The Human Health Benefits of Improving Forest Health in California

Investigating the Links Between Forest Management, Wildfire Smoke, and the Health Sector

PEER-REVIEWED REPORT

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BLUE FOREST

The Human Health Benefits of Improving Forest Health in California

Investigating the Links Between Forest Management, Wildfire Smoke, and the Health Sector

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About CCST
The California Council on Science and Technology is a nonpartisan, nonprofit organization established via the California State Legislature in 1988. CCST responds to the Governor, the Legislature, and other State entities who request independent assessment of public policy issues affecting the State of California relating to science and technology. CCST engages leading experts in science and technology to advise state policymakers—ensuring that California policy is strengthened and informed by scientific knowledge, research, and innovation.

About Blue Forest
Blue Forest is an innovative climate finance non-profit that addresses pressing environmental challenges by developing ecological investment opportunities. As part of that work, Blue Forest works on research and development to demonstrate the environmental, economic, social, and cultural outcomes of ecosystem restoration interventions, motivates new and traditional sources of funding to implement restoration projects, and finances long-term commitments to increase the pace and scale of restoration. In partnership with the US Forest Service and the World Resources Institute, a particular area of focus is forest restoration in the western U.S. to address the catastrophic wildfire challenge.

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Acronyms and Abbreviations

AIRPACT	Air Indicator Report for Public Awareness and Community Tracking
APCD	Air Pollution Control District
AQI	Air Quality Index
AQMD	Air Quality Management District
CAL FIRE	California Department of Forestry and Fire Protection
Cal/OSHA	California Division of Occupational Health and Safety
CalBRACE	California Building Resilience Against Climate Effects
CARB	California Air Resources Board
CCHVIz	Climate Change Health Vulnerability Indicators
CCST	California Council on Science and Technology
CDC	Centers for Disease Control and Prevention
CDPH	California Department of Public Health
CEQA	California Environmental Quality Act
CMAQ	Congestion Mitigation Air Quality
COI	Cost of Illness
COPD	Chronic Obstructive Pulmonary Disease
CRFs	Concentration-response functions
CSAC	California State Association of Counties
CVI	Community Vulnerability Index
ED	Emergency Department
EDD	Employee Development Department
EMS	Emergency Medical Services
EPA	Environmental Protection Agency

FCRs	Findings, Conclusions, and Recommendations
FOFEM	First Order Fire Effects Model
GDP	Gross Domestic Product
HAQAST	Health and Air Quality Applied Sciences Team
HCAI	California Department of Healthcare Access and Information
HEPA	High-Efficiency Particulate Air
HMS	Hazard Mapping System
HPD	Healthcare Payments Data
HRRR	High-Resolution Rapid Refresh
HVAC	Heating, Ventilation, and Air Conditioning
HYSPLIT	Hybrid Single-Particle Lagrangian Integrated Trajectory model
IFNF	Innovative Finance for National Forests
kg/ha	Kilograms per hectare
km	Kilometer
m	Meter
MERV	Minimum Efficiency Reporting Values
NAAQS	National Ambient Air Quality Standard
NEI	National Emissions Inventory
NEPA	National Environmental Policy Act
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
OEHHA	California Office of Environmental Health Hazard Assessment
OSHPD	California Office of Statewide Health Planning and Development
PAHs	Polycyclic Aromatic Hydrocarbons
PM	Fine particulate matter

$PM_{2.5}$	Fine particulate matter less than 2.5 microns in diameter
PM_{10}	Fine particulate matter less than 10 microns in diameter
RCRC	Rural Counties Representative of California
SNAPP	Science for Nature and People Partnership
STILT	Stochastic Time Inverted Lagrangian Transport
SVI	Social Vulnerability Index
T_{PT}	Smoke costs of treatments under Proactive Treatment scenario
$\mu g/m^3$	Micrograms per cubic meter of air
USDA	U.S. Department of Agriculture
USFS	U.S. Department of Agriculture Forest Service
VOC	Volatile Organic Compounds
VSL	Value of a Statistical Life
WHO	World Health Organization
W_{NT}	Smoke costs of wildfires under No Treatment scenario
W_{PT}	Smoke costs of wildfires under Proactive Treatment scenario
WRF-CHEM	Weather Research and Forecasting model coupled with chemistry
WRF-SFIRE	Weather Research and Forecasting model coupled with the fire-spread model
WRF-SFIRE-CHEM	Weather Research and Forecasting model coupled with the fire-spread model coupled with chemistry
WUI	Wildland Urban Interface

About this Study

Funding Source: This study was supported by a grant entitled "Linking Public & Forest Health: Developing a Cost Benefit Model to Reduce Wildfire Smoke Impacts with Forest Management" from the Innovative Finance for National Forests (IFNF) program, which is co-managed by the U.S. Department of Agriculture, Forest Service, and U.S. Endowment for Forestry and Communities. Additional funding to CCST was provided as part of CCST's Disaster Resilience Initiative, which is supported by an allocation of one-time funds from the State of California to accelerate the transmission of information between science and technology experts and policymakers to increase California's resilience to ongoing, complex, and intersecting disasters. Additional funding to Blue Forest was provided by the J.M. Kaplan Fund and Alumbra Innovations Foundation to support the development of conservation finance efforts that lead to positive impacts and outcomes.

Study Process. CCST organized and directed the study leading to this report. Members of the CCST Steering Committee were appointed based on technical expertise and a balance of viewpoints. ***Appendix H: Steering Committee Members*** provides information about CCST's Steering Committee membership. All experts who contributed to the study were evaluated for potential conflicts of interest. Under the guidance of the Steering Committee, a team of experts (authors) assembled by CCST developed the findings based on original technical data analyses and a review of the relevant literature. ***Appendix I: Report Author Biosketches*** provides information about the authors. The Steering Committee met regularly to interact with the lead authors as the authors studied each of the issues identified in the scope of work (***Appendix J: Scope of Work***). With regular interaction, the authors and the Steering Committee (study team) were able to collaborate to develop a series of findings, conclusions, and recommendations defined as follows:

> ***Finding.*** *Fact(s) the study team finds that can be documented or referenced and that have importance to the study.*
>
> ***Conclusion.*** *A reasoned statement the study team makes based on findings.*
>
> ***Recommendation.*** *A statement that suggests an action or consideration as a result of the report findings and conclusions.*

The committee process ensures conclusions are based on findings, and recommendations are based on findings and conclusions. Both the authors and the Steering Committee members proposed draft conclusions and recommendations. These were modified based on peer review and discussion within the Steering Committee, along with continued consultation with the authors. Final responsibility for the conclusions and recommendations in this report lies with the Steering Committee. All Steering Committee members have agreed with these conclusions and recommendations. The conclusions and recommendations expressed in this publication are those of the Steering Committee and authors, and do not necessarily reflect the views of the organizations or agencies that provided support for this project.

The full report has undergone extensive peer review; peer reviewers are listed in ***Appendix M: Expert Oversight and Review***. Eight reviewers were chosen for their relevant technical expertise. More than 300 anonymous review comments were provided to the study team. The study team revised the report in response to peer review comments. A report monitor appointed by CCST then reviewed the response to the review comments and when satisfied, approved the report.

Executive Summary

In California's smoky future, improved forest health means improved human health.

Authors: Jennifer Montgomery, Joshua Graff Zivin, Heidi Huber-Stearns, Adam Kochanski, Ryan Tompkins, Jun Wu

Our report examines the connections between forest management, wildfire smoke, and human health through interviews with health sector organizations in California and a review of the scientific literature. We highlight the knowledge gaps and the data, research, and collaborations needed to effectively fill them, as well as steps the State of California, the federal government, and others can take to ensure the improved health of all who live under frequently smoky skies. **Broadly, we find:**

1. Wildfire smoke impacts human health and health sector organizations' workforces, operations, and ability to provide services, yet the costs are largely unquantified. Quantifying these costs would enable state and local health sector organizations to make more informed decisions regarding budgeting, resource allocation, and response.

2. Many interviewed health sector organizations see value in future engagement with forest management to mitigate adverse outcomes and costs associated with wildfire smoke, but require avenues for collaboration and more information on the potential benefits of forest management to human health and the health sector.

3. Comprehensive statewide and/or locally specific information on the adverse human health impacts of wildfire smoke are not readily available but could be generated from additional analysis of existing data resources. The data and methodologies to support the above understanding require thoughtful, forward-looking, collaborative, coordinated research design that is informed by use cases appropriate for California.

4. A small but growing body of research suggests that management to improve forest health can be tailored to reduce total smoke impacts and benefit human health. Informed prioritization of management strategies that promote forest resilience and human health across California's many landscapes will benefit from filling data gaps relating the costs and efficacy of various treatments under different conditions.

California has always had—and always will have—smoky air. As early as 1542, Spanish explorer Juan Rodriguez Cabrillo described the Los Angeles area as a "smoky valley," quite likely due to a combination of the natural and cultural fires which have burned in what is now known as California since time immemorial (Ryan, Knapp, and Varner 2013; Stephens, Martin, and Clinton 2007; Leenhouts 1998). Significantly, many ecosystems in California have evolved with fire and are adapted to fire, with many requiring fire as an essential ecological process for ecosystem health and resilience (Cisneros et al. 2017).

Historically, many Indigenous communities moved cyclically among areas rich in seasonal natural resources, lighting beneficial cultural fires behind them to restore important ecological resources (Marks-Block and Tripp 2021). The natural reduction in fire intensity owing to cultural burning practices, combined with the ability to relocate more easily, allowed Indigenous peoples to avoid many of the most serious adverse health impacts of smoke from fires. Smoke from cultural fires also yielded many benefits, including the cooling of rivers and streams to benefit salmon populations, driving pests from food sources such as acorn crops, and producing greater ecological diversity (David, Asarian, and Lake 2018; Roos et al. 2021; Long et al. 2017; 2016).

When Europeans displaced and dispossessed Indigenous peoples, prohibited the use of Indigenous cultural burning practices, suppressed wildfire, and built fixed structures and communities, the adverse health impacts of wildfire smoke were temporarily suppressed. However, these fire exclusion and past management practices have generated an excessive density of trees in many of California's forests. Alongside climate change, the degraded conditions of our forests have created conditions for increasingly frequent catastrophic wildfires—and wildfire smoke—that are nearly impossible to suppress. Added to that, the population of California exploded from a conservative estimate of 310,000 Indigenous people before Spanish Mission settlement (Akins and Bauer 2021) to almost 40 million people today. Many of these communities now live near densely forested areas in the Wildland Urban Interface (WUI), increasing population exposure to fires and smoke, but also increasing fire frequency with many human-caused ignitions and homes as fuel to the fires. These modern conditions have made the adverse human health impacts of wildland fire smoke impossible to avoid.

Reducing catastrophic wildfires will require a multi-prong approach, including improving forest health, reducing human caused ignitions, and tackling the root cause of climate change through reduction in anthropogenic greenhouse gas emissions. In this report, we focus specifically on improving forest health through proactive management. Healthier forests will require a commitment to ongoing and expanded forest management treatments across multiple landscapes and repeated over time (Hunter and Robles 2020; Williamson et al. 2016; Jones et al. 2022; U.S. EPA 2021). Treatments tailored to individual landscapes will be necessary to achieve the benefits of smoke reduction and for fewer adverse human health impacts. The adverse health impacts of wildland fire smoke may be one of the largest health costs of wildfires in recent years (CCST 2020). Yet, these cost estimates are often speculative regarding impacts to human health; the health sector; local, state, and federal governments; and communities. Research around wildland fire smoke is increasing, including emerging research on strategies to reduce wildland fire smoke (Graw and Anderson 2022). However, more explicit evidence is needed on the connections between wildland fire smoke, human health outcomes, and forest management (D. L. Peterson, McCaffrey, and Patel-Weynand 2022).

> **"Absent a reorientation of California's approach to wildfire, these alarming trends are likely to worsen. However, there are important steps California can take as a state to minimize the destructiveness of wildfires and their attendant costs."**
>
> *— The Costs of Wildfire In California (CCST, 2020)*
>
> This statement holds equally true for the impacts of wildland fire smoke to human health.

As California grapples with preexisting air quality concerns, increasingly catastrophic wildfires, and the cascading aftermath of pandemic impacts to the health sector, the state has needed to focus heavily on the immediate needs of its overburdened health care systems and on the vulnerable populations that experience a disproportionate number of impacts from compounding disasters. At the same time, forests continue to burn out of control and create more smoke, so taking a longer-term view on broader landscape challenges is critical.

