow Farm in San Diego, shown here. Participants benefited from meeting and learning from experienced urban farmers at their farms. *Photo:* Rachel Surls.

Regulatory Basics" workshop reported an improved understanding of policies that impact UA. Attendees at the "Production Issues" workshop reported that they gained knowledge of how to manage pests. Participants in the "Marketing and Business Management" workshop indicated that they gained knowledge of the key elements of a successful marketing campaign, while "Food Safety Basics" attendees reported that they left the workshop with an improved understanding of on-farm food safety risks.

Open-ended responses indicated that participants not only valued the workshop content, mode of delivery, and quality of speakers, but highly valued networking as an outcome of the workshop series. Participants enjoyed meeting like-minded individuals, talking to other farmers and sharing information and advice.

Post-event survey responses

Ninety participants responded to the follow-up survey administered two to three months after the event. The goal of this post-workshop survey was to assess how participants used what they learned, what ongoing challenges they faced, and additional resources they desired. Demographically, there were no significant differences between the day-of-event respondents (n = 192) and the smaller group of post-survey respondents (n = 90).

Using what they learned

Two to three months after the workshops, respondents indicated that they were implementing what they had learned. Of the 90 post-event survey respondents, 48 (53%) had attended the "Legal Basics" workshop, 32 (36%) attended "Production Issues," 43 (48%) attended "Marketing and Business Management," and 40 (44%) attended "Food Safety."

Regarding legal and regulatory matters, the majority of respondents (n = 48) had connected with a regulatory agency or resource-providing organization that they learned about at the workshop (62.5%), engaged in urban agriculture advocacy or policy work (39.6%), took steps toward participating in urban agriculture incentive zones (33.3%), brought their farm operation into regulatory compliance (27.1%), legally expanded sales to new outlets (18.8%), or taken other steps, such as securing licenses and permits (18.8%).

In terms of food production, participants (n = 32) reported implementing a number of recommended practices, including identifying and managing a pest (50%), improving soil management practices (50%), improving the design of their farm or planned farm (34.4%), trying one or more new pest management strategies (31.3%), improving water use efficiency (28.1%), reducing pesticide usage (25%), trying a new crop (21.9%), and other outcomes (12.5%) such as improved ability to manage weeds and planting cover crops.

Respondents also implemented business practices based on the workshops. More than half (53.5%) of all respondents (n = 43) developed or improved their marketing plan, 32.6% changed one or more business practices, more than a quarter (25.6%) improved sales, 20.9% tried a new distribution channel, and 18.6% reported some other impact, such as improving labor practices or establishing a formal business (e.g., LLC).

As for food safety, out of 40 respondents, nearly two-thirds (67.5%) had identified food safety risks on their farm as a result of a workshop. More than half (52.5%) had developed and implemented food safety plans for their farm, 35% had begun keeping records to track the food they sold or donated, 30% had trained their workers on GAPs and standard operating procedures (SOPs), and 20% had developed and implemented a soil safety plan. In open-ended responses, many reported developing a plan and schedule to implement food safety practices using the resources provided.

Networking again arose as a central theme, as it had in the day-of evaluations. Participants reported the value of networking to enhance market opportunities, relationship and community building, mentorship, education, and community engagement. For example, one farmer noted, "I met someone [at the workshop] who runs a farmers' market and later applied to her market."

Ongoing challenges

In the post-event survey, participants were also asked to identify the most important challenges facing urban farmers (table 4). Of those who responded to that question (n = 55), more than half (56.4%) reported the economics of urban agriculture as a challenge. Economic

TABLE 4. Challenges facing urban farmers

Responses to the open-ended question "What are the most important challenges facing urban farmers?"*	n = 55	Post-workshop survey
The economics of urban agriculture (costs, business planning, marketing, access to capital, the challenges of making ends meet)	31	56.4%
Land access (finding and getting permission to use land, availability, tenure)	18	32.7%
Networking (having access to information, knowledge sharing, and mentoring, support from other farmers)	14	25.5%
Production-related (soil management, pest management, other production-specific info, and skills)	9	16.3%
Legal and regulatory (understanding laws and policies, working through bureaucracies)	5	9.1%
Other or unclear	3	5.5%

* Responses were summarized by themes, and respondents could share multiple challenges.

challenges included business planning, financing, marketing, and overall profitability due to the high costs of operations. The second greatest challenge was related to finding land and securing tenure, with 32.7% of participants identifying land access as a critical challenge. Networking, including access to information, knowledge sharing, and mentoring, was identified as a challenge by 25.5% of respondents. Production-related challenges such as soil and pest management were identified by 16.3% of respondents. Only 9.1% identified legal and regulatory issues, such as understanding laws, policies and permitting as key challenges. Participants were asked an open-ended question about what additional training or resources they desired. Most of the responses centered around the economics of urban farming, including more detailed practical workshops. They also mentioned resources related to business planning, financing, taxes, insurance, marketing (particularly to restaurants and grocery stores), certifications, and zoning compliance. More hands-on production-related workshops were requested, including practical methods for crop planning, composting, and rainwater catchment.

Strengthening urban farmer networks was another prominent theme, with proposals for establishing some form of enduring network (rather than one-off events), such as an urban farmer association and a directory or network to promote sharing of resources.

Insights from evaluation

Based on evaluation results, the UC ANR Urban Agriculture Workshop series was an effective vehicle for sharing knowledge with urban farmers. Workshop attendees put their knowledge into action, using what they learned to improve business practices, reach new markets, try new production practices, develop food safety plans, and obtain necessary licenses and permits.

Evaluation findings have limitations. Workshop attendees were not necessarily representative of all urban farmers in California. As mentioned previously, the total number of urban farmers in California is unknown. Participants self-selected to attend workshops, complete day-of evaluations, and respond to post-workshop evaluations. Outreach and the workshops themselves were conducted in English and may have missed non-English-speaking audiences. Additionally, participants were a mix of urban farmers along with individuals who were planning to become urban farmers or were simply curious about urban agriculture. Given that the study population was a convenience sample comprising those who attended the workshops, the results have limited external validity. Even so, evaluation results can help to inform what is presently known about urban farmers in California, their challenges, and their needs.

Evaluation results offered insights into the pathways taken into urban farming and the level of experience of urban farmers. Self-identified gardeners made up almost 63% of participants, suggesting that there may be many aspiring urban farmers hoping to scale up from gardening to farming. Of those participants who did identify as farmers (52%), very small acreages are typical, with almost 75% working on one acre or less. New farmers were by far the most likely to participate, which suggests that many urban agriculturalists are beginning farmers.

Demographically, workshop participants who self-identified as farmers were more diverse than farmers in California as a whole. Just over half of farmer participants (53.5%) self-identified as "white" compared to 94.2% of farmers in California (USDA 2017). Also of note, approximately 60% of day-of-event survey respondents who identified as farmers were female, while less than 40% of all farmers in California are female. These results suggest that urban farmers in California may be more heterogeneous than "traditional" farmers.

The evaluation results also offer insights into what challenges urban farmers are facing; this can help UC ANR's team and other farm educators craft future outreach programs.

More than half of the participants responding to the post-workshop evaluation highlighted that the economics of urban agriculture was the most challenging issue they faced as urban farmers. The second most mentioned challenge for participants was land access. The literature on urban agriculture also highlights these as major challenges for urban agriculture practitioners (Arnold and Roge 2018; Siegner et al. 2018; Surls et al. 2014). These challenges are mirrored by small and beginning farmers in rural areas. According to Ahearn (2011), having the opportunity to acquire suitable land and achieve profitability of small operations are key challenges that beginning farmers typically face. Constraints may be even more severe in urban communities, where the cost of land and labor is especially high, and small available acreages place limits on production.

UC IPM Advisor Emeritus Cheryl Wilen discusses weed management. Urban farmers are often beginning farmers, and benefit from learning important basics of production, such as the tenets of integrated pest management (IPM). *Photo:* Rachel Surls.

The third most important challenge, which might also be seen as an opportunity, was respondents' difficulty in finding and maintaining networks to provide "go-to" people and organizations for ongoing questions. The workshops themselves provided this networking function to participants; this was one of the most highly regarded elements of the workshops. Not only did participants want access to information from agricultural professionals and their peers; they also desired mentoring and peer-to-peer learning opportunities. More than simply providing new knowledge, increased networking can enhance economic outcomes by helping farmers increase their sales via additional connections (Khanal et al. 2020).

Implications for future training

As farm educators plan future urban agriculture programs, the evaluation results suggest that the most important needs for training, technical assistance, and resources are related to economic sustainability. With very small acreages, urban farmers have limitations on what and how much they can grow. Given the additional economic strain that the COVID-19 pandemic has placed on small farmers since this evaluation was conducted, the need has likely intensified for educational programs related to economic viability.

The challenge of land access is another area in which UC ANR's team and other farmer educators could expand training and technical assistance. This issue is tied to the challenge of economic viability, since land in California's cities is typically very expensive. Urban agriculturalists need guidance on finding land and negotiating low-cost leases.

The results suggest policy directions as well. State and municipal governments could more actively engage with implementing comprehensive policies to support equitable land access. For example, while California law AB551 (Urban Agriculture Incentive Zones) offers property tax incentives for landowners who offer their land for urban farms, it does not address inequities in land access faced by communities of color.

Finally, based on the high value placed on participant networking, the results suggest an important role for UC ANR and other groups to facilitate local connections among urban farmers. This could be done through increasing the time available for networking at future workshops, or by supporting virtual or in-person gatherings where urban farmers can connect.

As California continues to urbanize, and more cities and communities explore ways to support urban farms, UC ANR and other groups that support the state's farmers can be key partners in supporting agriculture on a continuum, from rural to urban. CA

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RESEARCH ARTICLE

Recycled water could recharge aquifers in the Central Valley

Recycling more wastewater can help recharge aquifers in suitable areas of the Central Valley.

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Abstract

Drawing out too much groundwater, or overdrafting, is a serious problem in California. As a result, groundwater sustainability agencies are considering using recycled municipal wastewater to recharge aquifers. In our study, we employ suitability mapping and the models C2VSimFG and Ichnos to identify appropriate areas for managing aquifer recharge with recycled water in California's Central Valley. The factors that influence suitability include soil properties, proximity to recycled water sources, and the residence time, or amount of time that recharged water spends underground. There are many suitable areas in the Central Valley that are immediately adjacent to water recycling facilities. However, adequate supply is an issue in most locations. Roughly half of the groundwater sustainability agencies in critically overdrafted basins of the Central Valley have enough potentially suitable locations to meet their recharge goals, but not all of them have access to enough recycled water. The methods demonstrated here can serve as tools for agencies considering using recycled water for aquifer recharge.

