

# 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.

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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).

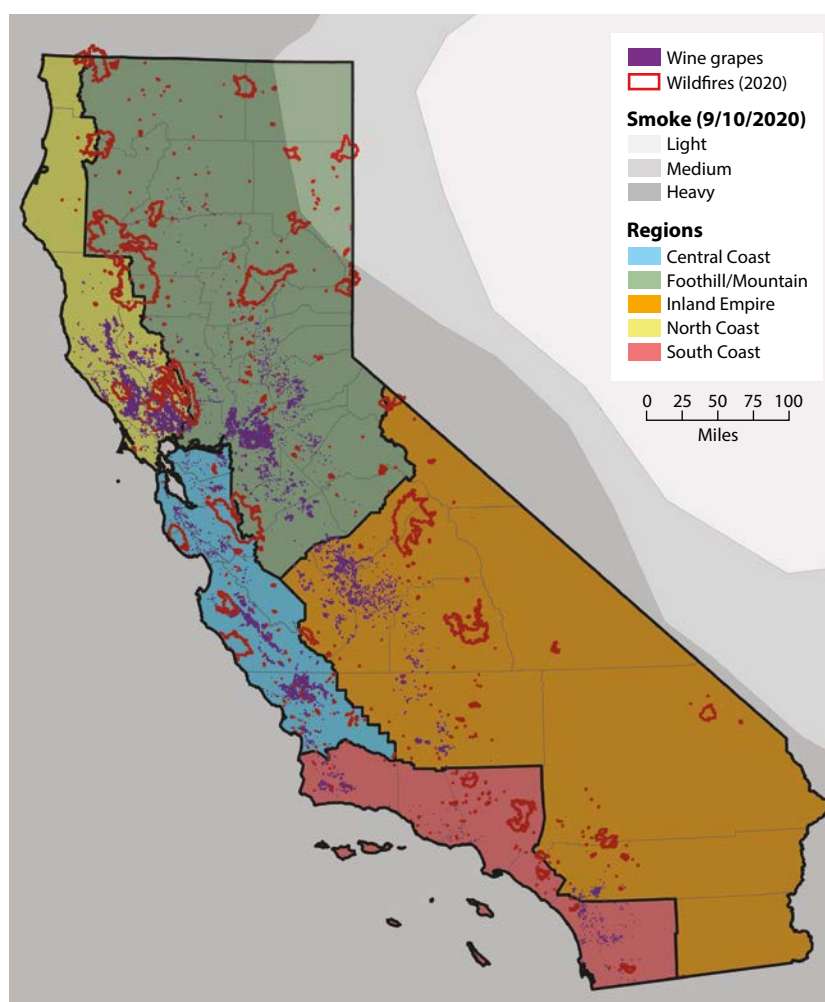
A wildfire burns near a Northern California vineyard. The majority of respondents to the authors' survey believe wildfire risk to wine grape growing or wine-making operations is greater today than 5 years ago. Photo: Ordinary Mario, iStock.com.



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.

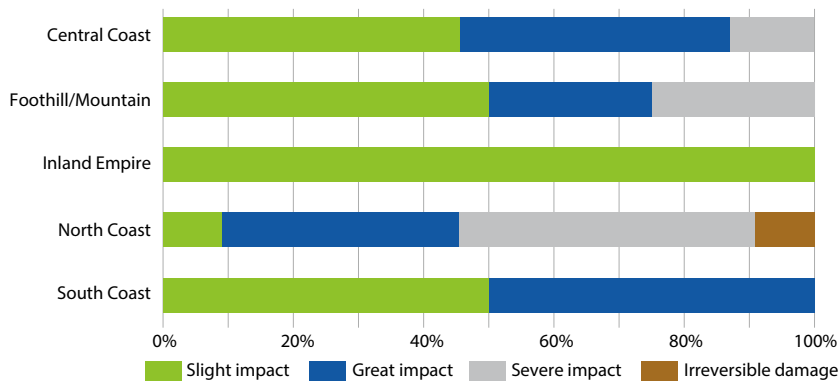
To better understand the nature of wine grapes’ exposure to smoke, respondents who incurred the impact “grapes exposed to wildfire smoke” were asked to characterize the outcomes of that impact (technical appendix, Q 14). The percentage of respondents who noted “grapes exposed to wildfire smoke” varied