It is at the intersection of these issues that we explored the value of forest management for human health benefit, by inviting a subset of relevant parties from the health sector—broadly including public health, healthcare providers, and health insurers—to engage in discussion with us about forest health and smoke.

Opportunities for cross-sector collaboration to meet shared goals may exist if accelerated and proactive forest management can meet ecologic, human health, and economic triple-bottom lines for the health and forest management sectors. Providing funding to accelerate work; advocating for increased forest management including beneficial fire; considering health tradeoffs in forest management planning and implementation; and developing coordinated public communication campaigns are all ways for non-forestry parties like the health sector to engage in forest management. The goal of working together is not for relevant and interested parties in non-forestry sectors to make technical decisions around forest management activities, but rather for these parties to support, promote, and provide perspectives that can lead to improved outcomes for all. The first step to facilitating this potential engagement is to understand the health sector's perspectives on the issue.

The goal of this study was to better understand private and public health sector concerns about wildland fire smoke; what impacts they may have experienced; how those organizations responded to smoke events; and if those in the health sectors are calculating the actual costs to their organizations and other impacts of smoke exposure. We also asked interviewees about their familiarity with forest management and links to wildfire smoke and human health. Next, we asked about potential motivations, barriers, information, and institutional structures that might motivate, support, and create opportunities for health sector engagement in forest management.

Our interviewees included public health representatives from local, state, and Tribal governments and non-governmental entities as well as representatives from health systems, including hospitals, clinics, and healthcare delivery organizations. We also spoke with health insurers, including those serving Medicare and Medi-Cal groups. We note here that reaching those interviewees who primarily serve more vulnerable populations (people with more pre-existing medical conditions and/or less access to resources to navigate smoke events) and interviewees serving Tribal governments and Indigenous communities was challenging given our timeframe, recruitment methods, and the reality of asking for people's time in an overburdened system. We emphasize the need to expand our recruitment methods and resources, prioritize the inclusion and representation of these communities within our study team, and engage with our academic, research, and community partners who explicitly partner with those serving vulnerable populations.

We heard two key messages from health sector interviewees. First, they have directly experienced adverse impacts from wildfire smoke, including impacts to their employees, facilities, and the populations they serve, and they often struggle to access sufficient resources and information to respond at the necessary scale. Second, many interviewees saw a connection between forest health and human health. However, interviewees identified that studies and data linking improved forest management to improved human health are critical precursors to engagement. These data could motivate the health sector to engage in supporting forest management programs, where the health sector has not previously seen a role for itself.

This report also summarizes the current state of the publicly available data products and modeling tools for estimating the adverse human health impacts of wildland fire smoke. We also review the preliminary but growing body of research evaluating the potential for forest management to provide a human health benefit by reducing the net smoke impacts from fire-dependent forests over time. This analysis highlights that smoke and health impact data, agreed-upon metrics, and consensus on the efficacy of various wildland forest and smoke management practices are not readily available for localities across California. However, preliminary evidence does show that forest management can benefit human health. To fully recognize the costs of adverse smoke impacts, significant cross-disciplinary and cross-governmental research, data collection and sharing, and analysis and implementation of shared management practices will be required.

We recognize that while there is a significant amount of data on forest fuel reduction programs to reduce wildfire risk, it is not yet clear how effectively these forestry programs translate into reductions in smoke, adverse human health impacts, and negative impacts to organizations. This gap in understanding is primarily due to a lack of standardized information regarding several critical factors. First, there is no authoritative data product quantifying the portion of the observed $PM_{2.5}$ concentration (and the many other components in smoke) in the air that can be attributed to wildland fire smoke, leaving researchers to independently estimate smoke $PM_{2.5}$ concentrations for each new study on the adverse health impacts of smoke. Second, the relationship between smoke $PM_{2.5}$ concentrations and adverse health outcomes requires further research to better understand the differences in the health risk of uncontrolled wildfire, and in particular fires that burn through the WUI, compared to more controlled beneficial fire. Additionally, the influence of population vulnerability on smoke-related health impacts is a complex aspect which needs to be more fully explored. Lastly, there is a need to determine the extent to which forest management programs—including prescribed burning—effectively reduce net smoke health impacts over the long term. As a result, it is challenging to assess the economic burdens of smoke—and who bears them—which is critical to motivate the health sector to engage with forest management. Addressing the above knowledge gaps is vital to comprehensively assess and manage the adverse impacts of smoke on air quality and public health.

Health costs associated with wildfire smoke impacts are difficult to quantify with currently available data and are complicated by population vulnerability factors such as geography, socio-economic status, employment type, and pre-existing interrelated health conditions such as asthma and chronic obstructive pulmonary disease (COPD), among others. To address these intersectional concerns, new methodologies must be agreed upon by all parties with an economic, ethical, or legal interest in managing wildland fire smoke for better human health outcomes. Public and private land and air quality managers, researchers, academics, health care providers, insurers, and public health personnel will all need to work collectively to achieve the goal of better long- and short-term health outcomes.

Conclusions and Recommendations

On the following pages, based upon the substantive **Findings** in the report, we present **Conclusions and Recommendations** that can be implemented in the near, middle, and long terms while land and air management agencies from the state and federal governments continue to develop policy in collaboration with their health, forest, and air quality management partners.

It is well understood that wildfire smoke exposure exacerbates human health risks and can make underlying human health worse (Black et al. 2017). However, through our interviews, we heard a need for more information about these linkages to human health—how to communicate wildfire smoke impacts and improve preparedness; gaps in knowledge around the chronic and mental health impacts of wildfire smoke; and how wildfire smoke exposure and adverse health impacts differ among forest management approaches. California public health and air regulatory agencies are developing guidance on wildfire smoke preparedness and response, but more tailored and locally specific guidance may be needed.

As such, our study also highlights the lack of knowledge about some of the connections between wildfire smoke and health impacts. However, even without a full accounting of the smoke and public health costs, we do know that wildfire smoke is unpredictable in timing, severity, and location and that it negatively impacts human health.

Continue on to read our summary of findings for each chapter along with our conclusions and recommendations on how best to strengthen the linkages between forest health and human health.

Chapter 2: Summary of Findings in Support of Conclusions and Recommendations

The California health sector—including government Departments of Public Health—understands that wildfire smoke negatively impacts their employees, their operations, the public they serve, and their bottom line. However, they are uncertain what data or information they need to strategically plan for future wildfire smoke events. In addition to planning for smoke events, the health care sector would like to better serve their communities by understanding the intersection of interacting events such as extreme heat and have plans in place to better communicate guidance strategies. California and the federal government can help craft strategies and operations for both needs.

Chapter 2: Conclusions and Recommendations

FCR #10. **Conclusion:** There is an opportunity to improve public health guidance on wildfire smoke response during multiple interacting events, such as COVID-19 or extreme heat.

FCR #11. **Recommendation:** California health, emergency response, environmental, and research-focused agencies and foundations should work with the health sector to fund and develop guidance for public health entities and health systems faced with coinciding environmental and health emergencies.

FCR #17. **Conclusion:** Wildfire smoke is a growing problem and is demanding more of the health sector's resources to manage and respond to smoke events. Additional guidance on wildfire smoke response and preparedness for health sector groups is needed.

FCR #18. **Recommendation:** To help California health sector organizations proactively prepare for and respond to wildfires and wildfire smoke events, public health and air regulatory agencies should collaborate on developing evidence-based best practices for public communication, facility management, and health care delivery during these events.

FCR #20. **Conclusion:** Interviewed health sector organizations are interested in the financial costs of wildfire smoke events. Quantifying these costs would enable state and local health sector organizations to make more informed decisions regarding budgeting, resource allocation, and response.

FCR #21. **Recommendation:** California health, emergency response, and research-focused agencies and foundations should work with the health sector to develop procedures to quantify and track the impacts and associated costs of wildfire smoke on their organizations' workforce, operations, and ability to provide services.

FCR #22. **Recommendation:** Health insurance groups should share sufficiently de-identified datasets on claims and healthcare expenditures to complement healthcare utilization data from health systems to better support tracking the costs of wildfire smoke events.

Chapter 3: Summary of Findings in Support of Conclusions and Recommendations

There is a general awareness among California-based health sector organizations of forest management's potential to decrease severe fires, largely due to direct experience of living in California during repeated catastrophic fire events. California-based health sector organizations are generally not considering forest management as a wildfire smoke mitigation tool relevant to reducing human health impacts. Many of the motivations for future health sector support for forest management activities (improved human health outcomes, cost savings, and improved financial returns) will depend on more and better quantitative information.

Chapter 3: Conclusions and Recommendations

FCR #32. **Conclusion:** Interviewed health sector organizations are interested in exploring opportunities for engaging with forest management but require avenues for collaboration, policies to motivate and enable participation, and more research into health and the health sector benefits of forest management.

FCR #33. **Recommendation:** California and federal agencies responsible for forest management, environmental regulation, and health research should continue to fund and support multidisciplinary research that demonstrates how forest management could change wildfire smoke risk and its subsequent impacts on human health and the health sector, at actionable levels of spatial resolution.

FCR #34. **Recommendation:** California and the federal government should further prioritize health sector interested parties' participation in forest management advisory bodies (e.g., California Wildfire & Forest Resilience Task Force, Forest Service Wildfire Crisis Strategy) to strengthen the linkages between public health and forest management planning and practice.

Chapter 4: Summary of Findings in Support of Conclusions and Recommendations

There is a need for agreed upon, standardized methodologies and data products to analyze how smoke from wildland fire impacts human health. Although it appears that forest management practices have a role in reducing wildland fire smoke, there are few studies that have specifically investigated the effectiveness of management activities to reduce wildland fire smoke health impacts on affected communities. Currently, communities cannot look up their specific regional smoke impact or understand what the potential benefits from forest management could be. Additional guidance on, and funding for, wildfire smoke response and preparedness for health sector focused groups is needed. Additional guidance on, and funding for, studies of proactive forest management strategies to reduce overall smoke impacts is needed.

Chapter 4: Conclusions and Recommendations

FCR #36. **Conclusion:** Ongoing, retrospective tracking of smoke metrics would facilitate more comprehensive assessments of the human health impacts of wildland fire smoke across California.

FCR #37. **Recommendation:** California and the federal government should consider creating regularly updated data products that retrospectively track air pollution concentrations attributable to wildland fire smoke, population exposure to smoke, and cases of adverse health outcomes attributable to smoke.

FCR #39. **Conclusion:** Data linking smoke impacts back to source wildland fires would facilitate assessments of which landscapes pose the greatest potential risk to human health and thus potential priorities for forest management activities to reduce wildfire risk and improve forest health.

FCR #40. **Recommendation:** California and the federal government should expand available smoke data products to include estimates of smoke impacts by individual wildland fires. Tracking smoke impacts back to source fires is foundational data for research on the potential human health benefits of alternative forest management strategies.

FCR #42. **Conclusion:** Standardized methodology for estimating wildland fire smoke metrics (smoke air pollutant concentrations and adverse health outcomes attributable to smoke) would facilitate comparison of smoke impact results across studies and could provide useful metrics for management, response, and public education.

FCR #43. **Recommendation:** California and the federal government should support efforts to create methodological guidelines for estimating smoke air pollutant concentrations and counts of adverse health impacts attributable to wildland fire smoke in order to facilitate future research efforts.

FCR #45. **Conclusion:** Data on the contributions of burned homes and other human-made materials to wildland fire smoke would allow for more comprehensive estimates of smoke impacts and facilitate assessments of the relative human health impacts of fires that burn a mix of human-made materials and vegetation in the wildland-urban interface (WUI), compared to fires that burn primarily vegetation in the wildlands.

FCR #46. **Recommendation:** California and the federal government should support the development of methodologies to estimate smoke emissions from human-made materials and should expand smoke emissions inventories to additionally include emissions estimates from developed landscapes that are burned by wildland fires.

FCR #48. **Conclusion:** Research to estimate the differences in health impacts related to how fires burn, what fires burn, and population vulnerability to smoke (i.e., to derive concentration-response functions) would facilitate more accurate estimates of the population-level health impacts from smoke exposure of different kinds of fire and the potential inequities in smoke impacts across population subgroups.

FCR #49. **Recommendation:** Research funders should support studies to develop concentration-response functions that can be used to estimate the effect of differences in how fires burn, what fires burn, and population vulnerability on resulting health impacts from smoke exposure.

FCR #51. **Conclusion:** Research to estimate chronic, cumulative, or mental health outcomes would facilitate more comprehensive data on the of the adverse health impacts from smoke.