California's Central Valley is a productive agricultural region with a history of unregulated groundwater pumping, which has resulted in overdrafting of groundwater (Springhorn et al. 2021). The Sustainable Groundwater Management Act (SGMA) of 2014 seeks to address overdraft by directing the Department of Water Resources to assign priority levels — critically overdrafted, medium, and high priority — to basins, and requires those with the greatest overdrafts to create and implement groundwater sustainability plans (GSPs). Out of the Central Valley's 45 subbasins, 11 are considered critically overdrafted (DWR 2020a), meaning that "continuation of present water management practices would probably result in significant adverse overdraft-related environmental, social, or economic impacts" (Springhorn et al. 2021). Within these 11 critically overdrafted subbasins, 36 groundwater sustainability agencies (GSAs) submitted GSPs (fig. 1) (Springhorn et al. 2021). These plans outline how GSAs will meet groundwater sustainability goals.

A field of sunflowers near Sacramento. Locating suitable land and available water are potential challenges for recycled water managed aquifer recharge in the Central Valley, with lack of available water likely to be the greater obstacle. *Photo*: tfoxfoto, iStock.com.

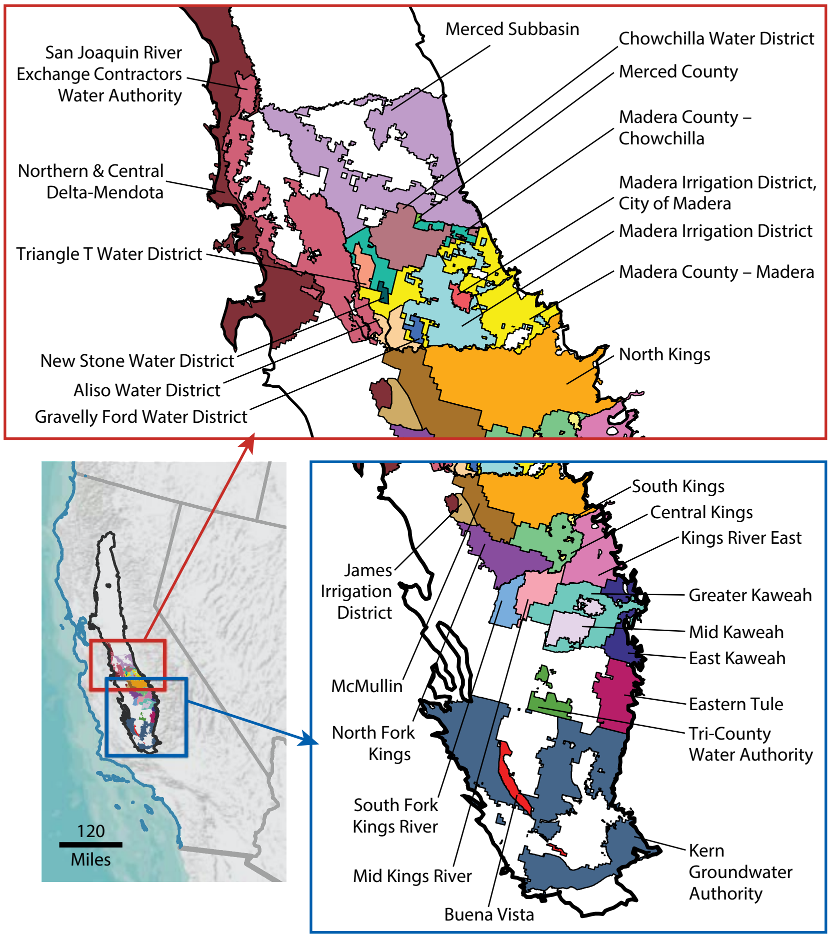

FIG. 1. Map of GSAs in critically overdrafted basins in the Central Valley requiring land for recharge (Benjamin Gooding, DWR, personal communication; DWR n.d.; DWR 2020b). *Sources:* Esri, USGS, NOAA.

One potential approach to groundwater sustainability is through managed aquifer recharge (MAR). MAR is the deliberate infiltration of water into aquifers for storage; storing water in aquifers tends to have less evaporative loss and fewer adverse effects on rivers than storing water in surface reservoirs. MAR can mitigate aquifer depletion, enhance dry-season streamflows, and improve the quality of recycled water used for infiltration (Bekele et al. 2011; Kourakos et al. 2019). Analysis of the GSPs submitted for basins in critical overdraft revealed that 29 of 36 GSAs have plans for using surface water to meet recharge objectives, resulting in about 200 MAR projects (Ulibarri et al. 2021). Recharge with high magnitude streamflows has shown promise for flood and overdraft mitigation, but the uncertain timing, amount, and location of these flows pose logistical challenges (Alam et al. 2020; Dahlke and Kocis 2018). Lack of nearby source water is a major factor preventing MAR projects from reaching recharge goals (Perrone and Rohde 2016). In fact, unallocated surface water is insufficient to fulfill the requirements of the 200 or so proposed MAR projects during a typical water year, suggesting that proposed MAR projects may need to reconsider their water source (Alam et al. 2020; Ulibarri et al. 2021).

One alternative water source for MAR is recycled water. Title 22 of the California Code of Regulations allows disinfected tertiary recycled municipal wastewater to be used for MAR, subject to water quality and residence time requirements. Disinfected tertiary is the highest quality of non-potable recycled water recognized in the regulatory code and is suitable for virtually any use except direct consumption (CCR 2018). Under the California Water Code, the owner of a wastewater treatment facility has exclusive rights to the treated water, though they must receive approval for new uses from the State Water Resources Control Board if a change might result in reduced flow to a watercourse (California Water Code 2002). Because treatment facilities are often owned by public utilities, it may be easier for a municipality to obtain treated wastewater than to obtain water from other sources (SWRCB 2021b). Conventional wastewater treatment plants may be replaced by facilities producing recycled water at the end of their lifespan or may be upgraded to produce recycled water for improved effluent quality (Cooley and Phurisamban 2016; Crook 2004). MAR projects using recycled water, called Groundwater Replenishment Reuse Projects in Title 22, have been implemented in the Orange County Water District and Montebello Forebay in Los Angeles County (McDermott et al. 2008; Mills and Watson 1994).

Despite the widespread interest in MAR siting and the potential of recycled water for recharge, few studies have examined the suitability of locations in California for recycled water MAR. Those that do focus largely on economic and logistical optimization (Bradshaw and Luthy 2017; Fournier et al. 2016; Merayyan and Safi 2014). Nevertheless, planning recycled water MAR requires consideration of unique criteria, such as natural attenuation of potential contaminants and proximity to a treatment plant for water supply (Ahmadi et al. 2017; Pedrero et al. 2011). In this paper, we identify areas in the Central Valley suitable for recycled water MAR and locations where future projects could be developed if existing wastewater infrastructure is upgraded to produce recycled water. Additionally, we evaluate the current recycled water produced at existing treatment facilities and compare it to predicted needs by each GSA as outlined in their plans.

Determining suitability

Suitability mapping was used to identify land within the Central Valley which might be ideal for recycled water MAR. Criteria were compiled in the form of ArcGIS raster maps of the valley, with each 328-foot-by-328-foot (100-meter-by-100-meter) pixel evaluated for each criterion. Each criterion was evaluated in one of two forms: (1) numerical or (2) binary. Numerical suitability scores were used for soil suitability and source proximity; binary suitability scores were used for land cover and proximity to drinking water sources. The binary score maps were multiplied by the averaged numerical score map to exclude unsuitable areas, resulting in a map giving an overall suitability score.

Land within the Central Valley was numerically scored — from 1 to 100, where 1 is unsuitable, and 100 is ideal — using two criteria: (1) relative suitability for MAR based on soil and (2) proximity to a potential recycled water source. The soil suitability and source proximity scores were combined with equal weighting.

Soil suitability was determined using the modified Soil Agricultural Groundwater Banking Index (SAGBI), which scores suitability of land for MAR on agricultural land (ag-MAR) in terms of deep percolation, root zone residence time, topography, soil salinity, and soil surface conditions (O'Geen et al. 2015) (fig. 2). The modified version assumes deep tillage in restrictive soil horizons, increasing infiltration potential.

Proximity to a potential source of recharge water was scored linearly from 1 (farthest, least suitable) to 100 (nearest, most suitable) (fig. 3). Beyond three miles (4.8 km), transporting the water is usually infeasible, so all farther locations received the least suitable score of 1 (online appendix section 6.4). Facilities were identified from the State Water Resources Control Board's 2019 Volumetric Annual Report of Wastewater and Recycled Water (SWRCB 2021a). The proximity score was calculated under three scenarios, considering (1) only facilities producing disinfected tertiary water, (2) any facility with recycled water, and (3) any treatment facility, including those only producing wastewater.

Suitable areas

Some areas cannot be used for recycled water MAR due to existing land cover or proximity to drinking water supplies; therefore, a binary assessment of suitability (i.e., suitable, unsuitable) was performed for (1) land cover and (2) proximity to drinking water sources.

Land cover was determined using the Land IQ 2018 crop map; the National Land Cover Database (NLCD) 2016 map of the Coterminous United States was used to fill gaps (Land IQ and DWR 2021; USGS 2021). Areas identified as undifferentiated urban (Land IQ) or as open water, wetlands, forest, or developed (except for "Developed, Open Space"; NLCD) were deemed unsuitable for MAR operations and excluded from further consideration (fig. 4).

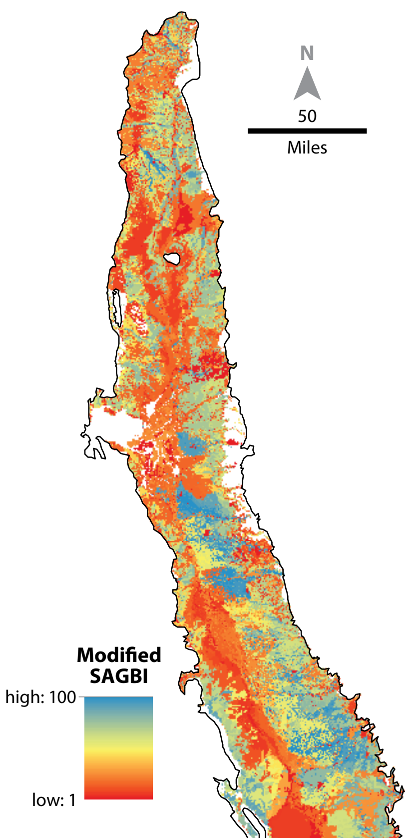

FIG. 2. Modified SAGBI for the Central Valley. A value of 100 indicates optimum recharge conditions; a value of 1 indicates recharge is unfeasible.