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

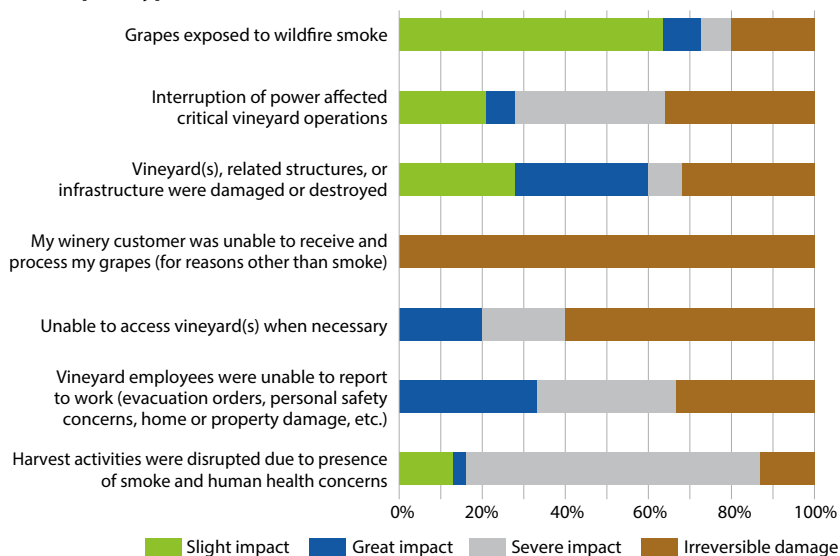
Region	Number of respondents	Professional role		Years of experience	
Central Coast	31	Grower	18 (40%)	0–10	4 (14%)
		Vineyard manager	3 (7%)	11–30	17 (59%)
		Comm. winegrower	24 (53%)	>30	8 (28%)
Foothill/Mountain	18	Grower	14 (42%)	0–10	2 (11%)
		Vineyard manager	5 (15%)	11–30	8 (44%)
		Comm. winegrower	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.

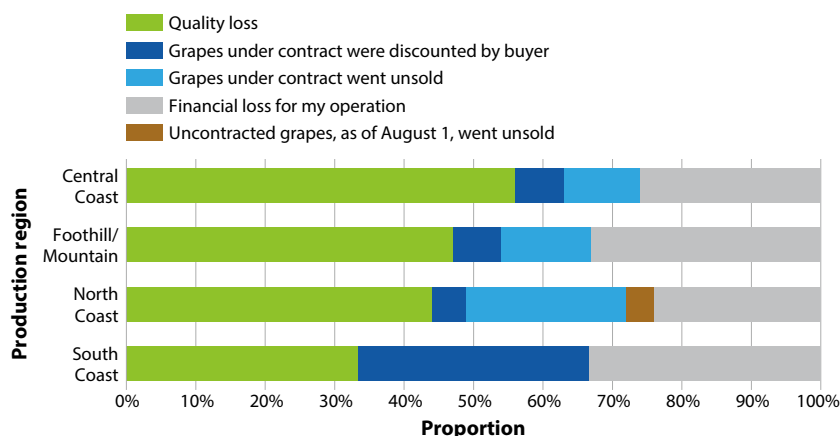
## (A) Region



## (B) Impact type



**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.

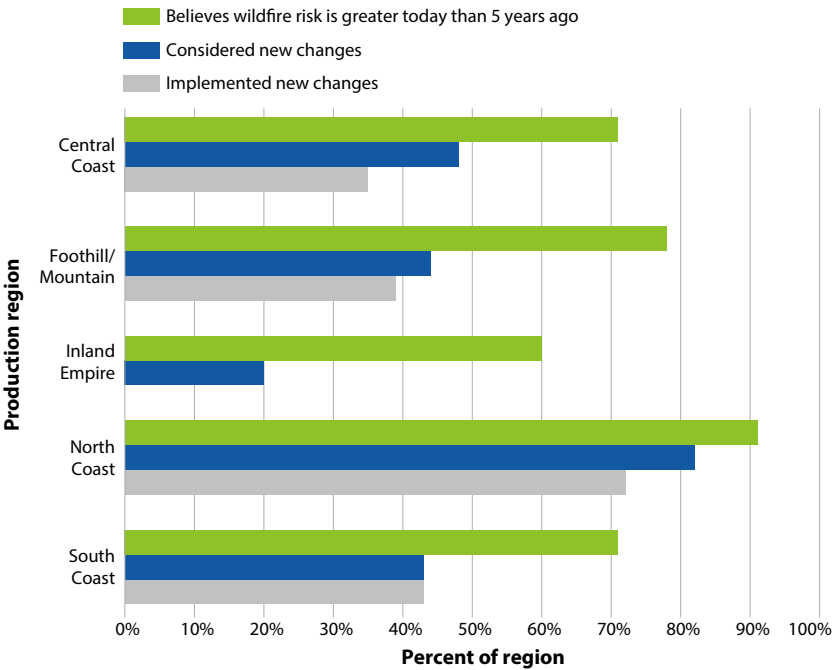
Despite the perception of increased risk, relatively fewer respondents have considered and/or implemented changes to their operation in response to wildfire risk (fig. 4; technical appendix, Q 5–6), and 22% of those who believe risks to be greater did not consider or implement operational changes. For 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.