FCR #52. **Recommendation:** Research funders should support studies to better understand the chronic, cumulative, and mental health impacts of smoke exposure and to develop concentration-response functions that can be used to estimate cases of such adverse health outcomes in populations exposed to smoke.

Chapter 5: Summary of Findings in Support of Conclusions and Recommendations

Most research on forest management and restoration activities focuses on effects to fuel accumulations; the resulting predicted wildfire behavior and emissions; and effects on carbon balances; but few evaluate subsequent human health benefits and impacts of smoke. Further research is necessary to evaluate how other forest management activities (e.g., mechanical vegetation treatments, prescribed fire) affect not only fuel accumulations, but potential wildfire smoke emissions and subsequent human health impacts.

Chapter 5: Conclusions and Recommendations

FCR #54. **Conclusion:** Scientific evidence for the human health benefits of improving forest health are limited, but preliminary results are supportive.

FCR #55. **Recommendation:** California, the federal government, and other research funders should support additional research to study the smoke-related human health tradeoffs of different possible forest management strategies in order to improve forest and human health.

FCR #57. **Conclusion:** Although evaluating the climate-related carbon tradeoffs of wildland fire smoke is valuable for understanding the relative costs or benefits of alternative forest management strategies, carbon tradeoffs results should not be used as a proxy for inferring the human health tradeoffs of a management strategy.

FCR #58. **Recommendation:** Evaluations of the cost/benefits tradeoffs of alternative forest management strategies should include separate analyses for the potential human health tradeoffs and for the potential climate tradeoffs of wildland fire smoke.

FCR #60. **Conclusion:** The potential human health benefits of management in non-forested, fire-dependent ecosystems, such as chaparral shrublands or grasslands, is currently unknown.

FCR #61. **Recommendation:** California, the federal government, and other research funders should support additional research to evaluate the human health tradeoffs of management strategies to improve the health of non-forested, fire-dependent ecosystems including chaparral shrublands and grasslands.

Closing Thoughts

We know that a smoke-free future does not exist for California, but a "less smoke" future is possible (Williamson et al. 2016; Schweizer and Cisneros 2017; Jones et al. 2022). Whether or not the expected smoke impacts from resilient forests are greater or less than the expected smoke impacts of degraded forests depends on the context and requires careful study. Based on that knowledge, we advocate most strongly for additional, focused studies on the differences in smoke production and health impacts between active and passive forest management strategies. Without these studies and data, we cannot address the critical human health needs of all residents of California in an informed fashion (D'Evelyn et al. 2022).

The data problem is an overarching theme throughout this report. Health sector interviewees note the lack of data, but they are uncertain exactly what data are needed and if having those data would directly translate to better human health outcomes, or how their actions could support forest management activities. Making the necessary linkages between forest management and human health impacts may not be enough to engage the health sector in forest management efforts if there are other impediments to engagement. Data can and *will* be the key driver of future agreement and engagement.

It remains unclear who oversees the creation and sharing of the necessary data and supporting smoke-related information for the health sector. Lack of individual ownership—understandable since forest management, air pollution, and human health, while intertwined, are spread across differing jurisdictions—should motivate the need for new governance structures and policies which could bring the disparate parties together in pursuit of the shared goals of forest and human health.

We also heard from our interviewees that health sector organizations are managing other health crises, often with limited resources, which affects their ability to engage with wildfire smoke and forest management. It is critical to acknowledge, respect, and authentically reflect the challenges we heard from the health sector so we can work together to not only find ways to support these aforementioned needs, but also to wrap these into our broader understanding of how human health and the environment are interconnected.

There is an invaluable opportunity to lay the foundation for better collaboration between health sector organizations and governmental air and land managers on wildfire smoke. Improved collaboration could pay dividends in our responses to, and preparation for, other climate-related natural disasters, especially among vulnerable populations. Wildfire smoke-induced health and organizational impacts often manifest as equity and access issues, disproportionately affecting more remote and/or resource-constrained communities. We must recognize how wildfire smoke can compound inequities in accessing basic needs in our advocating for better linking the forest management and health sectors.

We must ask ourselves how federal, state, Tribal, and local agencies can meet our healthcare partners' needs, to the extent that they are well articulated. If not possible, how do we change the paradigm? We urge increased capacity, clearer priorities, and yes, more funding to do the necessary research. This will both use existing and create new data and studies to inform decision-making and allow dissemination to interested parties in effective and culturally appropriate modes of communication to target audiences (i.e., those providing health care and health support services). Additionally, continued clear leadership and strong crosscutting communication, combined with agreed upon metrics and consistent data and data sharing, will be required to communicate more effectively. Without better communication, data sharing and an understanding of the connection between actions, costs, and outcomes, it will be difficult to make the case to healthcare systems for more and varied forest management approaches.

Overall, while there is general agreement from the interviewees (and the reviewed research) that addressing the connections between forest health, smoke, and human health is crucial, identifying exactly *who* should be responsible for the research and initiating collaboration continues to be challenging. This lack of clarity is a significant concern, especially in the larger context of climate change and while the public health sector continues to face resource and staff limitations on the heels of a pandemic. While there is a need for *some* enhanced funding, the two most important actions toward forging a public-private alliance between governments and healthcare systems would be to: (1) better recognize, value, and align the shared interests among governments and health care systems, and (2) enhance and improve data collection, data reporting, and sharing on both forest management treatments and the resulting wildfire smoke impacts.

As such, the Steering Committee recommends and advocates for better cross-disciplinary communication and enhanced collaboration among various federal, state, and local agencies with interested healthcare partners, as well as the additional research and funding necessary to better address this issue.

This Executive Summary is based upon the findings, conclusions, and recommendations presented and discussed in greater depth and detail in the full report.

Chapter 1: Introduction

Authors: Kimberly Quesnel Seipp and Teresa Feo

Due to a combination of factors including climate change, land use planning, and overgrown and unhealthy forests, California has been experiencing unprecedented catastrophic wildfire seasons, with widespread smoke plumes that expose populations statewide to harmful levels of air pollutants (***Figure 1***). This heightened wildfire smoke exposure has led to adverse health outcomes, which are costly and detrimental to California residents and the health sector. Forest management is an effective tool to improve forest health, reducing the risk of severe wildfires, wildfire smoke, and subsequent health impacts. However, forest management activities that use beneficial fire also emit smoke. Better understanding the trade-offs in smoke emissions, population exposure, and health outcomes from various forest management strategies could lead to improved decision-making that considers multiple outcomes. Opportunities for cross-sector collaboration to meet shared goals may exist if accelerated and proactive forest management can meet ecologic, human health, and economic triple-bottom lines for the health and forest management sectors. This study aims to uncover the links between forest health, wildfire smoke, and human health, and to explore the health sector's perspectives of wildfire smoke and their interest in engaging in forest management.

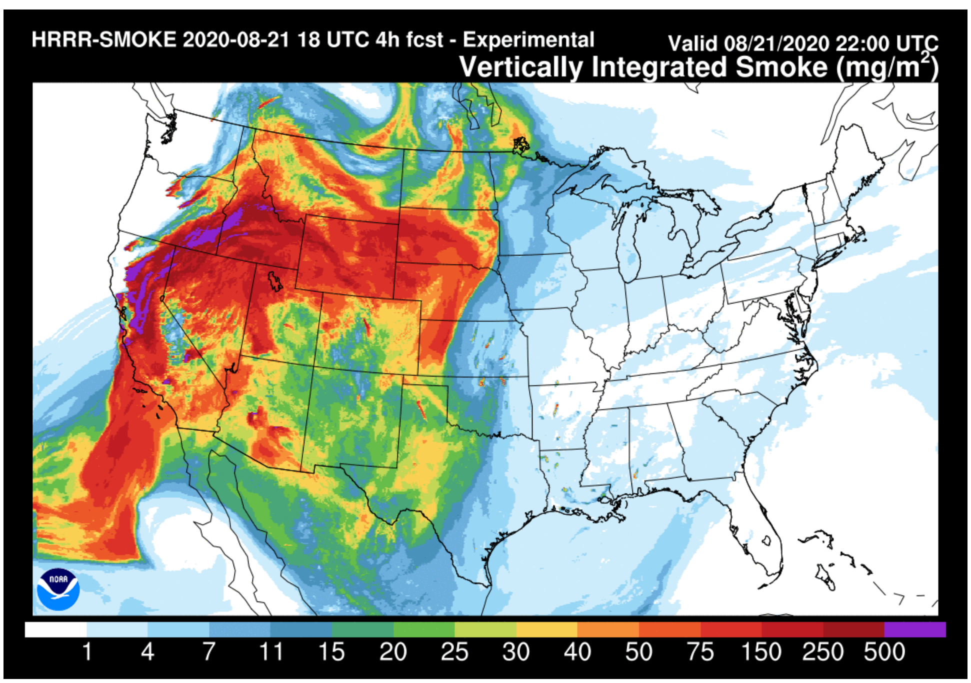


Figure 1. NOAA HRRR-Smoke Forecast for August 21, 2020, showing harmful levels of smoke PM2.5 air pollution across California and other western states. Forecast generated by the experimental NOAA High-Resolution Rapid Refresh (HRRR) Smoke Product.

1.1 Management is critical for improving the resilience of California's forests

There is widespread recognition that climate change, land use planning, and 20th-century forest management strategies (i.e., harvesting large fire-resistant trees, mandating replanting of trees at high densities, and suppressing nearly all wildland fires) have contributed to degraded forest conditions in California and across the Western U.S. (Prichard et al. 2021). Degraded forests present challenges for ecosystems and lead to more severe wildfires that further damage ecosystems and exceed our fire suppression capabilities (see ***Definitions Box 1. Types of Fires*** and ***Definitions Box 2. Forest Conditions***). The risks associated with degraded forests have been increasing and are expected to continue to grow with catastrophic results (Larkin et al. 2015; Ford et al. 2018; J. C. Liu, Mickley, Sulprizio, Yue, et al. 2016; Burke et al. 2021).

Unhealthy forests are a particular challenge for California, which has more than 33 million acres of diverse forested ecosystems (Swanston et al. 2020). A large portion of these forests are classified as dry, frequent fire adapted, mixed-conifer forests of the Western U.S. and are found across the Sierra Nevada, the Cascades, and the mixed-conifer and woodland forests of the interior Coast Ranges and Southern California (***Figure 2***). This mixed-conifer forest type, hereafter referred to as 'forest,' is the focus of this report given the broad and sweeping scientific evidence that forest management activities—including beneficial fire (i.e., prescribed burning, cultural burning, and managed wildfire), mechanical and hand thinning, and meadow restoration—can improve forest resilience (Prichard et al. 2021; Stephens et al. 2020). Here we use the term 'forest management' to collectively refer to activities with the goal of forest restoration and/or fuels reduction (***Definitions Box 3. Forest Management and Treatment Activities***). Across California, public and private forest and land managers are employing these strategies to restore forest health and reduce the risk of catastrophic wildfires. We focus on forest management in this report as one avenue to reducing the risk of catastrophic wildfire, acknowledging that multiple approaches, including reducing human caused ignitions and tackling the root cause of climate change through reduction in anthropogenic greenhouse gas emissions, are required.

Forest restoration treatments are designed to recover both forest structure (e.g., vegetation distribution) and processes (e.g., fire, nutrient cycling, etc.) necessary to achieve a resilient and healthy condition (Stephens et al. 2021). For the mixed-conifer forests of California, efforts to restore structure are typically focused on reducing the density of trees and surface fuels (from hundreds of trees per acre to as few as tens of trees per acre), increasing the heterogeneity of tree spacing (from even spacing between trees to more various sized clumps of trees separated by open patches), increasing the range of tree ages (from single age stands to a mix of young, middle, and old age trees), and promoting tree species compositions that are more reflective of natural fire regimes.