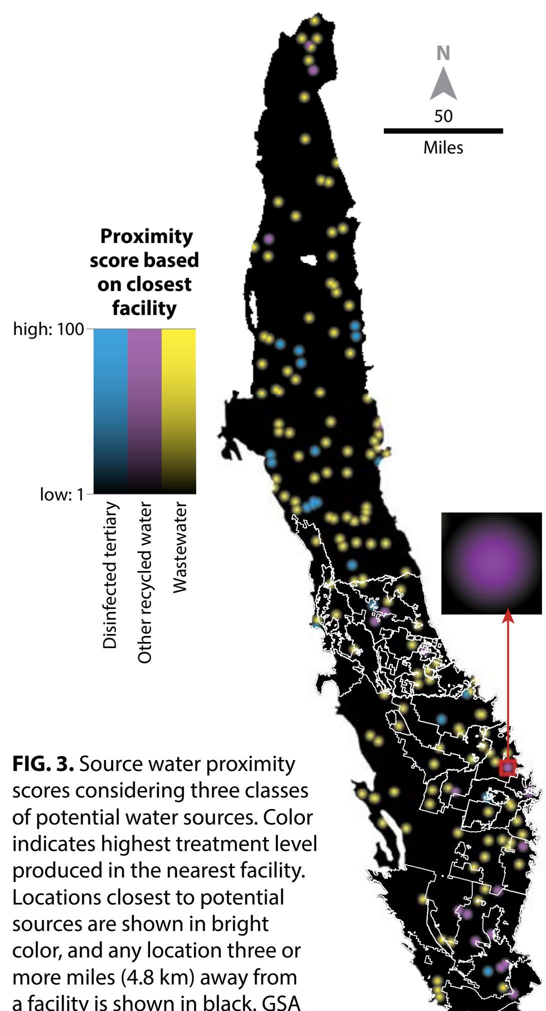

FIG. 3. Source water proximity scores considering three classes of potential water sources. Color indicates highest treatment level produced in the nearest facility. Locations closest to potential sources are shown in bright color, and any location three or more miles (4.8 km) away from a facility is shown in black. GSA boundaries outlined in white.

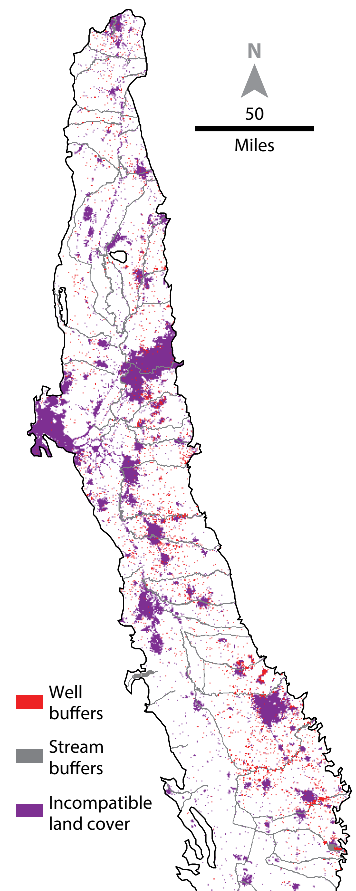

FIG. 4. Excluded locations in the Central Valley; reason for exclusion indicated by color.

We exclude some areas from consideration for MAR in order to protect drinking water sources. Recycled water MAR requires a minimum residence time between recharge and recovery for potable use (CCR 2018). Areas where surface recharge would reach a potable well or major river within a year were deemed unsuitable for recycled water MAR. Title 22 requires that recycled water undergo a 12-log virus reduction before being incorporated into a potable supply; i.e., finished water must contain one trillion times fewer active viruses than the original wastewater (CCR 2018). Six-log reductions can be credited to subsurface residence time, with 1-log reduction credited to each month spent underground (CCR 2018). Residence time demonstrated with a model as opposed to a tracer study receives only half credit; because we use a model, we considered residence times of at least one year (CCR 2018).

To determine residence times prior to arrival at wells and rivers, the groundwater system was modeled using the C2VSimFG, a finite element model that simulates surface and groundwater flows in the Central Valley (Hatch et al. 2020). Then, a particle tracker, Ichnos, was used to identify where surface recharge would arrive at any well or flow into a river within one year, by tracking backwards from the wells and rivers to the surface (Kourakos 2021) (appendix sections 4 and 5). For alternative methods, see appendix section 9.5. Any location in the Central Valley where surface recharge would reach a well or river within one year was excluded from further consideration (fig. 4). Additionally, Title 22 forbids impoundment of disinfected tertiary water, including in recharge basins, within 100 feet (30.5 meters) of a domestic well (CCR 2018). Accordingly, all wells classified as domestic were assigned a 100-foot buffer in which the land was deemed unsuitable (fig. 4).

To determine the location of domestic wells within the Central Valley, we used well completion reports (CNRA 2021). The data were quality controlled using methods by Jasechko and Perrone (2017). Records were retained for unique, active wells that produce water for human consumption (i.e., public, domestic, and transient non-community wells) with data for latitude, longitude, and completed depth (appendix section 3). Wells for other purposes were not considered for protection, because MAR uses disinfected tertiary water. Disinfected tertiary water may be used for most non-potable uses, including irrigation of food crops, without further treatment (CCR 2018). Of the 243,983 well completion records in the Central Valley, 50,031 were retained. Domestic wells received the required distance buffer, and then all classes of potable wells were evaluated using the groundwater models noted above.

Modelling groundwater transport requires knowing the screened interval of each well. Screen depths should be recorded in the Online System for Well Completion Reports (OSWCR) but are missing from approximately 45% of the retained well reports. Linear models of screen bottom depth (as a function of total well depth) and top of screen depth (as a function of bottom of screen depth) were developed for each subbasin to fill in the missing data (appendix section 3). The depths of the wells were then compared to the depths of the aquifer units used in the models. There were 3,906 wells that could not be modeled because they were either too shallow or too deep, resulting in a total of 46,125 wells included in the models. We also simulated a more conservative scenario in which the wells were modeled as fully screened to account for possible leaks in the casing (appendix section 9.3).

The majority of exclusions were due to land cover and were near major population centers, resulting in exclusion of several otherwise suitable areas. Particle tracking indicated that 1,086 wells (of 46,125) captured water within a year of its infiltration. Combining this with the 100-foot domestic well buffer resulted in the exclusion of 21 mi^2 (60 km^2) for well protection (fig. 4).

Following the exclusion of all unsuitable areas in the Central Valley, the final scores of the remaining land in the valley were divided into three equal intervals classified as “Good,” “Moderate,” or “Poor” recycled water MAR potential. (For alternative classification, see appendix section 9.4.) The total area of land with good suitability within the boundary of each of the 29 critically overdrafted GSAs with plans for MAR was compared with the area needed to meet its recharge goals, as determined from GSP project descriptions or estimated based on recharge type in cases where land needs are not defined (appendix section 7). The feasibility of meeting the stated goals was evaluated based on the availability of enough suitable land.

Water availability

The main focus of this analysis is the identification of suitable land; however, suitable land requires available water if a GSA is to consider MAR feasible. The quantity of potentially available recycled water was determined from the 2019 discharge volumes of each treatment facility in the Central Valley (SWRCB 2021a). Totals for each facility were calculated for disinfected tertiary water, all recycled water, and all effluent (including wastewater). This allows for consideration of the amount of disinfected tertiary water currently being produced, as well as the amount that could potentially be produced if existing facilities were upgraded to provide a higher treatment level. Water from the treatment facilities was divided among GSAs in proportion to the total amount of good suitability land surrounding the facility falling within their boundaries. Average annual water needs for surface recharge (excluding flood projects) were determined from estimates included in GSPs. These estimates were then compared with the amount of potential recycled water. For analyses considering water needs for different types of MAR, see appendix section 9.7.

Limitations of method

The suitability mapping process is subject to six limitations, underscoring the importance of local assessments as part of proposed MAR projects.

1. SAGBI is a powerful tool for evaluating the physical suitability of land for MAR, but it addresses only surface conditions. It does not address the ability of the underlying aquifer to store water in terms of thickness and specific yield of water-bearing units or depth to the existing water table (Fisher et al. 2017; Russo et al. 2015). While SAGBI incorporates soil salinity, it does not consider other potential contaminants that may be leached from agricultural soil, such as nitrate or pesticides, or geogenic contaminants like uranium, chromium, or arsenic (Lopez et al. 2021; McClain et al. 2019; Murphy et al. 2021; O'Geen et al. 2015). To the best of our knowledge, maps of soil contamination covering the entire Central Valley are not publicly available. (For a low-resolution analysis including estimates of groundwater arsenic and nitrate, see appendix section 9.1.) Because SAGBI was not developed for use with recycled water, it does not evaluate the potential of the soil to attenuate residual pathogens or chemicals. While MAR has been successful with a variety of source water qualities and environmental conditions, specific water quality improvements will depend on local soil properties (Bekele et al. 2011; Fox et al. 2001; Miller et al. 2006; Sharma et al. 2008).
2. Delineation of well protection buffers is limited by the resolution of reported locations and of C2VSimFG. Well completion reports submitted prior to 2015 report locations by township, range, and section, introducing an uncertainty of 0.7 miles (1.1 kilometers) to these wells' locations (appendix section 2.1).
3. C2VSimFG has an average element area of 407 acres, which is a fine resolution relative to the size of the Central Valley, but cannot capture local variations that could result in faster than expected arrival times (Gerenday 2022; Hatch et al. 2020). This is one reason for the reduced log-reduction credits assigned to modeled residence times by Title 22 and highlights the need for local testing (CCR 2018).
4. The 100-foot domestic well buffers are smaller than the 328-foot raster cells used for suitability calculations, making isolated wells effectively "invisible" (appendix section 6.2).
5. For the sake of simplicity, this analysis assumes that all water from the treatment facilities could be available for MAR; however, high quality recycled water generally already has a use from which it would need to be diverted for MAR. Consideration of the total water budget within a GSA and whether such diversion is feasible is beyond the scope of this study.
6. While linear distance to facilities is considered, it is not known whether the water can be practically transported over intervening topography.