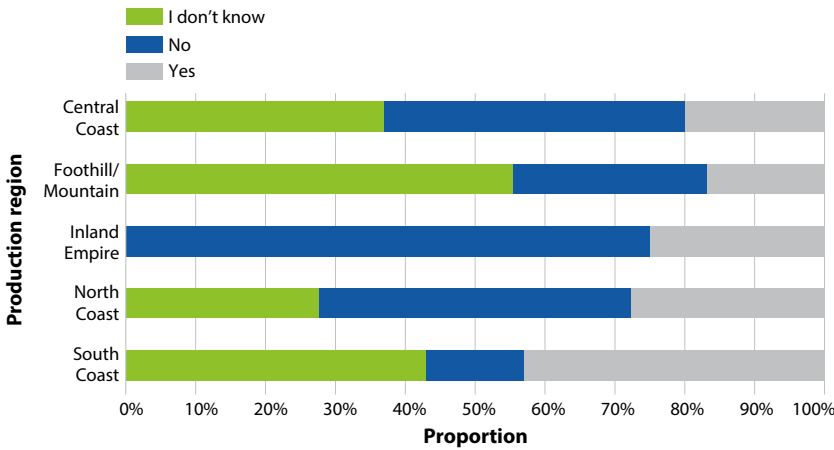
### Wildfire information lacking

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).

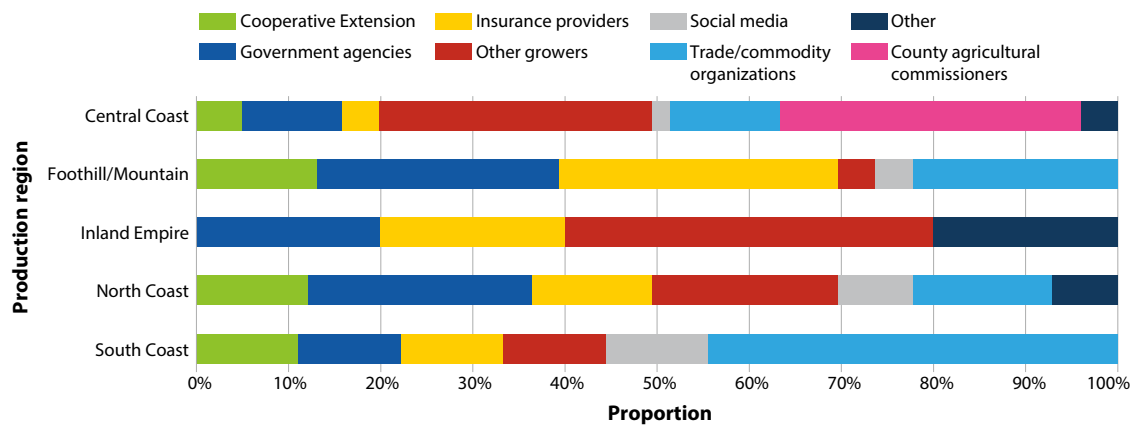


**FIG. 5.** The percent of respondents from each region that believes they do (gray), do not (blue), or are not sure (green) they have sufficient information to manage wildfire risk.

### 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 Kincadee 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](https://calag.ucanr.edu)

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*The authors wish to thank the California wine grape growers, wine producers, and industry professionals who helped disseminate and/or participated in this survey. The authors thank Ian Vogel for creating the map featured in figure 1. Finally, the authors thank two anonymous reviewers and the editors at California Agriculture for their comments that improved the quality of the manuscript.*



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