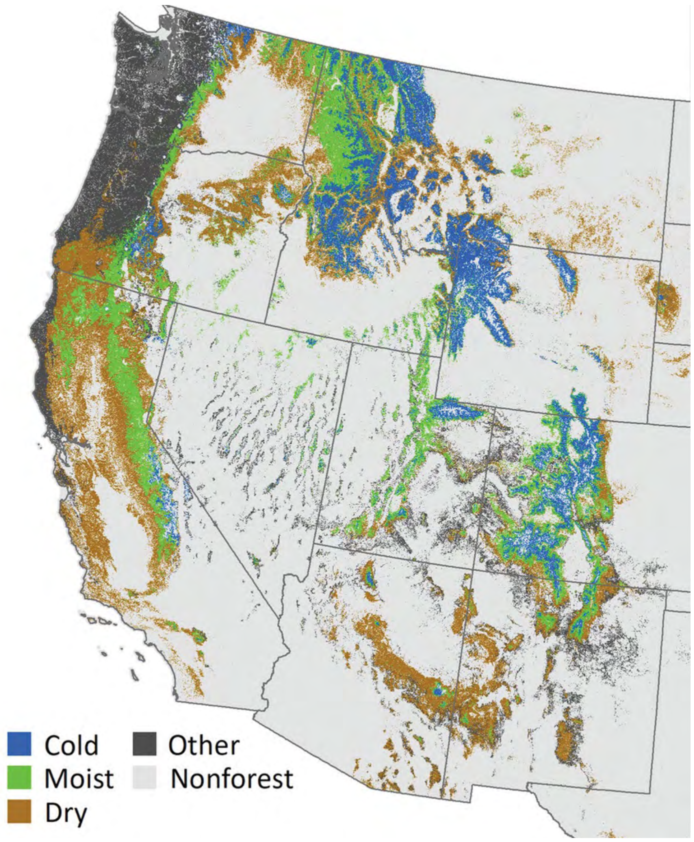


Figure 2. Forest types across the Western US. Adapted from Figure 2b from Hagmann et al. (2021).

Fire is an important ecological process for these forests, and efforts to restore natural processes are mainly focused on reintroducing frequent low and mixed severity fire to the landscape (Stephens, Battaglia, et al. 2020). Many of California's forests are degraded in part because there is a deficit of frequent, low-severity fire and an increase in high-severity fire (J. N. Williams et al. 2023; Cisneros et al. 2017). Prior to European colonization, an estimated 4.5 million acres burned annually across the state, and smoke was likely an ever-present reality during fire seasons (Ryan, Knapp, and Varner 2013; Stephens, Martin, and Clinton 2007; Leenhouts 1998). Many of these fires were intentionally ignited by Indigenous peoples to achieve cultural and resource management benefits. Over the past century, forests have experienced much less wildland fire due to fire suppression policies and prohibitions against Indigenous cultural burning practices (Marks-Block and Tripp 2021). Additionally, contemporary fires are burning with greater proportions and larger patch sizes of high-severity fire (Miller and Safford 2012; J. N. Williams et al. 2023). For these fire-deficit forests, restoration is best achieved, in part, by reintroducing the regular occurrence of ecologically beneficial fire back to the landscape.

Definitions Box 1. Types of Fires.

Types of Fires

- **Wildland Fire:** Any fire that occurs in vegetation, natural fuels, rangelands, or wildlands. Wildland fires may also spread into developed areas and burn homes, cars, and other human-made materials. Collectively refers to wildfires, prescribed fires, and cultural fires.

- **Wildfire:** A wildland fire originating from an unplanned ignition, such as lightning, volcanos, and unauthorized or accidental human-caused fires.

  - **Suppression Wildfires:** Wildfires managed with the strategic intent to confine or extinguish the fire as quickly as possible to limit the number of acres burned and to avoid negative catastrophic outcomes. Also includes beneficial fires that have escaped control and are subsequently declared wildfires to be managed for suppression.

  - **Managed Wildfires (for resource objectives and ecological purposes):** Wildfires managed with the strategic intent to promote spread across wildlands under desirable conditions to achieve specific beneficial wildland management objectives, including fuels reduction, ecosystem resilience, carbon resilience, watershed management, and reducing the risk of future catastrophic fire.

- **Prescribed Fire:** A wildland fire originating from a planned ignition in accordance with applicable laws, policies, and regulations to achieve specific wildland management objectives. Includes both broadcast burns (fires allowed to burn across a tract of land) and pile burns (fires that burn stacks of vegetation that have been collected into a pile).

- **Cultural Fire:** Also referred to as cultural burning, traditional fire, or Indigenous prescribed fire. The purposeful use of wildland fire by Tribes, Tribal organizations, or Indigenous individuals to achieve a variety of purposes and outcomes including wildland management objectives, stewardship goals, and spiritual reasons. Generally considered to have similar land management outcomes, but with distinct implementation from prescribed fire. Cultural fire may also involve preparing cultural materials and post-burn stewardship (e.g., raking ash into soil to promote plant regrowth).

- **Agricultural Fire:** A type of prescribed fire employed on land used, or intended to be used, for raising crops or grazing.

Sources: (NWCG 2022; Clark, Miller, and Hankins 2022; California Wildfire & Forest Resilience Task Force 2022)

Fuels reduction treatments are designed to alter forest structure in ways that specifically affect fire behavior and reduce the risk of uncontrolled, catastrophic wildfire. For California's mixed-conifer forests—affected by a long history of fire exclusion—mitigating fire risk is typically achieved by reducing the density per acre of small diameter trees and surface fuels. Fuels reduction treatments can employ many of the same techniques as forest restoration and, depending on the prescription, can also accomplish restoration objectives. However, because fuels reduction projects are narrowly designed to focus only on increasing wildfire resistance, they do not always align with broader restoration objectives to improve forest resilience to multiple disturbances (e.g., drought, insects, and fire). For instance, a treatment prescription that reduces the density of small trees in a young stand while creating patchier tree spacing would achieve both fuels reduction and restoration objectives. Conversely, a treatment prescription that reduces tree densities to a uniform tree spacing may achieve fuels reduction objectives but not fully meet restoration objectives (Stephens et al. 2021).

Stewarding healthy forests will rely on the ongoing use of treatments spread across landscapes and frequently repeated in perpetuity (Hunter and Robles 2020; Williamson et al. 2016; Jones et al. 2022; U.S. EPA 2021). The effect of any single individual treatment might be small, but when paired with other treatments, the feedback between successive treatments across the landscape and over time can compound their cumulative benefits (North et al. 2021). For example, a wildfire in an untreated part of the forest might burn at such a high intensity that it easily jumps an adjacent fuel break treatment to burn catastrophically into a town. However, a similar wildfire in a proactively treated forest might burn at a lower intensity such that the adjacent fuel break is effective at reducing the spread of the fire into an urban area, thus improving fire management and containment strategies. Similarly, a mechanical thinning treatment, followed the next year by a prescribed fire, may generate more benefits than either treatment would have on its own (Stephens and Moghaddas 2005; Schwilk et al. 2009; Moghaddas et al. 2018).

1.2 Forest management strategies will lead to smoke trade-offs

A robust body of evidence demonstrates that wildfire smoke exposure can lead to numerous adverse physical health outcomes (including respiratory and cardiovascular mortality and illness) and behavioral and mental health outcomes that disproportionately impact vulnerable populations (Hill, Jaeger, and Smith 2022; Jaffe et al. 2020; U.S. EPA 2021; D'Evelyn et al. 2022; Cascio 2018). Wildfire smoke impacts populations close to wildfires in the Wildland Urban Interface (WUI), as well as millions of people across large geographic extents when wind patterns transport smoke far from the wildfire footprint.

Definitions Box 2. Forest Conditions.

Forest Conditions

Terms describing forest condition do not have strict definitions and there is considerable ongoing debate in the literature resulting in multiple proposed definitions for each term. The definitions used in this study are taken from U.S. Department of Agriculture Forest Service policy documents that set management policy for public forest lands; see citations for additional discussion.

- **Healthy Forest:** Forest conditions that provide for human needs and the resilience, recurrence, persistence, and biophysical processes that lead to sustainable ecological conditions (Kolb, Wagner, and Covington 1994; Trumbore, Brando, and Hartmann 2015).
- **Resilient Forest:** The capability of an ecosystem to endure disturbances (e.g., wildfire, drought, etc.) and retain its structure and functions; the capacity of an ecosystem, which is subject to disturbance or change, to reorganize and renew itself (Bone et al. 2016).
- **Degraded Forest:** Changes within the forest which negatively affect the structure or function of the stand or site, and thereby lower the capacity to supply products and/or services. Forest degradation results in biodiversity loss, greenhouse gas emissions, and diminution of ecosystem goods and services (Stanturf et al. 2014; Ghazoul et al. 2015; Vásquez-Grandón, Donoso, and Gerding 2018).

During much of the last century, most of California's forests were unmanaged (aside from fire suppression efforts) under a de-facto no-treatment strategy (Laaksonen-Craig, Goldman, and McKillop 2003; Holland et al. 2022; Quinn-Davidson and Varner 2011). At the same time, fire suppression policies across Western North America led to the majority of fires being extinguished quickly. Between 1997 and 2002, 97% of all fires were contained before they reached 300 acres (Calkin et al. 2005). This widespread suppression meant that the negative smoke impacts of the no-treatment strategy for any forest were minimal (***Figure 3a***). However, the current climate and degraded forest conditions are now fueling wildfires that regularly exceed our suppression capabilities and produce widespread harmful levels of smoke (***Figure 3b***; Wang et al. 2020; U.S. EPA 2021; Fann et al. 2018). As a result, the health costs of smoke from wildfires burning through unhealthy forests are now conservatively measured in the billions of dollars (Wang et al. 2020; U.S. EPA 2021; Fann et al. 2018), creating monumental financial impacts on exposed populations and the health sector.

California and federal land management agencies have adopted strategies to increase the pace and scale of forest management, including a commitment to jointly treat 1 million acres per year in California by 2025, through a Shared Forest Stewardship agreement (California Forest Management Task Force 2021; Brown Jr. 2018; State of California and US Department of Agriculture Forest Service 2020). Forest management strategies that restore beneficial fire to the landscape—such as prescribed fire, cultural burning, and managed natural fire—create smoke and incur at least some adverse health impacts (***Figure 3c***). However, beneficial fires are expected to have relatively fewer negative health impacts than a similarly sized wildfire due to the ability to control the conditions under which the fire produces smoke, the lower intensity of the fire, and the opportunity to notify communities in advance to prepare for smoke (Hill, Jaeger, and Smith 2022). The smoke from beneficial fire can also provide benefits to human health by improving the health of many traditional foods and resources important to Indigenous communities (Long et al. 2016; David, Asarian, and Lake 2018; Long et al. 2017).

A smoke-free future is no longer possible for California. The new reality of frequent, large, destructive wildfires in California suggests that the expected smoke costs of management strategies to improve forest health (even those that rely extensively on beneficial fire) could now be much lower than the expected smoke costs of business-as-usual, no-treatment strategies (Williamson et al. 2016; Schweizer and Cisneros 2017; Jones et al. 2022). It is no longer a foregone conclusion that increasing beneficial fire to restore forest health would result in a net negative impact to human health.

> 1. **Finding:** Forest management strategies to restore forest resilience for ecological benefit are expected to expand the use of beneficial fire and to have at least some negative impact to human health from smoke exposure.

> 2. **Conclusion:** Whether or not the expected smoke impacts from resilient forests are greater or less than the expected smoke impacts from degraded forests depends on the context and requires careful study.