Eastern valley most suitable

Suitability of land for recycled water MAR is dependent on recycled water proximity, as the poor proximity score of any land not within three miles of a treatment facility overrides the other factors and results in a low overall suitability score (fig. 5). The majority of land is

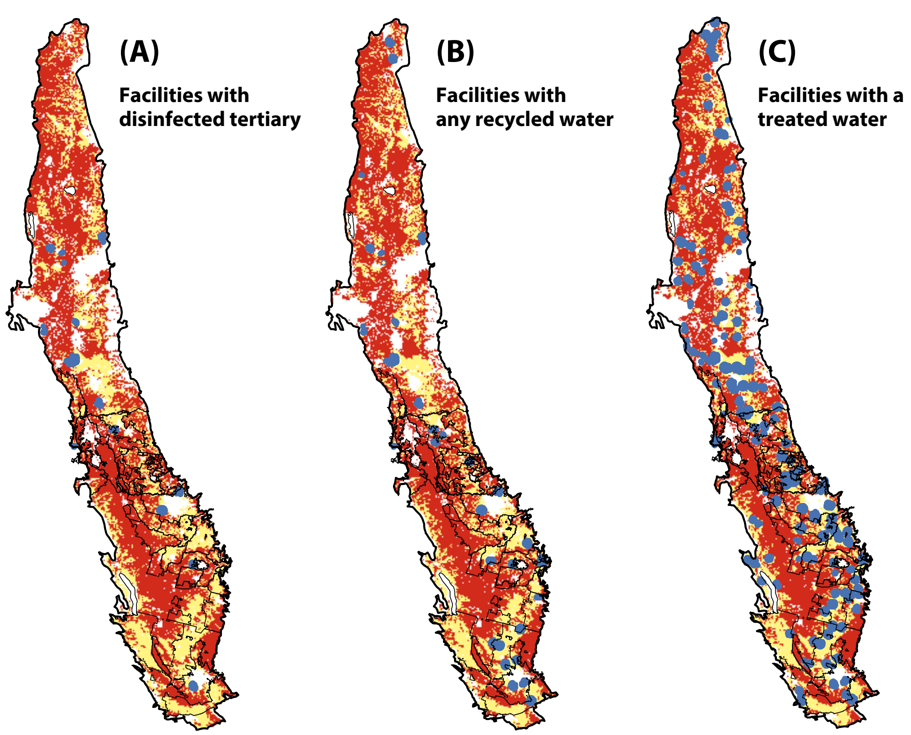

FIG. 5. Suitability of potentially available land considering (A) only facilities producing disinfected tertiary, (B) any facility with recycled water, (C) any treatment facilities, including those with only wastewater. Good areas (blue) are visually enlarged; for a map with all areas to scale or for regional maps, see appendix section 8.1.

rated as poorly or moderately suitable (table 1). Land of good suitability is more likely to be found on the eastern side of the valley, where soils tend to be better for infiltration and there is a higher density of recycled water sources. Areas in the southwest tend to be unsuitable due to a relative scarcity of treatment facilities and limited deep percolation capacity. The majority of land rated as suitable (87% to 91%) is agricultural, with deciduous fruit and nut crops making up one of the largest portions (appendix section 8.3).

If treatment plants currently producing disinfected tertiary water are the only water source, two of 29 GSAs have enough suitable land, assuming average land needs (figs. 6 and 7). If all facilities producing any kind of recycled water are considered, six GSAs have enough suitable land. If facilities only producing wastewater are also considered, an additional eight GSAs would have suitable land to meet their needs. Several others may have enough land under these water conditions if minimum, instead of average, land needs are assumed in cases where recharge areas are unspecified in GSPs (see fig. 6 upper error bars and appendix section 7).

We also assess whether recycled water could be used as a potential source to meet the water needs of MAR projects proposed within each GSP (fig. 8). The North Kings area could have access to enough total recycled water to supply its recharge goals if water treatments were upgraded. Similarly, if all treated water, including

TABLE 1. Area (mi^2; 1 mi^2 = 2.6 km^2) available to each GSA by suitability

	Facilities with disinfected tertiary			Facilities with any recycled water			Facilities with any treated water		
	Good	Moderate	Poor	Good	Moderate	Poor	Good	Moderate	Poor
Aliso Water District	0	7.6	33	0	7.6	33	0.035	7.9	33
Buena Vista	0	0.24	79	0	0.24	79	0.089	4.9	74
Central Kings	0	160	66	0	160	66	24	150	50
Chowchilla Water District	0	48	78	0	49	77	2.8	53	70
East Kaweah	0	100	68	2.2	100	64	11	97	61
Eastern Tule	0	80	140	0.25	80	140	5.0	84	130
Gravelly Ford Water District	0	3.5	9.6	0	3.5	9.6	0.0	3.5	9.6
Greater Kaweah	2.2	88	230	4.5	91	220	4.9	100	210
James Irrigation District	0	0.9	42	0	0.9	42	0	6.7	37
Kern Groundwater Authority	0	890	580	21	880	570	34	870	570
Kings River East	0	170	100	5.9	160	98	20	150	94
Madera County - Chowchilla	0	14	52	0	16	50	0.097	17	49
Madera County - Madera	0.11	49	190	1.4	58	180	5.0	67	170
Madera Irrigation District	0	110	94	0.94	110	89	15	120	68
Madera Irrigation District, City of Madera	0	1.9	2.2	0	1.9	2.2	1.8	2.2	0.14
McMullin	0	73	110	0	73	110	4.5	77	100
Merced County	0	1.7	0.12	0	1.7	0.12	0	1.7	0.12
Merced Subbasin	0.78	140	320	3.3	150	310	11	160	290
Mid Kaweah	0.86	18	98	0.86	18	98	1.3	26	90
Mid Kings River	0	77	57	2.7	80	52	7.8	76	50
New Stone Water District	0	0.31	6.2	0	0.31	6.2	0	0.31	6.2
North Fork Kings	0	36	220	0	36	220	0.98	45	210
North Kings	5.9	160	150	5.9	160	150	18	160	130
Northern and Central Delta-Mendota	0.37	96	310	0.37	96	310	2.9	110	300
San Joaquin River Exchange Contractors Water Authority	0	25	360	0	25	360	1.1	36	350
South Fork Kings	0	17	85	0	17	85	0.10	30	72
South Kings	0	2.4	1.0	0	2.4	1.0	1.5	1.6	0.34
Tri-County Water Authority	0	41	53	0	41	53	0.089	41	53
Triangle T Water District	0	0.86	22	0	0.86	22	0	0.86	22
Central Valley total	**25**	**5,500**	**11,000**	**87**	**5,500**	**11,000**	**400**	**5,900**	**10,000**

Highlighting indicates type of facilities necessary to meet land needs:
☐ = current facilities with disinfected tertiary, ☐ = facilities with any recycled water, ☐ = facilities with any treated water (including wastewater), ☐ = needs not met.

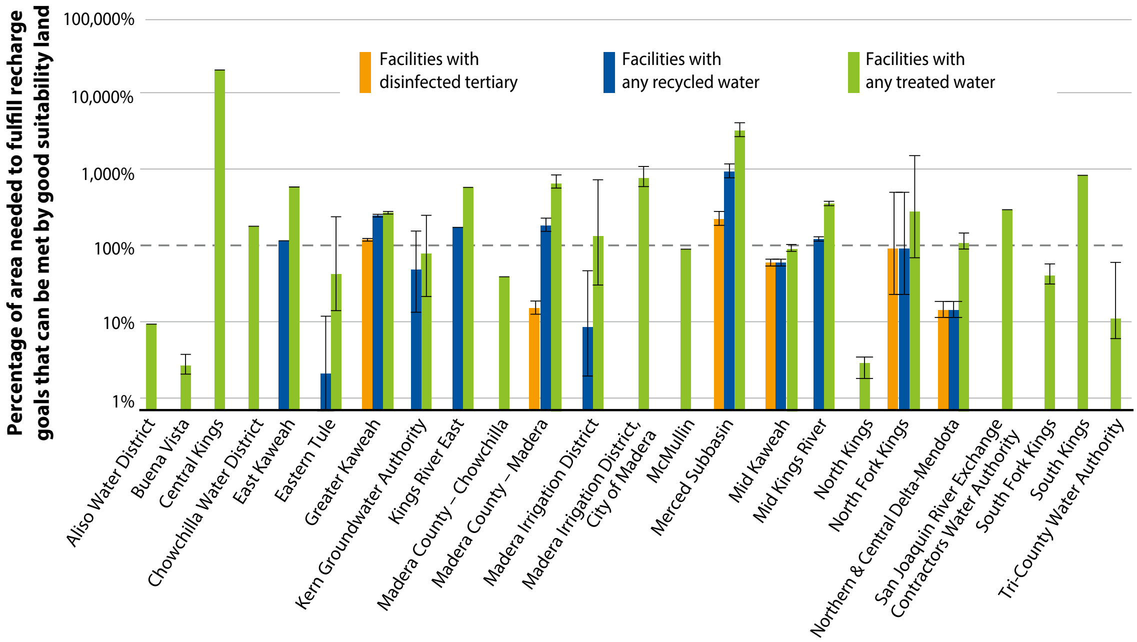

FIG. 6. Land with proximity to facility assessment. Percentage of area needed by each GSA to fulfill recharge goals that can be met by good suitability land, considering proximity to different types of treatment facilities (e.g., facilities with disinfected tertiary, facilities with any recycled water, and facilities with any treated water). Some plans did not explicitly state land needs; for these plans, we estimated a mean, minimum, and maximum amount of land based on proposed MAR projects. For these GSAs, bars represent the mean land; minimum and maximum estimated land requirements are shown with error bars. GSAs without suitable area not shown. Dashed line indicates that 100% of area needed to fulfill recharge goals can be met by good suitability land within proximity to treatment facilities.

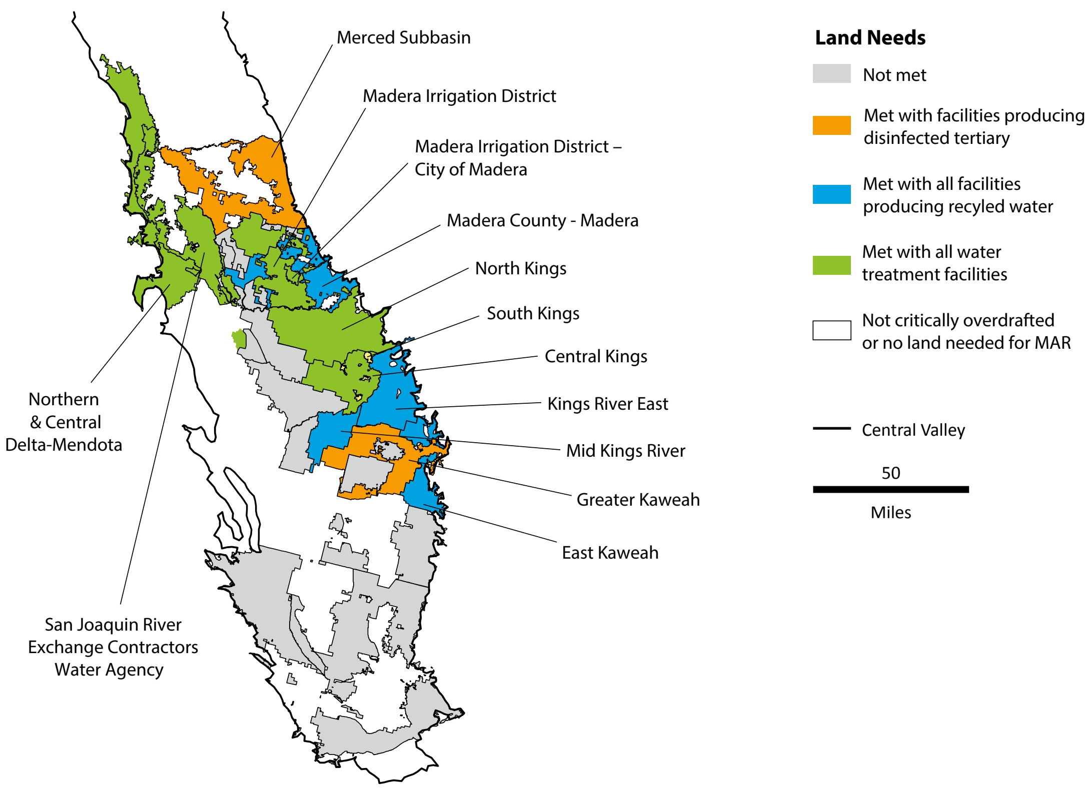

FIG. 7. GSAs by most conservative scenario in which land needs can be met (if any). GSAs needs met by: disinfected tertiary facilities only shown in orange; all facilities with any recycled water shown in blue; and all treatment facilities, including those with only wastewater, shown in green. GSAs without enough suitable land given their current facilities shown in gray.