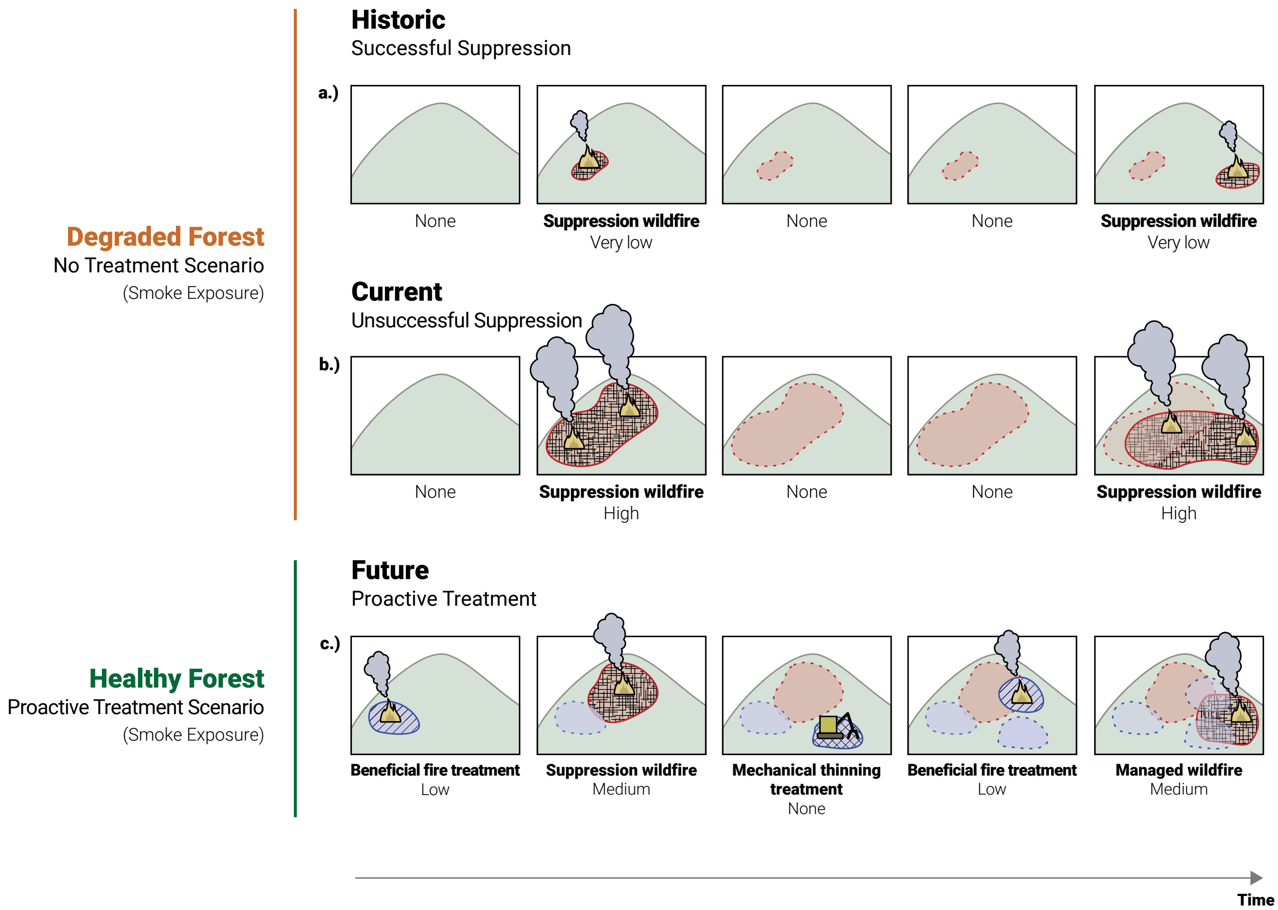


Figure 3. Expected smoke exposure from degraded forests compared to healthy forests under alternative treatment scenarios. Adapted from Figure 1 from Hunter and Robles (2020) and Figure 1 Jones et al. (2022).

(a) and (b): No-treatment scenario. Forested area receives no treatments to improve forest health and all wildfires are managed for suppression (red footprints). Smoke impacts are minimal **(a)** when suppression efforts are generally effective at keeping burned acres low. Smoke impacts can be large **(b)** when uncontrolled wildfires exceed suppression capabilities and burn millions of acres.

(c): Proactive-treatment scenario. Forested area receives a series of treatments (blue footprints) spread across the landscape and over time to improve forest health and reduce the catastrophic impacts of wildfires managed for suppression. Depending on conditions, the amount of smoke produced by a healthy forest could be less than an unhealthy forest.

Definitions Box 3. Forest Management and Treatment Activities.

Forest Management

Forest management can broadly be defined as the practical application of ecologic, economic, and social principles to the management and conservation of forests to meet various specific goals and objectives. Here we use the term ‘forest management’ to collectively refer to treatment activities with the goal of forest restoration to improve forest health and/or fuels reduction to reduce wildfire risk.

Examples of Treatment Activities

- **Beneficial Fire:** Also referred to as good fire. Wildland fires that are purposefully used to achieve specific goals and objectives. Collectively refers to managed wildfires, prescribed fires (see ***Definitions Box 1***), and cultural fires.

- **Mechanical Thinning:** In Western North American forestry, mechanical thinning is commonly used to refer to mechanical logging methods to selectively harvest commercial and non-commercial trees, often to meet fuel reduction, forest restoration, or other management goals and objectives through a combination of thinning from below and crown thinning (removing selected branches from the crowns of trees to decrease the density of the forest canopy) (Knapp et al. 2004; Stephens and Moghaddas 2005; Schwilk et al. 2009).

- **Mastication:** Re-arranging forest vegetation (e.g., small trees and shrubs) and downed material by chipping, shredding, or grinding material into smaller pieces to alter the arrangement of fuels and modify potential fire behavior. Mastication can be used to mechanically thin when re-arranging small trees from live fuels standing on the landscape into dead and down surface fuels.

- **Hand Thinning:** This term is commonly used in Western North American forestry to describe thinning from below using hand operated chainsaws. The slash or refuse material could then be piled by hand in small piles, left to cure, and then burned in the wetter season. Hand-thinned slash and debris could also be chipped and removed or spread on the site.

1.3 Cross-sector collaboration to meet shared goals

Forest management projects are primarily designed to improve ecological resilience and reduce wildfire risk, but there are also many co-benefits. Resilient forests are at lower risk for destructive, high-intensity wildfires while also providing a host of ecosystem service benefits (Covington 2000; Kalies and Kent 2016; Hurteau et al. 2019; Schoennagel et al. 2017; Stephens et al. 2012). Treated forests can protect water supplies and water quality, reduce risk to infrastructure, protect habitat, and provide many other benefits compared to untreated forests (Seipp et al. 2023). Given these multiple benefits, coordination and collaboration between those traditionally responsible for decision making (e.g., public and private forest and land managers, policymakers, state and federal agencies, etc.) and those impacted by forest management but not traditionally involved (e.g., water and electric utilities, health entities, etc.) can benefit all parties and help realize shared goals. The goal of working together is not for relevant and interested parties in non-forestry sectors to make technical decisions around forest management activities, but instead for these parties to support, promote, and provide perspectives that can lead to improved outcomes for all.

Examples of this collaborative approach demonstrate the potential for results. Healthy forests are critical for water supply provisioning, but more than half of our water supply comes from forested land that is managed by the federal government rather than by the water utilities themselves (N. Liu et al. 2021). This mismatch has led to some in the water sector engaging in forest management. Water suppliers across the Western U.S., such as those in Denver, Colorado; Flagstaff, Arizona; Ashland, Oregon; and Yuba County, California, have all partnered with public land managers to help fund forest management to decrease the risk of severe wildfire and protect their headwaters (Seipp et al. 2023). These contributions catalyze and accelerate work to the financial benefit of both the water and land managers, but also the local communities. As another example, California's Wildfire and Forest Resilience Task Force includes a goal around sustainable and accessible recreation, which ensures that recreation is considered in decision making. This inclusion is critical given the interconnectedness of forest health, outdoor recreation, and sustainable rural economies. In all cases, collaboration is meant to advance the mutually beneficial goal of forest resilience.

Degraded Forest No Treatment Scenario	**Healthy Forest** Future Proactive Treatment Scenario
↑ **Smoke emissions**, dispersion, and population exposure.	↓ **Reduced** smoke emissions, dispersion, and population exposure.
↑ **Adverse health impacts** and health sector organizational impacts from wildfire smoke exposure.	↓ **Reduced** adverse health impacts and health sector organizational impacts from wildfire smoke exposure.
↑ **Financial costs** to the public, vulnerable populations, and health sector.	↓ **Reduced** financial costs to the public, vulnerable populations, and health sector.

Figure 4. The potential population smoke exposure, health, and health sector tradeoffs of alternative forest management scenarios.

There is evidence that accelerated and additional forest management, compared to the current pace and scale, improves ecological functioning and resilience, which can lead to significant cost savings for land managers by reducing wildfire suppression costs (Holland et al. 2022). If forest management also leads to decreased wildfire smoke emissions and population exposure, reduced adverse health outcomes, and cost savings for the health sector, there is an opportunity for land managers and the health sector to partner in pursuit of the shared goal of resilient forests (***Figure 4***).

Potential avenues for health sector engagement and collaboration with public and private land managers could include (but are not limited to):

- Including a more holistic analysis of smoke-related health impacts in both environmental and public health planning and implementation;
- Cost-sharing forest restoration projects to accelerate the pace and scale of work;
- Advocacy to state regulators to expand prescribed burn windows to accelerate the pace and scale of work; and/or
- Working together to help the public safely live with wildfire and wildfire smoke through communication and educational outreach about beneficial fire, preparedness, and personal protection.

There is growing consensus that the potential for a smoke-free future does not exist for California (Petek 2022; NASEM 2022b). Wildfire smoke is expected to worsen with climate change, further elevating this crisis and amplifying adverse health impacts. California's forests will burn, but managed healthy forests are expected to burn differently than unmanaged degraded forests (Schweizer, Preisler, and Cisneros 2018; Blades et al. 2020). However, the extent to which improving forest health could result in human health benefits is now a scientific question requiring careful study (Jones 2017).

3. **Finding:** Given the multiple benefits of resilient forests, cross-sector, multi-stakeholder collaboration during the planning and implementation of forest management projects can yield benefits for multiple sectors.

4. **Conclusion:** Bringing in additional sectors that are impacted by degraded forests and could therefore benefit from forest management, like the health sector, could be mutually beneficial for improved health outcomes and more resilient forests, but exploration of the interest, motivations, and barriers to this collaboration is required.

1.4 Goals and organization of the report

Because of the wide spatial extent of smoke events, as well as the large number of people who experience health impacts of degraded air quality, improved health outcomes could be one of the largest sources of value in reducing wildfire risk. Although the direct and indirect links between forest management and protected human health are complex, there has been a recent call to better integrate the health sector into forest management practice and planning (D'Evelyn et al. 2022).

The goal of this study is to lay the foundation for facilitating this integration in two main parts:

Part I: Qualitative Interviews

We conducted interviews with 60 individuals at public health, health system, and health insurance organizations working in California to better understand their perceptions around wildfire smoke, wildfire smoke impacts, and forest management as a tool to decrease risk. We also explored motivations, barriers, information, and institutional structures needed for health sector engagement in forest management.

- ***Chapter 2: Perspectives on Wildfire Smoke Impacts to Human Health and the Health Sector in California***
- ***Chapter 3: Perspectives on the Connections Between Forest Health and Human Health***

Part II: Literature Review

We conducted a literature review of scientific research on the connections between forest health, wildland fire smoke, and human health. We reviewed peer-reviewed academic literature, technical reports, and other publicly available data resources and modeling tools relevant for understanding the potential human health benefits of improving forest health in California (additional details in ***Appendix K***). For smoke data products and modeling tools, we focused our review on resources that report California-specific data. For studies evaluating the smoke tradeoffs of forest management, we expanded our review to include any relevant research worldwide due to the limited number of published studies. The review includes studies and resources published prior to May 31, 2023.

- ***Chapter 4: Data Resources for Estimating the Health Impacts of Smoke***
- ***Chapter 5: Evidence that Forest Management can Benefit Human Health***.

Part I: Qualitative Interviews with California Health Sector Organizations

Chapter 2: Perspectives on Wildfire Smoke Impacts to Human Health and the Health Sector in California

Authors: Signe Stroming, Kirsten Hodgson, Kimberly Quesnel Seipp, Clare Loughlin, and Phil Saksa

Wildfire smoke impacts human health and health sector organizations' workforces, operations, and ability to provide services, yet the costs are largely unquantified.

Health impacts from wildfire smoke may be the largest cost of wildfires. Studies suggest that the economic cost of short- and long-term health impacts associated with smoke exposure across the nation reach nearly $100 billion annually, although they are still under-quantified (Bayham et al. 2022; Fann et al. 2018; CCST 2020). If there is an opportunity for improved health outcomes and organizational cost savings from decreased wildfire smoke, because of forest management, then increased collaborative engagement between land managers and the health sector could lead to benefits for both parties. Providing funding to accelerate work, advocating for increased forest management including beneficial fire, considering health trade-offs in forest management planning and implementation, and developing coordinated public communication campaigns are all potential ways for the health sector to engage in forest management. The first step to facilitating this potential engagement is to understand the health sector's perspectives on these issues.

Here we describe findings from our interviews about health sector concerns about wildfire smoke and the health, organizational, and financial impacts of wildfire smoke events. ***Figure 5*** is a conceptual diagram of the impacts that the health sector is experiencing.

2.1 Methods and motivations

The goal of our exploratory qualitative study was to uncover the ways in which California health sector organizations experience the impacts of wildfire smoke and to evaluate their understanding of the linkages between wildfire smoke, human health, and forest health. We chose semi-structured, conversational interviews as our research approach over other methodologies (e.g., surveys) because the topic of forest management is new to the health sector, so we anticipated that interviews would lead to more dialogue and richer insights than a survey.

California's health sector (together with educational services) represents 7.5% of the state's GDP and includes a wide array of roles and sub-sectors (California State Assembly 2023). We focused on the three segments within California's health sector that research suggests are most impacted by wildfire smoke, either directly or by supporting those affected:

- Public health, including local, state, and Tribal governments; and non-governmental organizations.
- Health systems, including hospitals, clinics, and healthcare delivery organizations.
- Health insurers, including those serving Medicare and MediCal groups.