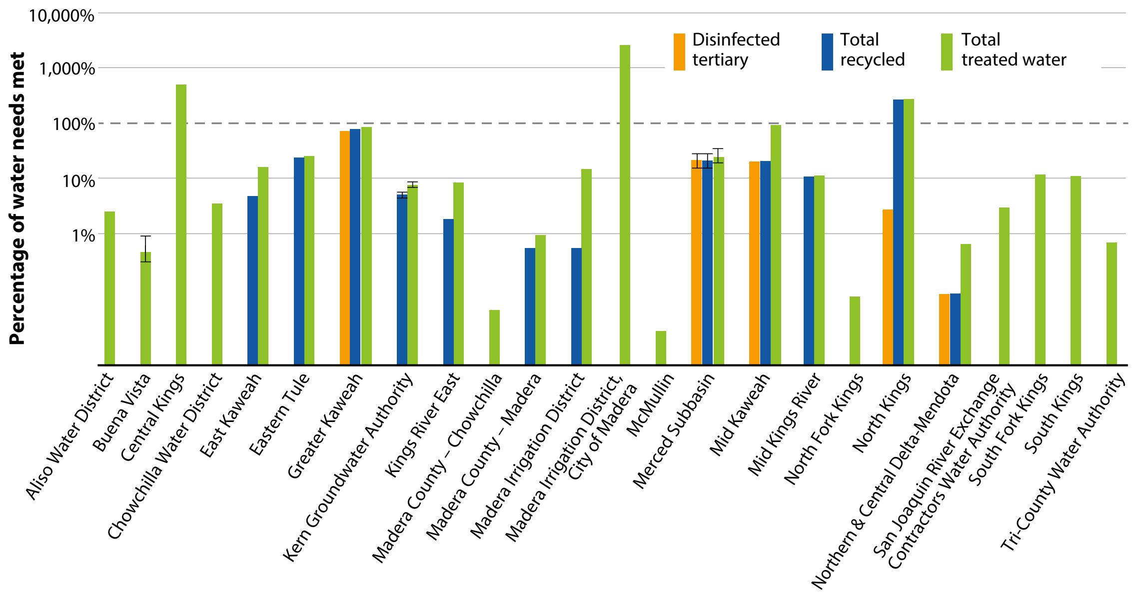

FIG. 8. Water needs assessment based on recharge goals set in GSPs and types of water produced in facilities near or within each GSA. Percentage of water needed by each GSA to fulfill recharge goals that can be met by different types of available water, assuming treatment processes can be upgraded where needed. Some plans did not explicitly state water needs; for these plans, we estimated a mean, minimum, and maximum amount of water based on proposed MAR projects. For these GSAs, the bars represent the mean; minimum and maximum estimated water requirements are presented with error bars. GSAs without available water are not shown. Dashed line indicates 100% water needs are met by available water.

wastewater, is considered, North and Central Kings, as well as Madera Irrigation District – City of Madera, could access enough recycled water to meet their goals. These three GSAs also have enough potentially suitable land when all facilities are considered. Sensitivity analyses considering water needs for different types of projects yield the same result in terms of which GSAs have sufficient recycled water but do show a difference in terms of how close some GSAs are to meeting their goals (appendix section 9.7).

Increasing recycling capacity

Local recycled water availability is the most limiting factor in siting recycled water MAR projects. This is evident from the fact that recharge for recycled water MAR projects tends to be conducted at the treatment facility, and many MAR operators cite limited water availability as their greatest challenge (Al-Otaibi and Al-Senafy 2004; Bennani et al. 1992; Lopes and dos Santos 2012; Perrone and Rohde 2016; Pi and Wang 2006). In order for a project to be successful, suitable land and water must be available in the same location. Constructing or retrofitting facilities to produce disinfected tertiary water can result in more potential for recharge. Costs of upgrading wastewater treatment plants to produce recycled water suitable for MAR may range from \$140,000 to \$620,000 per acre-foot over 30 years (Cupps and Morris 2005). If patterns of groundwater extraction remain the same, increased water recycling capacity will likely be needed to balance overdraft in the Central Valley. Depending on the degree of future recycling and groundwater depletion, such efforts may be able to offset 41% to 94% of groundwater depletion statewide by 2030 (Badiuzzaman et al. 2017). Over the period of 2005–2018, the average decline in groundwater storage in the Central Valley was between 8,600 and 20,900 thousand acre-feet per year (Springhorn et al. 2021). Total effluent produced by treatment facilities in the Central Valley in 2019 was only enough to offset 3% to 7% of this deficit (SWRCB 2021a). The majority of facilities currently producing disinfected tertiary water in the Central Valley are not located in critically overdrafted basins (fig. 3); however, they may provide a future opportunity for lower priority basins as they continue to develop their water management strategies.

Transporting water

It is possible to recharge farther from the source if transporting water is more feasible than obtaining suitable land nearby or if a regional facility distributes water to many decentralized sites. For instance, the Chino Basin Recycled Water Groundwater Recharge Program distributes recycled water to 11 infiltration sites distributed throughout Chino Basin (Campbell and Fan 2021). When completed, the Metropolitan Water District of Southern California's Regional Recycled Water Program will deliver recycled water for recharge through 60 miles (96.6 kilometers) of pipe to four regional groundwater basins (MWD 2016).

Major factors influencing the maximum acceptable distance include local land values and the cost and energy use of transporting water (Bradshaw and

Luthy 2017). Costs of land acquisition for recharge basins and conveyance rights-of-way estimated in GSPs range from $15,000 to $42,000 per acre, resulting in normalized costs of $5 to $42 per acre-foot of recharge over a 30-year period (Aliso Water District GSA 2020; Central Kings GSA 2019; McMullin Area GSA 2019; South Kings GSA 2019). Factors including the availability of existing conveyance networks and topography along the transport route affect costs (Fournier et al. 2016; Trussell et al. 2012). The cost of constructing new conveyance systems has been estimated at $2.3 to $34 million per mile or $25 to $1,100 per acre-foot, while the operation and maintenance costs range from $25 to $29 per acre-foot per mile (Bradshaw and Luthy 2017; Cooley and Phurisamban 2016; McMullin Area GSA 2019). Water savings due to recycled water MAR may be negated by water consumption for power generation if excessive uphill pumping is required to move recycled water (Fournier et al. 2016). Recycled water MAR projects more than one to two miles (1.6 to 4.8 kilometers) from their source tend to make use of gravity flow or are integrated with a wastewater system (Hutchinson 2013; Johnson 2009; Kanarek and Michail 1996; Page et al. 2010).

Local siting decisions

Although this study demonstrates the power of suitability mapping and groundwater modeling for evaluating large land areas for potential recycled water MAR, selecting locations is best done at the local level. GSAs are more likely to know the status and exact locations of wells and availability of land and water. If a GSA does not have a source of recycled water within its boundaries, it will have to negotiate with other entities. This is not surprising, as water recycling projects often require partnerships with multiple agencies, but it could be a challenge if another GSA already has plans for the water (Sokolow et al. 2019). Additionally, while mapping is a useful tool for selecting candidate sites, any recycled water MAR project will require local soil studies, pilot testing, and tracer experiments before operating at scale, as well as a series of permits to ensure minimal social and environmental impacts (Ulibarri et al. 2021).

Competing uses of water

Finally, the value of groundwater recharge must be weighed against that of other uses for water and land. For instance, 700,000 acre-feet (860 million meters^3) of recycled water was used for irrigation in California in 2019, comprising 50% of total reported reuse (SWRCB 2021a). In addition, surface outflows from treatment plants can support riparian ecosystems (Rohde et al. 2021). Currently, the majority of suitable land in the Central Valley is in use for agriculture. Growing seasons, as well as limits on how long perennial crops can

An aqueduct and water tower in the San Joaquin Valley. Upgrading water treatment facilities to produce a higher class of recycled water increases the number of locations in the Central Valley where recycled water MAR is possible. *Photo*: JohnnyH5, iStock.com.

tolerate flooding, place restrictions on the total time infiltration can occur on active farmland (Ganot and Dahlke 2021). Recharging recycled water on agricultural land is still largely unexplored (Grinshpan et al. 2021). Given the scarcity of available recharge water, it is unlikely that there will be an excess at times when MAR is impossible. Furthermore, the relative predictability of recycled water supplies can facilitate planning of water allocations (Perrone and Rohde 2016; SWRCB 2021a). Nevertheless, focusing recharge efforts on agricultural areas may require land fallowing. This can assist in bringing water budgets into balance and benefit habitats, but it will be expensive and require compensating farmers (Bourque et al. 2019). (For required MAR area broken down by whether plans include on-farm recharge, see appendix section 9.6.) Given that fruit and nut crops are among the state's most valuable, the cost of acquiring land may be high (CDFA 2021).

More recycled water necessary

Although recycled water MAR is feasible in many locations in the Central Valley, more recycled water sources are necessary to implement these recharge solutions across the valley. Currently, six GSAs have enough suitable land to meet their recharge needs with recycled water MAR, but none of them have enough suitable water. Upgrading treatment plants could increase the capacity that recycled water MAR could contribute to GSAs. Highly populated areas are more likely to have access to recycled water but tend to have less suitable land and a greater density of wells. Suitability mapping and particle tracking are useful tools for GSAs considering recycled water MAR. However, these areas will need infiltration studies and tracer tests to ground truth results and receive project approval. Recycled water MAR can help GSAs that have sufficient suitable land and access to water achieve their recharge goals, enabling them to comply with the Sustainable Groundwater Management Act and maintain a sustainable water supply. CA

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RESEARCH ARTICLE

Youth participatory action research: Integrating science learning and civic engagement

Youth participatory action research provides a meaningful approach to science learning and raising critical consciousness.