We sought to interview people who work in public health, especially at the local level, because of public health's focus on preventative action and their ability to provide insight into the broader communities they serve. We also wanted to hear perspectives from those running health systems or facilities in both rural and urban areas of the state, and from health insurance organizations that may be observing trends in care utilization or costs due to increased emergency room visits and care due to smoke impacts. We sought interviewees whose positions and experience enabled them to speak to the perspectives of their organization or a larger segment of the healthcare sector. Hereafter, we refer to these groups collectively as 'the health sector.'

Between June and December 2022, we reached out to 342 individuals representing 214 unique California-focused health organizations as potential interviewees. Our outreach was conducted via email, as phone numbers were not uniformly available for potential interviewees, and we lacked staff capacity for in-person outreach or phone calls. To explicitly incorporate perspectives from Tribal communities in California, we conducted targeted outreach to both federally recognized and non-federally recognized Tribes. However, we received few responses from potential interviewees serving Tribal governments and communities. Several factors, including email as our exclusive mode of outreach, the study team's positionality as non-Tribal researchers or organizations, as well as limited capacity and resources among Tribes, may have contributed to the low response rate. Future work in this area would benefit from additional modes of contact, investing more resources in overall outreach, relationship building with Tribal communities, and the inclusion of Indigenous leadership within the study team.

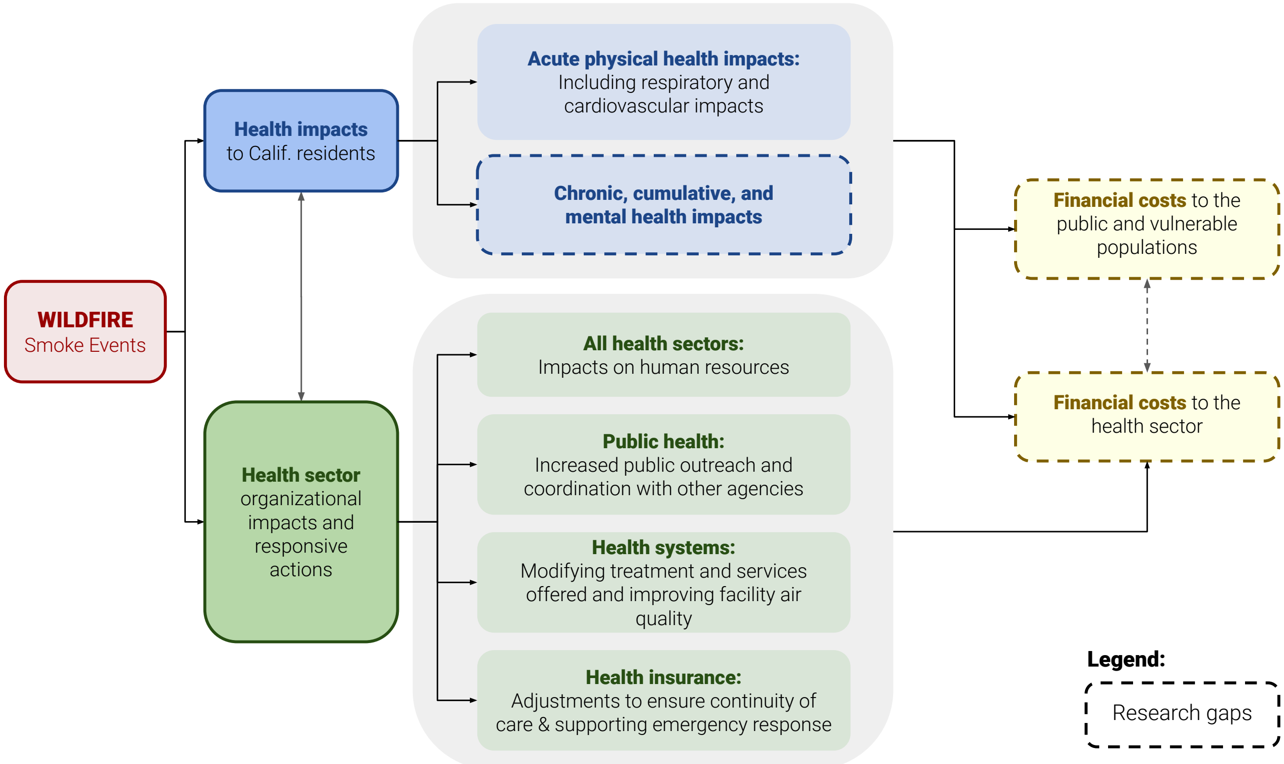


Figure 5. Conceptual diagram of wildfire smoke impacts on the health sector in California.

We conducted 56 semi-structured, exploratory interviews, with a total of 60 interviewees. A small number of our interviewees (n=4) did not belong to one of the three main health sector categories but were included because they had specific experience interacting with the California health sector and wildfire smoke events. These four interviewees represented a school district, a foundation, and a consulting group. ***Table 1*** describes interviewee breakdown by geographic region and organization type across interviewees. Our interviews capture perspectives from individuals who responded to email outreach from July to November 2022, when there were varying levels of air quality issues from wildfire smoke across the state of California, which could have impacted their responses based on personal lived experiences.

We structured our interviews in two sections. First, we explored interviewees' baseline levels of concern and direct experience with wildfire smoke,[1] guided by the following questions:

1 In our interviews, we did not differentiate between "wildfire smoke" and "wildland fire smoke," where the former refers to smoke from a wildland fire with unplanned ignition, and the latter more broadly includes planned ignitions such as prescribed fire or cultural burning (see Definition Boxes). "Wildfire smoke" was a more accessible term for our interviewees, and while any wildland fire has smoke impacts, we found our interviewees generally described impacts from smoke associated with wildfires, rather than smoke from prescribed fire or cultural burning.

Table 1: Total individuals interviewed (60*), by organization type and service region.

	Count (60)	Percent (100%)
Organization Type		
Public Health †	36	60%
Health System	13	22%
Health Insurance	7	12%
Other**	4	7%
Service Region* **		
Northern CA	24	40%
Central CA	10	17%
Southern CA	5	8%
State-wide	21	35%

* This table does not include one discarded interview, which was determined to be outside the population of interest.

† Public health interviews include interviews with state, local, and Tribal governments as well as non-governmental entities

** As our interviews progressed, we occasionally were referred to people whose work experience was aligned with our research goals but who did not work for one of the above categories. Our "Other" group thus includes a school district, grantmaking organization, and consultant.

*** Interviewees representing organizations serving groups in different parts of California. In some cases, interviewees represented organizations that operated across all of California or in multiple states. These are represented as "state-wide" interviewees. We based our classification of counties into Northern, Central, and Southern California regions on the delineations used by California Parks & Recreation CEQA notifications (CDPR 2023).

(1) is the health sector concerned about wildfire smoke and its impacts on the health of people living in California, and (2) how has wildfire smoke been impacting California's health sector organizations? Next, we explored potential opportunities for greater health sector engagement in forest management as a tool to decrease wildfire smoke risk, guided by the following questions: (1) is the health sector aware of forest management and its potential links to public health, and (2) is the health sector interested in engaging with public and private land managers around forest management and what are the motivations, barriers, and future opportunities for health sector participation in forest management? In their responses to our interview questions, interviewees were asked to speak to the perspective of their organization, to the extent possible.

All interviews were conducted virtually via Zoom and lasted one hour or less in duration. Interviews were recorded and transcribed with participant's verbal consent and uploaded into Dedoose, a software platform for qualitative research coding and analysis. We conducted our analysis in Dedoose through qualitative coding of patterns and themes. We used these codes to develop the Findings, Conclusions, and Recommendations of this report, which included identifying emergent cross-cutting themes. Themes and findings from our interviews are discussed in this chapter.

Appendix B: Qualitative Interview Methods through ***Appendix G: Memo to Steering Committee on IRB Requirements*** include details about our methods (including our interview guide and codebook), outreach and recruitment materials, and a list of interviewed organizations who consented to being listed in this report. Where possible, we provide examples of relevant patterns and themes in interviewees' own words; these quotes can be found in-text and in ***Appendix A: Supplemental Quote Tables***.

2.2 Health sector concern about wildfire smoke

Almost all interviewees said that their organizations are concerned about wildfire smoke. Many interviewees cited specific wildfires as the reason for their organization's concern about wildfire smoke. Interviewees tended to mention wildfires that had direct impacts on medical infrastructure or smoke events that affected major urban areas for long durations of time. Many interviewees cited the 2017 Tubbs Fire in Napa and Sonoma Counties as the start of their organization's concern with wildfires and wildfire smoke. Interviewees mentioned that the Tubbs Fire burned medical infrastructure and occurred in October when school was in session, leading to smoke-related school closures in the San Francisco Bay Area and elevating the need for public health guidance on how to reduce smoke exposure for children. A few interviewees also mentioned earlier fires, such as the 2013 Rim Fire in Tuolumne County, as the impetus for their organization's growing concern about wildfire smoke.

A few interviewees, particularly those serving coastal areas, described themselves as concerned when wildfire smoke is present in the air, but noted that is not a frequent occurrence. The few people who said that wildfire smoke is not a major concern could still point to specific fires or smoky years that impacted their or other populations.

Many interviewees, particularly those serving populations in fire-prone areas and/or the Wildland Urban Interface (WUI), emphasized that their concerns about wildfire smoke are intertwined with concerns about other wildfire impacts, including emergency evacuations and displacement; destruction of physical infrastructure and rebuilding costs; and facility closures or other disruption of medical care.

Many interviewees observed that the level of wildfire smoke they experience has increased over time, and that their organizations have grown more concerned about wildfire smoke in the last five to 10 years. Most of these interviewees also noted that wildfire seasons have been getting worse over time. Interviewees serving Tribal governments emphasized that while catastrophic wildfires seem to be increasing recently, Indigenous people have burned the landscape to manage the land since time immemorial, and the cessation of much of that burning has contributed to catastrophic wildfire risk.

Table 2 provides examples of interviewees' level of concern regarding wildfire smoke in their own voices.

> 5. **Finding:** Health sector organizations have grown more concerned about wildfire smoke, and wildfires themselves, in the last five to 10 years, largely driven by their experience with specific wildfire events.

2.3 Perspectives on wildfire smoke impacts to human health

All interviewees described concerns about the direct, acute health impacts of wildfire smoke exposure on specific populations they serve or the general population in California. The most mentioned health impact was the onset or exacerbation of respiratory disease. Specific respiratory concerns included COPD, asthma, emphysema, and lung cancer. The second most common health impact mentioned was cardiovascular disease. Other physical health categories of concern included stroke, migraines and headaches, and exacerbation of seasonal allergies.

In addition to these concerns about direct, acute health impacts during or directly following wildfire smoke events, several interviewees described concerns and a desire for more information about the long-term and cumulative effects of wildfire smoke exposure.

Many interviewees emphasized concerns about the health impacts from wildfire smoke exposure for specific vulnerable populations, including the elderly, children, and pregnant women. Similar concerns were raised regarding disadvantaged communities, such as those who have been racially marginalized, work outside, cannot afford home air filtration, or do not speak English. Interviewees shared that, because these populations have a high prevalence of health conditions, exacerbation of pre-existing conditions is their highest concern, along with inequitable access to resources to prepare for and respond to smoke events. Another exacerbating factor described by interviewees is that some communities in California already have poor air quality, especially in the Central Valley. Some interviewees serving Tribal governments highlighted that Tribal Nations have been displaced from their ancestral lands and in many cases moved to locations with more environmental hazards, such as greater smoke exposure.

Table 2: Voices from health sector interviewees on concern about wildfire smoke.