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Abstract

Strengthening young people's scientific literacy and civic engagement are important educational goals for Cooperative Extension. We implemented youth participatory action research (YPAR) projects over three years at five schools. The YPAR approach integrates science learning and civic engagement by empowering youth, with the help of adult facilitators, to decide upon a community issue to research, design and implement their research, and then plan a service project based on research findings to address the issue. We explored young people's and educators' perspectives on which project elements influenced youth participation, examined opportunities for youth science and civic-related learning, and asked educators to reflect on their own learning and development. Using data generated from youth focus groups and educator interviews, we found that YPAR grounds science learning in young people's lived experience. It also provides a meaningful approach to science learning through raising young people's critical consciousness of community issues. YPAR may be used in other extension programs to increase motivation for deeper and sustained participation in learning experiences.

Young people are faced with complex social, economic, and environmental issues, requiring them to become scientifically and civically engaged; their willingness to participate in public discourse is essential to the healthy functioning of democracy (National Academy of Sciences 2007; Rudolph and Horibe 2015). The University of California 4-H Youth Development Program has a role to play in providing youth with meaningful science learning that helps them make consequential contributions to personally and socially relevant issues.

Deepening scientific literacy

School-based science has an important role in improving young people's scientific literacy. However, despite new national standards (NGSS Lead States 2013), standardized testing has revealed low scientific literacy among youth in the United States, which has been stagnant for decades (NCES 2016). Scores on standardized tests have shown that youth at all grade levels

A 3-year UC study found that youth participatory action research (YPAR) is a promising model to engage youth with science learning while helping to prepare them to become both scientifically and civically engaged. *Photo*: National 4-H Council/Ben McKeown.

— elementary, middle, and high school — need to improve (NCES 2016). Additionally, the amount of time dedicated to science instruction in U.S. elementary schools is minimal (Blank 2013; NRC 2021). Further, there is too much use of didactic teaching methods, which have been shown to be largely ineffective for deepening scientific literacy (Rivera Maulucci 2010; Upadhyay 2021). In addition, educators are not well prepared to use effective experiential teaching methods (Banilower 2019). These challenges have limited young people's opportunities to prepare for the workforce and to engage in science-related public issues (Roth and Barton 2004). Furthermore, students — especially students of color — often find that science education minimizes involvement in authentic community issues, deemphasizes knowledge of and sensitivity to cultural diversity, and seldom brings awareness to structural inequity of science-related issues (Aikenhead 2006, 2022; Bottie et al. 2021; Jones and Burrell 2022).

Youth spend a great deal of time learning outside of a classroom (Banks et al. 2007; Falk and Dierking 2010). There is a growing recognition about the value of informal science learning (NRC 2009). Approaching science from a community perspective may give voice to youth and expand their access to science-related civic engagement (e.g., activism, public engagement, informed decision-making). Smith et al. (2015) argue that a critical component for advancing scientific literacy is offering youth authentic, community-based opportunities to apply science to real-world issues.

Critical consciousness

Our society needs civically engaged individuals who are able and willing to participate in public discourse. Young people have historically been limited in their forms of civic engagement, particularly when confronting social injustices (Kirshner 2015). There is a tendency to minimize young people's reflecting on "the structural awareness of social inequality and the ways in which historical processes perpetuate modern day disparities" (Diemer et al. 2021).

Supporting youth in deepening their civic engagement to confront and act against injustices can be accomplished, in part, by strengthening their critical consciousness (Gonzalez et al. 2020). Critical consciousness is developed through a cycle of reflection and action that strengthens three core components: critical reflection (awareness of social inequities), political efficacy or critical motivation (perceived ability to enact social change), and critical action (making change by participating in social activism) (Christens et al. 2016; Watts et al. 2011). Critical action involves addressing collective problems through joint action, mobilizing political pressure, and participating in both formal activism (attending public meetings, protesting, voting) and new forms of expression, such as forming online affinity groups (Bennett 2008).

Youth brainstorming action ideas for their project. The YPAR curriculum included developing a research plan, practicing data collection skills, conducting research, and analyzing data. *Photo*: Steven Worker.

Youth participatory action research

Youth participatory action research (YPAR) is a program model that combines science and civic engagement, where youth conduct research and then act to improve their lives and communities (Cammarota and Fine 2008; Mirra et al. 2016). In YPAR, youth explore and determine a research topic relevant to their lives; design and implement the research (including choosing methods, collecting and analyzing data, interpreting and sharing results); and then plan an action project based on their research findings (e.g., sharing results with decision-making bodies). Relationships between youth and adults constitute a core element of YPAR. This is referred to as the pedagogy of relationships (Mirra et al. 2016) and is conceptualized in positive youth development as developmental relationships (Scales 2018). The important aspect is the presence of supportive, caring adults who are willing to share power and establish productive youth-adult partnerships (Zeldin et al. 2013).

YPAR has shown benefits in strengthening scientific literacy and critical consciousness. Scorza et al. (2017) implemented YPAR in iterative cycles, in which young people administered surveys and presented findings, and argued that the youth were better able to "name their world in order to change it" through this process. Scott et al. (2015) found that YPAR helped students become change agents by supporting them in developing authoritative voices, renegotiating identities as a social process of belonging, and beginning to envision their role in creating a more just world. Reich et al. (2015) found that, through partnering with youth as researchers, a team generated new ideas in solving issues with public schooling that likely would not have been conceived by adults alone.

Given the growing base of literature on the value of YPAR, we found it surprising that it has not been widely adopted in 4-H and is only now emerging in other Cooperative Extension programs (such as UC CalFresh Healthy Living). Additionally, there are gaps in the literature about key pedagogical elements that influence youth participation, and thus their opportunities for learning. Almost absent from the literature are YPAR educators' reflections on their own learning and growth, which is a key strategy to advancing effective teaching (Sellars 2012).

Investigating YPAR outcomes

The purpose behind our research was to advance knowledge about the core pedagogical elements that help YPAR become a successful program model to engage youth in science learning and civic engagement. Our research objectives were to explore young people's and educators' perspectives on (1) key YPAR project elements, influencing youth participation, (2) opportunities for youth science and civic-related learning, and (3) educators' own learning and development.

Curriculum and participants

We implemented YPAR projects over three years at five schools with youth of color (see table 1). Educators were Cooperative Extension employees. Most educators were Latino or Latina; one was Asian. Educators were trained in the Community Futures, Community Lore curriculum (UC Davis 2021). The curriculum included support for the educator and youth getting to know each other, then choosing a focus, developing a research plan, practicing data collection skills, conducting research, analyzing data, creating a shareable product, and taking action to address their chosen topic.

Programs were implemented weekly during the school year for 60 to 90 minutes each session. Youth identified their own research topics; the only criterion was that it be a social or environmental issue. In practice, YPAR sessions were facilitated by the adult educator, with each session involving activities from the curriculum. Groups were facilitated in English, with the exception of Site 1, which was facilitated in Spanish. Activities were experiential, with youth actively involved in large and small group discussions, simulation activities, and independent work. Youth cohorts spent time identifying their own research topics with no constraints; youth were encouraged to select any environmental, economic, or social topic. Educators emphasized verbally that youth would be engaging in science research on their topics to plan for an action/service project. Youth identified topics that included creating an after-school club for learning and practicing English; reducing school cafeteria "fake food"; adding an ethnic studies class to school course options; addressing community racism and bias; and raising awareness on Native American history and accomplishments (table 1).

Developing patterns of meaning

Our research was exploratory, operating within a social constructivism epistemology, with a goal to "rely as much as possible on the participants' view of the situation" (Creswell and Poth 2018). We sought to "inductively develop a . . . pattern of meaning" rather than starting from a theory (Creswell and Poth 2018). Thus, we employed a multi-site, semi-structured interview design to solicit adolescent and educator meanings and experiences (Krueger and Casey 2015;

TABLE 1. Site descriptions, data sources, youth demographics, and YPAR research topics

Site	Grades	During or after school	Number and length of sessions	Youth	Data generated	Youth-identified research topic
1	High school	Y1: During	Y1: 23 (75min)	Y1: 16 (16 Latinx; 6 female/10 male)	Y1: 4 youth focus groups & 1 educator interview	Increasing afterschool options for learning the English language
		Y2: After	Y2: 8 (75min)	Y2: 10 (10 Latinx; 4 female/6 male)	Y2: 4 youth interviews & 2 educator interviews (same educators as Site 4 Y2)	
2	Middle school	Y1: After	Y1: 11 (90min)	Y1: 4 students (4 Latinx; 4 male)	Y1: 1 youth focus group	Reducing school cafeteria "fake food" and increasing healthy options
		Y2: After	Y2: 12 (60min)	Y2: 7 students (5 Latinx, 2 African American; 5 female/2 male)	Y2: 1 educator interview (same educator as Site 3 Y2)	
3	High school	Y2: During	Y2: 13 (60min)	Y2: 11 students (5 Latinx, 2 African American, 4 non-identified; 6 female/5 male)	Y2: 1 youth focus group & 1 educator interview (same educator as Site 2 Y2)	Adding an ethnic studies class to school course options
4	High school	Y2: After	Y2: 12 (60min)	Y2: 8 (5 Latinx, 1 African American, 2 White; 5 female/3 male)	Y2: 2 youth interviews & 2 educator interviews (same educators as Site 1 Y2)	Y2: Addressing community racism and implicit bias
		Y3: During	Y3: 21 (60min)	Y3: 14 (8 Latinx, 1 African American, 3 White, 2 Asian; 10 female/4 male)	Y3: 2 youth focus groups & 2 educator interviews	Y3: Strengthening how local businesses work with and serve teenagers
5	High school	Y3: After	Y3: 24 (60min)	Y3: 12 (10 Asian, 2 Asian & White, all female)	Y3: 1 youth focus group	Raising awareness on Native American history and accomplishments

Y1 = Year 1 2018–2019; Y2 = Year 2 2019–2020; Y3 = Year 3 2020–2021.

Weiss 1994). During spring 2019, 2020, and 2021, the authors conducted educator interviews individually and youth focus groups in small groups. We developed semi-structured interview protocols, with 16 educator prompts (see Appendix A online) and 10 youth prompts (Appendix B). Interviews were recorded and transcribed. In total, we conducted six educator interviews (Year 1: one interview, Year 2: three interviews, and Year 3: two interviews) and 15 youth focus groups (Year 1: five focus groups, Year 2: seven focus groups, Year 3: three focus groups). Note that, due to the COVID-19 pandemic, Years 2 and 3 interviews were conducted remotely using a virtual meeting platform; thus, chat logs (when used) were also included as a data source.

We applied thematic analysis to anchor our inquiry in the data (Braun and Clarke 2006; Braun and Clarke 2022). Thematic analysis is a flexible analytical method for constructing themes in qualitative data (Terry and Hayfield 2021); it has been applied in a wide range of disciplines, including social sciences (Braun et al. 2019). The authors were experienced with applying thematic analysis to qualitative interview data.

The first four authors analyzed transcripts collaboratively using a consensus-based and systematic process designed to emphasize diverse perspectives. The first analytical steps were coding the 2019 educator transcripts and developing independent codes. These codes were used as a sensitizing lens for developing codes for the 2019 youth transcripts. The four researchers then discussed their reasoning and the evidence relied on for code development and application. To analyze the 2020 and 2021 educator and youth transcripts, one author served as the primary coder, with the other three authors as secondary reviewers. We then met to reach consensus on code application, a form of accountability to reach inter-coder agreement. Additionally, when an analytical decision was made — for example, the conditions under which a code was applied to text — the primary coder was responsible for returning to earlier transcripts to ensure appropriate code application. We originally had one code for "science learning," which we then further analyzed using Smith et al.'s (2015) definition of scientific literacy, looking for evidence of youth reflecting on their experiences in relation to content knowledge, reasoning skills, attitudes and interest related to science, and authentic contributions. See table 2 for a final list of themes and codes.

The second analytical step was to segment the data for deeper analysis across sites. Text excerpts for each code were combined from each transcript (denoted with youth/adult, site name, and year). One researcher was assigned to each code to identify patterns across sites, supported by evidence. Each researcher completed an analytical memo for his or her assigned codes (Merriam and Tisdell 2016). These memos were presented to the team for discussion and reinterpretation; the memos went through several versions before the team reached consensus.

Learning and engagement

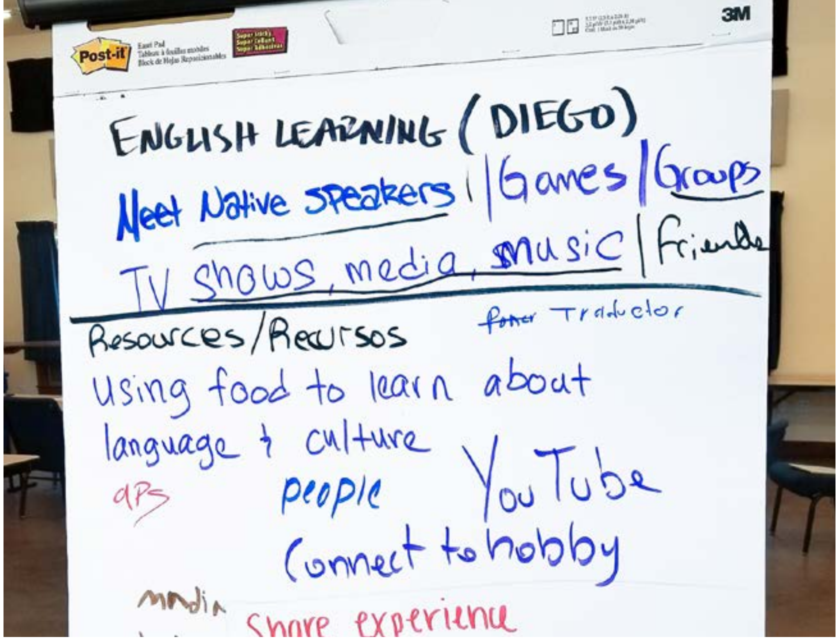
We discuss findings in three parts aligned with our research objectives: (1) young people's and educators' perspectives on key YPAR project elements influencing youth participation, (2) opportunities for youth science and civic-related learning, and (3) educators' reflections on their own learning and development. We replaced real names with pseudonyms.

An emergent finding was the importance of topic selection. Young people reported that they were more motivated to participate when the topic reflected something relevant in their lives. All cohorts selected topics influenced by their personal experiences, which

TABLE 2. Emergent codes and themes*

Theme	Codes
YPAR process and elements	• Youth (psychological) ownership of YPAR • Topic reflecting youths' lived experience (voiced connections between YPAR and youth lives) • Pandemic impacts • Affordances, constraints, or influence of setting (personal or cohort)* • Implementation of the YPAR curriculum (motivation to join, stay/leave, or curricular lessons)*
Educator roles and learning	• Educator-as-resource (roles) • Educator preparation* • Educator learning and growth
Science learning	• Science-related content • Reasoning skills, science practices • Science-related interest, attitudes, and motivation • Science contributions, applications, real-world connection
Critical consciousness (civic engagement)	• Critical reflection (self-awareness, social awareness, global awareness) • Critical motivation (political efficacy, perceived ability and capacity to enact change) • Critical action (actively seeking to make change)
Youth development*	• Youth development (confidence, youth voice, sense of agency, empowerment) • Social connection (peer-to-peer or educator-to-peer)

* The table includes all codes and themes identified during data analyses; however, we only report on those related to our three research objectives.



Student inquiry questions. Young people reported that they were more motivated to participate when the topic reflected something relevant in their lives. *Photo*: Steven Worker.

were directly related to the power dynamics within their school and community. For example, recent immigrant youth (Site 1) experienced a classroom environment that did not sufficiently meet their need to learn English, a skill they recognized as necessary for learning and social acceptance. Youth at another location (Site 3) identified racism through their own direct experiences and an awareness of similar experiences by other youth of color. These youth took risks to address issues that are meaningful and relevant to their lives, have larger social and cultural implications beyond their own communities, and represent forms of structural inequities and injustices. The significance of topic selection was evident; young people voiced displeasure when the selected topic was something they were not interested in.

> *Make sure everyone is engaged and find the topic interesting to them because they're not gonna care about the project and making something happen if they're not interested. — Naomi (Site 4, 2021)*
>
> *^Exactly. — Joey (Site 4, 2021)*

Educators' influence

Youth and educators both described various roles the adult educators played that either promoted or constrained youth participation, as well as shaping the YPAR process and outcomes. Youth reported that educators acted as mentors. The young people also reported that they felt they were able to relate to the educators in different ways, such as their similar or shared ethnic background, cultural experiences, and age. Youth viewed educators as listeners who provided guidance in their YPAR experiences.

> *I think I was placed in a very unique position just because of my age . . . So I really never saw myself as a teacher, more of a mentor just because I've been in their position more closely than [co-educator name] has. — Malcolm (educator, Sites 1 and 4, 2020)*

As mentors, the educators facilitated YPAR while allowing youth to make decisions and take ownership of their projects. Educators mentioned that bilingual ability helped them serve as translators for open communication and as a resource to provide support for the youth. Besides shared language, educators also described shared personal cultural experiences that enabled them to relate to youth, and vice versa, which also afforded them opportunities to facilitate open conversations. An educator reflected,

> *And a lot — most of the students I had were of a Hispanic background . . . so, especially since I can relate because I'm from this background as well. — Alina (educator, Sites 2 and 3, 2020)*

The ability of educators to serve as a cultural translators helped them explain and relay information in a way that was understandable and relatable to youth (e.g., technical scientific terms and concepts). Furthermore, throughout the YPAR process, educators provided the time, space, and flexibility for youth to discuss matters that were both related and unrelated to the project. Establishing a safe space allowed for trust to develop between educators and youth, resulting in successful YPAR experiences.

> *It was these students who come from very, like, diverse backgrounds and sometimes don't have that person . . . in their school to say, "Hey, I got you" or "Hey, I'm listening" — like actively listening . . . and actually validates your thoughts and feelings . . . instead of just passively. — Alina (educator, Sites 2 and 3, 2020)*

Pandemic impacts

Encouraging and maintaining youth engagement and motivation was a key focus for educators, especially when the COVID-19 pandemic forced the shift from in-person to virtual programming in the middle of the 2020 school year. During this shift, educators described being flexible and learning ways to adapt the curriculum to time, space, and technology limitations. For example, educators described adding interesting activities from other curricular resources to supplement the primary curriculum and shortened certain activities to allocate more time for youth to work on their projects, in order to keep them motivated. Additionally, educators felt uncertain about youths' ability to understand the material through online interactions; as a result, educators adopted different practices. For example, one educator shared that, when sessions were virtual, he did a lot more speaking than the youth did. Furthermore, educators described using a lot of flexibility and patience in adapting to virtual programming.

> *Be patient with the students. Everybody was dealing, or still kind of dealing with virtual remote learning. And yeah, really reach out to those quiet kids early on . . . really reach out more and listen,*

do something that elicits their responses . . . don't worry so much about how fast you're going but worry about making sure everybody's coming up along. — Derek (educator, Site 4, 2021)

Educators also described celebrating small victories with youth and providing them with recognition for work being done, to keep youth engaged and motivated in their YPAR projects. This was important for both in-person and online programmatic platforms.

Learning by doing

Young people shared that their participation in YPAR helped them strengthen their scientific literacy as it relates to social science issues, including all four aspects of scientific literacy (Smith et al. 2015): content knowledge, scientific reasoning skills, attitudes and interest, and applied participation.

At all sites, young people reported that their prior experience, identity, and culture informed the selection of a group research topic. Both educators and youth reflected that their topics had saliency in the young peoples' lives and reflected their passion for creating change; e.g., more relevant methods to learn English (Site 1), improving food options (Site 2), and addressing racism and bias (Sites 3 and 4). The youth-identified topics were social science issues, cross-disciplinary, and personally meaningful.

See that fake cafeteria food, they just heat it up; but when you actually want to cook the real food, you have to actually, like, use time and actually know when it's like done. They [school administration] should spend less money on the equipment [physical education] and all that because it's still in pretty good shape and more on food, like actual food. — Mike (Site 2, 2019)

Youth reported engagement in science practices, most notably exploring existing literature (conducting background research to see what others had done before, looking up previous empirical research, data collection tools, and findings), designing and collecting data through surveys and interviews (methodology), and learning that research methods would vary based on the research question.

It would just be a different procedure [for another topic] compared to like the food [topic]. — Eurico (Site 2, 2019)

Educators observed and recognized youth participation in various science practices, including selecting appropriate methods for data collection and analyses. For example, one educator shared about the young people's survey methods.

We talked about all the research methods, and surveys seemed to be the most effective one for them to . . . answer their research project question. — Derek (educator, Sites 1 and 4, 2020)

When asked how they saw youth develop scientific practices, another educator responded about quantitative data analysis.

Doing data analysis, getting the surveys and putting them into a graph or a nice chart for it to be, like, aesthetically pleasing, but also being able to grasp the idea that's at hand. — Alina (educator, Sites 2 and 3, 2020)

Another educator observed that youth learned the value of using science to address a research topic.