Theme	Illustrative Quote
Concern about wildfire is growing in the health sector.	**Q1.** "It's pretty much a standard concern anytime we have a wildfire close to here, just because of the weather phenomenon of inversions and these mountain valleys… Anytime there's a fire close, we have air quality problems." – Health System Interviewee [id303] **Q2.** "What we've seen is an increase in frequency and duration [of wildfires]. So you have an entire population of folks just consumed by the thickest smoke you could possibly imagine, for months on end, and it settles in these valleys and just stays there. And so you have people with pre-existing conditions, that have asthma or COPD, and that gets exacerbated, which does strain our operations. And as you can imagine, too, the smoke infiltrates into our buildings. So you're attempting to provide care in an environment that is potentially unsafe to people that are already sick." – Health System Interviewee [id096]
Wildfire smoke is not a primary concern but has impacted us in the past.	**Q3.** "It's very low on the list of concerns. Although when a fire happens and there's a lot of smoke that we're all breathing, then it becomes a concern. But…from within [my organization in] the health system… for the most part, it's something that most doctors and nurses don't think about, to be honest." – Health System Interviewee [id561]
Concern about health impacts from wildfires and wildfire smoke are intertwined.	**Q4.** "2017 really was sort of a precipitating event that [showed that wildfire smoke] is a real concern. Beyond just the immediate injuries and deaths associated with [the fire] and the property destruction, we know that we're seeing incredible health impacts well beyond the borders of where a fire is." – Public Health Interviewee [id626]

Differential vulnerability to impacts from wildfire smoke are discussed further in ***In focus: Wildfire smoke impacts on vulnerable populations.***

Impacts on mental and behavioral health for the interviewed organizations' service populations emerged as a recurring theme. Mental health impacts were generally tied not only to wildfire smoke, but wildfires themselves, and associated with the psychological impact of evacuations, losing homes, and fear of future fires. Some interviewees identified the smell of wildfire smoke as a trigger for feelings of trauma and fear associated with wildfires. Most interviewees who mentioned mental health impacts also described the lack of research and probable under-representation of mental health in wildfire smoke impact assessments.

In ***Chapter 4: Data Resources for Estimating the Health Impacts of Smoke***, we explore the available literature on health impacts from wildfire smoke exposure.

> 6. **Finding:** Health sector organizations recognize that wildfire smoke causes negative health outcomes, particularly for vulnerable populations, but identify knowledge gaps about the chronic, cumulative, and mental health impacts of wildfire smoke exposure.

In focus: Wildfire smoke impacts on vulnerable populations

Many interviewees emphasized that vulnerability to wildfire smoke impacts is not uniformly distributed across California. Below, we share how our interviewees described differential impacts from wildfire smoke on vulnerable populations in California, and how groups representing and serving those populations are taking action to respond to and prepare for wildfire smoke events (***Figure 6***). Here we use the California Department of Public Health's (CDPH's) and the Centers for Disease Control and Prevention (CDC's) climate and health vulnerability framework to frame interviewees' perspectives, where vulnerability is understood to be the propensity to be adversely affected and is defined as a function of exposure, sensitivity, and adaptive capacity (CDPH 2021; Manangan et al. 2014). In ***Chapter 4: Data Resources for Estimating the Health Impacts of Smoke***, we discuss existing data resources on population vulnerability as an input for estimating health impacts from wildfire smoke exposure.

Exposure: First, interviewees described groups who are more vulnerable due to greater exposure to wildfire smoke. These groups include agricultural or other outdoor workers, the unhoused, and those with substandard housing or who do not have access to indoor air ventilation or filtration. Also, some groups are already disproportionately exposed to poor air quality by the nature of where they live, such as those in California's Central Valley, where agriculture, industry, and traffic emit air pollutants that are trapped in the valley due to its unique geography.

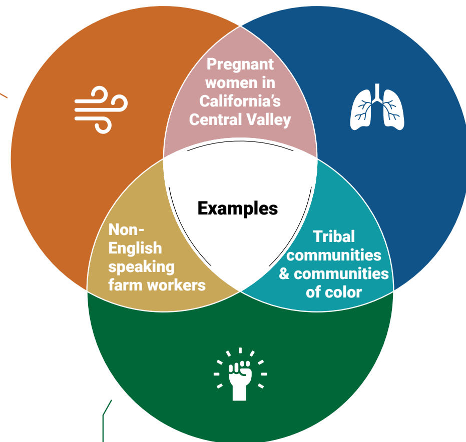
Q5. "[Wildfire smoke] is a contributing factor to the nation's already worst air quality in the country." – Interviewee serving a Tribal community [id089]

Sensitivity: Second, interviewees described certain demographics that are more sensitive or susceptible to adverse health outcomes from wildfire smoke exposure due to physiological differences, such as children, the elderly, and pregnant women. For example, interviewees pointed to exacerbation of asthma as a particular risk of wildfire smoke exposure for children. Interviewees also described vulnerability of those who have underlying health conditions that can be exacerbated by smoke exposure. Several interviewees serving Tribal governments and one interviewee serving communities of color highlighted higher rates of asthma, COPD, diabetes, and heart disease in their communities. Those in the Central Valley mentioned higher rates of Valley Fever (coccidioidomycosis), a fungal infection that can cause lung problems. One rural interviewee noted that higher rates of smoking predisposed their community to lung diseases, which are exacerbated by frequent wildfire smoke events.

Adaptive capacity: Third, interviewees described groups that are vulnerable because of their limited ability to adapt to or recover from wildfire smoke events. Several interviewees noted that socioeconomically disadvantaged groups may be unable to take protective measures, such as weatherizing their home, traveling to a Clean Air Space, or staying home from work if their work is outdoors. Other interviewees described barriers certain groups face in accessing care when they experience adverse health outcomes: socioeconomically disadvantaged groups may be unable to seek or pay for treatment; communities of color have historically faced discrimination and differential treatment in health systems; and undocumented immigrants may experience both financial barriers and discrimination, as well as a fear that seeking healthcare may increase likelihood of deportation. One interviewee also highlighted that agricultural workers in their community often speak little English or Spanish, instead speaking Indigenous languages, and thus could not receive air quality advisories or guidance.

Exposure

- **Populations living in areas that tend to have poor air quality**, such as wildfire-prone parts of the Sierra Nevada or California's Central Valley
- **Outdoor workers**, including agricultural laborers
- **Unhoused populations** or groups with substandard housing that lack access to indoor air ventilation or filtration



Sensitivity

- **Children, the elderly, and pregnant women**
- **People with pre-existing health conditions**, particularly respiratory or cardiovascular conditions
- **Tribal communities and communities of color** who have higher rates of underlying health conditions due to racism, disparities in health access, intergenerational traumas, and minority stress

Adaptive Capacity

- **Poor or socioeconomically disadvantaged groups** who cannot afford to take protective actions or absorb increased healthcare costs
- **Groups structurally or systematically excluded** from health systems
- **Individuals who do not speak English or Spanish** and who can't directly receive advisories or guidance

Figure 6. Interviewees described many factors that contribute to vulnerability to health impacts from wildfire smoke exposure. This figure displays the examples provided by interviewees, organized into the three domains of CDPH's Climate Change and Health Vulnerability Assessment Framework (CDPH 2021; Manangan et al. 2014).

Q6. "We have a lot of agricultural workers. We have a lot of people that don't have air conditioning or can't afford the air conditioning that they do have the infrastructure for, just because the power costs so much that all of these folks are vulnerable. And they may or may not speak English. And so they don't really get the news about heat waves coming on and where cooling shelters might be, or they may not have transportation to cooling shelters. So there's a lot of these kinds of logistical barriers that we know are going to make people vulnerable." – Public Health Interviewee [id880]

Q7. "We know that people have differential access to good health in [County] – we saw that during COVID as well. So our communities of color, in particular, Black, African American, Latinx, some of our Asian communities, all tend to be more vulnerable to effects of any conditions that threaten overall health in [County]." – Public Health Interviewee [id716]

Interviewees noted that these different types of vulnerabilities often coincide for certain demographics, especially Tribal communities, communities of color, agricultural and outdoor workers, and unhoused populations. Additionally, impacts from wildfire smoke may be amplified by, or coincide with, other health or environmental hazards such as extreme heat, drought, or COVID-19, and the same groups tend to be vulnerable to multiple hazards (see ***In focus: Other wildfire and wildfire smoke impacts and compound hazards***). Interviewees also noted that these groups are not only particularly vulnerable to acute health impacts from wildfire smoke exposure, but also likely more vulnerable to long term chronic impacts.

Q8. "The same communities that we're most concerned about during a wildfire and during wildfire smoke events, are the same communities that have just disproportionately been impacted by illness and death from COVID. They're the same communities that don't have adequate access to resources and services in their communities, from food to transportation to housing." – Public Health Interviewee [id626]

Q9. "My biggest concern is that those in the lower socioeconomic areas are going to suffer the most from chronic conditions later on." – Public Health Interviewee [id256]

Q10. "One of the big questions is what are the longitudinal impacts of wildland fire smoke? … As that smoke settles into our ag worker population, and you've got ag workers in the fields, …what's the impact of them seeing that same level of particulate matter day after day, week after week, recognizing that it's more impactful over time? We just don't have that data." – Public Health Interviewee [id850]

Organizations are taking diverse approaches to minimize risk to the vulnerable populations they serve:

- Multiple interviewees serving Tribal governments mentioned upgrading air filtration systems in Tribe-run healthcare facilities.
- Two interviewees serving Tribal governments described taking similar actions to county public health departments, including sending out air quality advisories, establishing Clean Air Spaces, and seeking to improve local, real-time air quality monitoring to enhance guidance.
- Two interviewees whose organizations serve vulnerable groups mentioned ongoing projects to analyze vulnerability in their communities and integrate findings into future climate resilience planning.
- One health system interviewee mentioned sending out teams to provide in-person outreach to unhoused populations during wildfire smoke events.
- One public health interviewee described efforts by local community-based organizations to translate air quality advisories into Indigenous languages to improve air quality guidance for the agricultural worker community.
- Another public health interviewee mentioned partnerships with the local housing authority to offer home weatherization assistance.

2.4 Wildfire smoke impacts to health sector organizations

After hearing about the health impacts of wildfire smoke, we asked interviewees if and how wildfire smoke has impacted their organizations. The impacts and associated responses they reported varied by organization type. However, the most mentioned organizational impact from wildfire smoke was consistent across sectors: the impact on human resources. These impacts include the inability of employees to travel to work, unsafe working conditions, and risks of damaging the mental and physical health of employees who may be required to provide essential care during wildfire smoke events. A few interviewees from wildfire-prone areas mentioned challenges with employee recruitment and retention due to frequent and severe wildfires and smoke. *Table 3* includes illustrative quotes of cross-sector impacts. Many interviewees, especially those serving populations in fire-prone areas and/or the WUI, described impacts from both wildfire smoke and wildfires. Hospital and clinic closures, emergency evacuations, and service interruptions tended to be described in relation to specific wildfires rather than wildfire smoke. Across the public health, health systems, and health insurance sectors, geography and proximity to wildfire events was associated with more impacts from wildfire smoke on both employees and operations. However, even interviewees located in less wildfire-prone areas described impacts from wildfire smoke.

While interviewees generally recognized that there are impacts to the health sector from wildfire smoke, health insurance interviewees tended to view their sector as less directly impacted by wildfire smoke than the public health and health systems sectors. For example, interviewees acknowledged that some insurance providers lacked a local presence, despite serving wildfire- and wildfire smoke-prone communities.

Given these impacts, we asked interviewees if and how their organizations are planning for future wildfire smoke events. Only a few organizations have created plans specifically for wildfire smoke response. Most plans mentioned were designed to address wildfire response (e.g., evacuations, emergency response, etc.), often as part of a Hazard Mitigation Plan. A few interviewees mentioned that wildfire preparedness was part of a larger climate adaptation or resilience plan. Within plans that had sections on wildfire, a few organizations included wildfire smoke advisories or communications. Public health entities often noted that their plans included advisory guidance or communications for schools.

> 7. **Finding:** The most common organizational impacts from wildfire smoke reported by health sector organizations in California are human resource impacts, including employees' inability to work due to the risk of smoke exposure, health impacts due to smoke exposure, and decreased recruitment and retention.

Table 3: Wildfire smoke impacts to organizations across health sectors with supporting quotes.

Impact or Responsive Action	Description or Examples	Illustrative quote
Cross Sector		
Impacts on employees	• Employees' ability to travel to work safely • Unsafe working conditions • If air filtration is not available, and it may impact the mental and physical health of employees • Health sector workforce recruitment and retention	**Q11.** "We walked in and it was really smoky, and everybody was wondering what to do. Should we go home? What's the safest place for us to be from a respiratory perspective?… it certainly impacted our ability to provide services for a while until we figured it out, and staff were worried about their health and safety." – Public Health Interviewee [id024] **Q12.** "Providers can't come in because of their own home housing situation. We've had some staff, probably a good number of them, suffer from migraines and headaches from smoke, and just really, just can't function. So our employee absenteeism goes up as a result." – Health System Interviewee [id530]
Impacts from wildfires themselves	• Destruction of healthcare facilities • Destruction of employees' homes • Closure of healthcare facilities • Power outages • Evacuation and displacement of people	**Q13.** "There [are] the wildfires themselves, and of course, the smoke as a consequence of the wildfires. So it's sometimes hard to separate those two … We are deeply affected by the wildfires themselves, having had health centers with whom we contract actually burned down, of course, and the homes and the displacement of a lot of our members, people being cut off from all of that by the fires themselves" – Health Insurance Interviewee [id171]

In focus: Other wildfire and wildfire smoke impacts and compound hazards

While our questions to interviewees largely centered around health and organizational impacts, interviewees volunteered additional concerns related to wildfires and wildfire smoke. Some interviewees mentioned other wildfire impacts with implications for health, including erosion, landslides, and drinking water contamination. Even natural disasters located elsewhere can compound wildfire smoke effects if they disrupt the medical supply chain: two interviewees described being unable to procure HEPA filters or masks due to hurricanes in the southeastern United States.