When we looked at the data, when we analyzed the data . . . I think that's where the students learned the value and the impact that this program — these survey questions — can be valuable to our research question. — Malcolm (educator, Site 4, 2021)

Passionate about change

While youth recognized that they were engaged in science practices, they said that the science itself was not the primary aspect that excited or motivated them to join or stay in the program. Youth were passionate about creating change in their community around their identified topic. Science was one tool to help achieve that change. When youth were asked "what was interesting?" almost all spoke about science in relation to their research topic.

The project we did was interesting because we collected information from people to be able to understand . . . the best methods to learn English. — Barrett (Site 1, 2019)

I really enjoyed seeing all our efforts coming to fruition [raising awareness of Native Americans] . . . and how much we've learned through different methods. — Takara (Site 5, 2021)

Using science to solve problems

Youth reported that science methods may be used to help solve problems or provide answers. They recognized that they could apply science to issues that directly impacted and were relevant to them. The YPAR model, coupled with the participants' lived experiences (e.g., recent immigrants learning English at Site 1; a shared racist experience at Site 3), led to the selection of a topic and helped youth see how they might make change using science. An educator commented that youth saw a connection between their topic and science:

So, deducing the problem was really scientific because they've got to understand their community and everything surrounding it and see and as they chose bias and racial — racial bias . . . What questions can we formulate to do some research for ourselves and definitely try to help the community *understand the problem at hand? — Malcolm (educator, Sites 1 and 4, 2020).*

Youth also demonstrated a growing ability to reflect critically upon social structures experienced by marginalized groups. When asked what kinds of problems can be addressed through science, a youth responded:

The program helped us analyze the problems of society, and if we would teach it to someone else, I think they would be equally equitable with all people. — Damiãn (Site 1, 2019)

Youth reported that science methods may be used to help solve problems or provide answers. They recognized that they could apply science to issues that directly impacted and were relevant to them.

Having youth and adults reflect on this fourth dimension of scientific literacy was surprising to the researchers. It was noteworthy that young people began to see science not as a discrete subject but rather as a tool for social transformation. Young people were appropriating scientific tools to better understand and change their world and using science practices as a means for critical reflection and action.

Reflecting on social issues

Youth reported growing in their ability to analyze and reflect on social issues and injustices; in other words, they developed critical consciousness to varying degrees. Critical consciousness manifested differently across the sites. Youth articulated experiences of attending school and living in their communities, and an increased awareness of how their participation in YPAR might be used to address and create change.

A lot of discrimination on the part of people who tell you that you are less for not knowing how to speak the language [English], because this is a country where only that language is spoken, or it is the main language of the country. And you could have regular classes as a normal student, so to speak, for the ones who do speak the language. — Julia (Site 1, 2019)

For example, Site 1 youth had an immediate need to learn English to help them navigate and be accepted in a new country. Their immigration status and language acquisition may have impacted their ability to critically analyze school structures. That is, Site 1 youth sought out-of-school activities to learn English as opposed to addressing the inadequacy of the school's language acquisition program. In contrast, youth at the other school sites were grounded in their place of residence and therefore were more able to critically analyze social forces that revealed inequitable structures and practices that helped guide their topic.

Improving teaching practices

Educators shared that they improved their awareness and abilities in facilitating youth development and science education using the YPAR approach, especially in youth leadership and youth-adult partnership. The YPAR process was a shift from a traditional expert-driven teaching approach. Youth engaging in YPAR took ownership of their learning and projects, while the facilitators guided them. Through this process, educators learned to listen instead of telling youth what to do; they learned to "take a step back" and let youth lead. The active engagement of youth helped educators teach research topics that might not be easy or interesting for youth to learn.

Like, you need to take that step back, guide them, facilitate them. You're here for if they had any questions. Like, I'm here to help you and if you need, if you guys are stuck, that's where I come in. I'm here because this is your project, this is your baby. — Alina (educator, Sites 2 and 3, 2020)

So, yeah, for me, coming into my first year doing this is really a learning curve for me. I've really learned about what the program stands for, what the goal is, how to help the students, not just necessarily teaching but be a mentor. — Malcolm (educator, Sites 1 and 4, 2020)

Educators also discussed learning about youth development, including developmental domains of adolescent youth, and how that impacts their group management and facilitating strategies. Working with older youth, educators described learning the dynamics of the group and providing them with flexibility and expectations as successful strategies.

Integrating science and action

Young people and educators from our YPAR project reported that youth strengthened aspects of their scientific literacy by engaging in analysis of a research question around a personally meaningful topic. Youth reported enhanced motivation to participate when the topic was relevant; conversely, youth reported a lack of motivation to participate when they were not interested in the topic. In our three years of experience, we found YPAR to be a promising model to engage youth with science learning while promoting engagement with authentic, real-world issues, to help prepare youth to become both scientifically and civically engaged. While it is likely that not all youth experienced the same level of growth in their scientific literacy, cross-site data analyses revealed there were opportunities for engagement in science practices and civic engagement. Levels of participation varied, due in part to the COVID-19 pandemic, and in large part to the educators, and their ability to act as cultural translators, mentors, and academic supports. Attending to the key pedagogical elements presented here (topic selection and educator roles) will likely help future YPAR projects improve opportunities for youth to strengthen their scientific literacy and critical consciousness.

A novel aspect of our research project was conceptualizing the relationship between development of scientific literacy and critical consciousness using a YPAR program model. We posit that there is likely a dynamic, multidirectional relationship between students' lived experiences, their selection of a YPAR topic, opportunities for engaging in science practices (and thereby science learning), and the development of critical consciousness. As we shared, young people selected a YPAR topic that reflected their lived experience, something that was relevant to their lives, and something they might be able to change. Educators provided YPAR as a process tool for studying their issue, using science tools and adult partnership. These all served to validate young people's lived experience and also led youth to critical questioning, development of a sense of efficacy, and then motivation for action. The potential value of YPAR to promote science literacy and critical consciousness is well known in the YPAR scholarly community (in social justice and activism; e.g., Ayala et al. 2018); however, it has been relatively absent as an approach in the positive youth development and Cooperative Extension circles. We hope our work moves YPAR forward as a useful program model integrating science learning and civic engagement.

Regarding raising critical consciousness specifically, the youths' awareness of some of the oppressive forces within their community environment (racism), sense of power to work against inequities (healthy school food), and engagement in collective action against oppression (ethnic studies) reflects their development of critical consciousness. Youth were members of, and lived in, communities in which power was primarily held by the dominant white culture. The weight and sense of that power impacted many of the youth involved in the YPAR project. Some expressed their own sense of inaction or lack of agency to address their concerns or ideas due to their understanding of the hierarchy of school systems and their perceptions of non-support from some school administrators of the dominant culture. Research has demonstrated that youth are interested in addressing complex issues that impact their lives and creating a more equitable future, and that they thrive when they feel connected to their schools and communities and feel supported to use their voice for social change; (see Lerner et al. 2005). For youth of color and marginalized youth, critical consciousness is associated with healing (Diemer et al. 2021) and what Phan (2010) calls "psychological armor" to mediate the negative effects of oppressive social forces. We argue that focusing on raising the critical consciousness of young people will likely also promote positive youth development in culturally relevant ways.

The COVID-19 pandemic greatly impacted our work. Our educators displayed a timely and flexible transition to virtual programming. The YPAR philosophical underpinnings — rooted in justice and critical consciousness — can be sensitive and require trust between youth and educators, which is more challenging in virtual environments. While our team of educators was mostly successful at maintaining youth interest, there were setbacks, and we generated many lessons learned in successful (and unsuccessful) methods in building trust and continuing to engage and motivate youth in virtual environments.

Scaling up youth programs

Future research is needed to explore how to scale up and disseminate YPAR more broadly in a variety of 4-H and other youth programs. There needs to be attention to sustainability; the educator plays a pivotal role, and enough time must be dedicated to fully implement YPAR. This will require either resources to hire staff or very dedicated and committed volunteers. Additionally, the issue of topic selection is an aspect ripe for future exploration. We placed few boundaries on topic selection, but we know it is a key element influencing youth's motivation and investment in the project. Would future YPAR efforts with boundaries on topic selection realize as much youth motivation or personal relevance? Furthermore, future work remains to examine how the context of program implementation influences youth participation. Our research did not analyze this specifically; however, we observed differences in participation and topic selection between cohorts taking place in school or after school. In-school programs seemed to generate more students but were constrained by school-based norms. After-school programs generally had fewer students, but they appeared more committed to the program.

Engaging youth in relevant educational experiences situated in community issues may improve motivation for deeper and sustained participation in learning experiences, while also preparing them for the real world. Efforts to improve scientific literacy and civic engagement are imperative, as demonstrated through the 2017 March for Science and more recently by vaccine hesitancy during the COVID-19 pandemic. YPAR is a promising approach to increase civic engagement and create effective public leaders. Both of these are priorities for change efforts in UC ANR research and extension. CA

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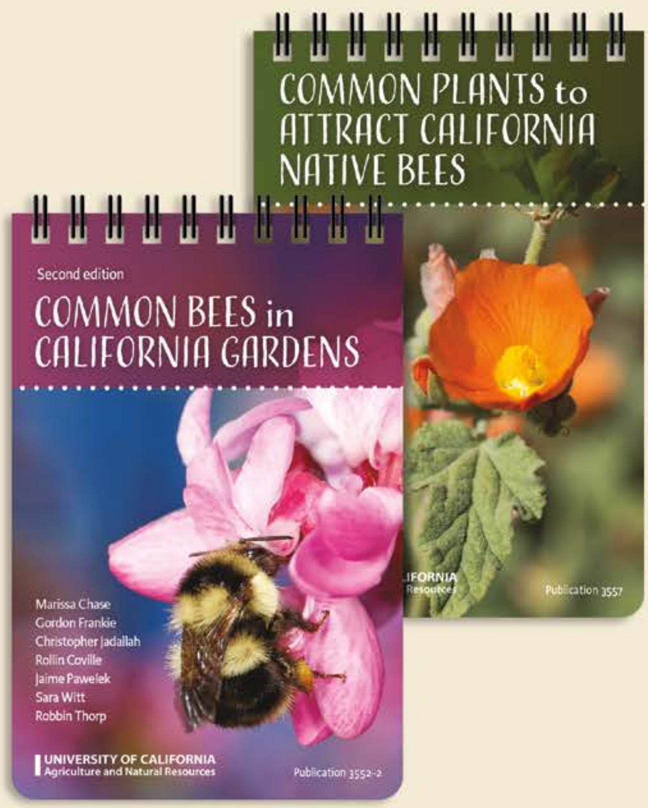

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