Additionally, interviewees mentioned the interaction between wildfire smoke and other events or environmental hazards. The two most mentioned compound hazard events were COVID-19 and extreme heat, with some interviewees also mentioning air pollution not related to wildfire smoke. Interviewees described how compounding impacts from multiple environmental or health hazards tend to impact vulnerable populations more than other groups (see ***In focus: Wildfire smoke impacts on vulnerable populations***).

Most interviewees mentioned COVID at least once in their interviews. ***Table A1*** includes quotes illustrating the ways that interviewees described how COVID and wildfire smoke events overlap and interact. The most common way that interviewees mentioned COVID was in relation to employee burnout and limited resources and capacity. Interviewees also frequently discussed how vulnerable populations disproportionately face the burdens of both COVID and wildfire smoke due to pre-existing health inequities and unequal access to healthcare services.

On the other hand, many interviewees said that due to COVID, their organizations were more prepared for air quality impacts during wildfire smoke events. They had purchased masks, upgraded air filters, and implemented other emergency response measures prior to wildfire smoke events, which led to better preparedness. COVID also led to the creation of new remote work infrastructure, and therefore those who work in offices could stay home during a smoke event. Similarly, COVID accelerated the adoption of virtual care, which was useful during wildfire smoke events.

Interviewees also frequently mentioned conflicting COVID and wildfire smoke guidance. For example, public health officials urged people to avoid gathering indoors to reduce the spread of COVID, whereas during wildfire smoke events, public health officials recommended staying inside with windows and doors shut (and air filtration in use) to reduce smoke exposure.

The second most frequently mentioned interacting event was extreme heat. As with COVID, many public health interviewees noted that guidance during times of extreme heat and wildfire smoke can be contradictory. Guidance around wildfire smoke often involves recommending that individuals stay inside to limit exposure, but for individuals without access to air conditioning during periods of extreme heat, public health guidance may recommend moving to cooler outdoor locations.

A final common interacting event brought up by many interviewees was air pollution due to smog, vehicle emissions, construction, or other sources. A few interviewees acknowledged wildfire smoke as a concern but characterized it as only one contributing factor to the air quality problems they already experience.

8. **Finding:** COVID has impacted health sector wildfire smoke response and preparedness in both negative and positive ways, such as reduced capacity and conflicting messaging about staying indoors (negative) and increased adoption of strategies to reduce exposure to airborne pollutants (positive).

9. **Finding:** Wildfire smoke events often coincide with extreme heat events, which result in conflicting recommendations for vulnerable groups without access to air conditioning or clean indoor air.

10. **Conclusion:** There is an opportunity to improve public health guidance on wildfire smoke response during multiple interacting events, such as COVID or extreme heat.

11. **Recommendation:** California health, emergency response, environmental, and research-focused agencies and foundations should work with the health sector to fund and develop guidance for public health entities and health systems faced with coinciding environmental and health emergencies.

2.4.1 Public health

Of the three groups interviewed, the public health sector has spent the most time considering wildfire smoke preparedness and response (***Table 4***). The most common way that public health entities respond to wildfire smoke events is public outreach and communication. In a few cases, interviewees from public health departments mentioned targeted outreach specifically to vulnerable populations. Public health entities disseminated information about Air Quality Index (AQI) levels and advisories, the health risks of wildfire smoke exposure, and available protective behaviors. These protective behaviors included staying inside during smoke events, wearing masks, and, in a few cases, information on creating homemade box fan air filters. A few public health departments directly distributed masks to the public or set up Clean Air Spaces, which are publicly available indoor spaces with filtered air during smoke events, though multiple interviewees expressed a desire for more information about the efficacy of these interventions. Interviewees also highlighted that wildfire smoke events often coincide with other events, such as COVID or extreme heat, and that this coincidence can complicate public health guidance (***In focus: Other wildfire and wildfire smoke impacts and compound hazards***).

Interviewees from local public health departments also often mentioned coordinating and partnering with other agencies or organizations during wildfire smoke events. These partnerships included coordination with the local Air District to issue air quality advisories, communicating with local healthcare facilities, and providing air quality information and guidance to school districts to inform school closures. New partnerships formed during or after wildfire smoke events were a frequently mentioned response by interviewees. Partnerships were almost always mentioned as part of communication plans—releasing joint materials, organizing meetings or work groups, collaborating on press releases, coordinating with groups that work with disadvantaged populations, etc. However, almost all communications were reactive; there were few mentions of organizations preemptively communicating about actions that the public should take during upcoming wildfire seasons. Some interviewees also mentioned a lack of available information about best practices for communicating and responding to wildfire smoke impacts. While there is a desire for more guidance, many resources have emerged in recent years (see ***In focus: Wildfire smoke resources for public health***).

While most public health interviewees mentioned receiving information on air quality from their local Air District, few mentioned working to increase the available air quality monitors in their area to improve real-time and location-specific decision-making. Public health interviewees also mentioned participating in organized emergency responses to wildfire and wildfire smoke events, often in coordination with fire departments or other first responders.

12. **Finding:** Interviewed California public health agencies are responding to wildfire smoke events by coordinating with other public agencies to disseminate information and guidance to the public, healthcare facilities, and schools.

Table 4: Wildfire smoke impacts to public health organizations with supporting quotes.

Impact or Responsive Action	Description or Examples	Illustrative quote
Public Health		
Public outreach, education, and communication	• Air quality advisories • Websites, press releases, press conferences, etc. • Information on air quality levels, health risks from smoke exposure, and available protective behaviors (e.g., staying inside, home weatherization, DIY box fan filters)	**Q14.** "If there are bad air quality days from wildfire smoke, everybody needs to be aware of that and what that can have as health effects." – Public Health Interviewee [id996] **Q15.** "We have to do a lot of messaging and talking [about wildfire smoke]. But I think the biggest problem with all this is we really don't have data [on chronic or long-term impacts of wildfire smoke exposure] to inform that." – Public Health Interviewee [id819]
Coordination with other local entities	• Working with Air Districts to disseminate air quality advisories • Consulting with health systems and healthcare facilities on AQI levels and available protective behaviors • Advising school districts on AQI levels to inform school closures • Coordination and assistance with emergency responders	**Q16.** "People start looking at each other in government. They're like, 'what do you do about this?'... So we do convene… we hosted calls with healthcare providers, with the schools and be like, 'This is what I know we should do and these are some of the messages for the people,'… It sort of became clear to me that maybe public health is kind of the gravitational center of that [wildfire smoke] response, even though, a priori, we hadn't been really tasked with that explicitly, nor had we been given tools to do that." – Public Health Interviewee [id877]
Providing materials or spaces for the public to reduce smoke exposure	• Distributing masks • Establishing a publicly available Clean Air Space • Improving air filtration in own facilities	**Q17.** "Since the [Fire], folks have become much more exposed to the different types of filtration…] We have seen an increase in requests for N95 masks to help with [smoke]." – Public Health Interviewee [id538]

In focus: Wildfire smoke resources for public health

We found that local public health entities and health systems want more guidance on best practices related to wildfire and wildfire smoke preparedness and response. In August 2022, during our interview process, the CDPH released an updated guide on wildfire smoke for public health officials, which includes guidance and resources on preparing for and responding to wildfire smoke, including for vulnerable populations (CDPH 2022a). The California Air Resources Board (CARB) also provides guidance on air quality monitoring, masking, and creating clean indoor spaces as part of its 'Smoke Ready California' initiative (CARB 2023b). Also available to public health departments is the California Building Resilience Against Climate Effects (CalBRACE) Project. Funded by the CDC, the program provides resources and technical assistance for states and local entities to conduct climate adaptation planning with a public health perspective. Part of the guidance for locally specific climate adaptation planning is estimating the additional health burden due to climate impacts, including wildfires and wildfire smoke (CDPH 2023b; 2023a). Included in the CalBRACE toolkit is a CDC guidance document on "Projecting Climate-Related Disease Burden: A Guide for Health Departments," but it does not include any guidance specific to wildfire smoke impacts (Hess et al. 2016). The Mariposa County Public Health Department is a featured case study of a local public health department using CalBRACE resources to adapt to wildfires and wildfire smoke (CDPH 2018).

CDPH also developed the Climate Change and Health Vulnerability Indicators data visualization platform (CCHVIz) which provides county-level data for local health departments and partners on key indicators (CDPH 2021). The CCHVIz platform includes air quality (measured by annual mean concentration of ambient $PM_{2.5}$) and wildfires (measured by "percent of population currently living in a high fire risk hazard zone"), though the data inputs are static and range from 2007 to 2013. Similarly, CalEnviroScreen 4.0, a data visualization tool developed by OEHHA to help identify California communities that are disproportionately burdened by multiple sources of pollution, includes ambient $PM_{2.5}$ annual mean concentration from 2015-2017 (OEHHA 2023). Neither CCHVIz nor CalEnviroScreen includes wildfire-specific $PM_{2.5}$ concentration, as comprehensive, spatial data on these estimates are not yet widely available (further discussed in section ***4.4 Smoke dispersion***). Recently, CDPH received $10 million in funding and 30 positions in the 2022-2023 budget to initiate a Climate and Health Surveillance Program, which would provide "near real-time notification for public health departments, first responders, and the community for emerging or intensified climate-sensitive diseases," including health impacts from wildfire smoke (CDPH 2022b; State of California 2022). In ***Chapter 4: Data Resources for Estimating the Health Impacts of Smoke***, we review available data resources on population vulnerability, health impacts from wildfire smoke, and estimates of costs of wildfire smoke.

Additionally, since 2019, Cal/OSHA has required employers to protect workers from wildfire smoke. The Section 5141.1 regulation applies to most outdoor employers, and requires that employers monitor air quality levels, communicate hazards to employees, and in most cases, reduce workers' exposure to smoke by air filtration, relocation or adjustment of work schedules, or provision of respiratory protective equipment (California Department of Industrial Relations 2021).

2.4.2 Health systems

Many health system interviewees described service and infrastructure impacts, including acute operational changes such as hospital evacuations or clinic closures, stopping regular programs, and patients missing routine appointments (***Table 5***). Increased emergency room visits, a commonly cited healthcare cost from wildfire smoke by researchers (see ***section 4.6***), were only mentioned by a few interviewees, most of whom represented health systems. Urban and rural interviewees experienced disruption of medical care differently. Some larger, urban providers said patients from rural areas would come to their hospital or clinic (because their local clinics or hospitals were crowded or shut down). In contrast, smaller, rural health system interviewees described the closure of their hospitals and clinics, or not being able to close since they are the only providers in the region.

Many interviewees from health systems described upgrading their facilities' air filtration systems in response to wildfire smoke events. These changes included upgrading HVAC systems using HEPA or MERV filters, purchasing portable air filters, and creating protocols around protecting indoor air quality for sensitive groups. In some cases, hospitals or health systems added or upgraded air quality monitoring within their own facilities.
A few interviewees described hiring and training staff to respond to wildfire smoke, especially in under-resourced rural areas prone to wildfire smoke impacts. Additionally, the need for pulmonary specialists was mentioned by multiple groups.

> 13. **Finding:** Interviewed health systems in California are responding to wildfire smoke events by improving air quality within their facilities, especially if they are in areas that experience direct impacts of wildfires or wildfire smoke.

Table 5: Wildfire smoke impacts to health systems with supporting quotes.

Impact or Responsive Action	Description or Examples	Illustrative quote
Health Systems		
Impacts to healthcare delivery	• Facility closures • Patient access, if they are unable or unwilling to travel during heavy smoke • Increased demand for healthcare services, during wildfire smoke events, at nearby facilities that are less affected by smoke, and after wildfire smoke events when patients begin seeking healthcare again	**Q18.** "We did at least close early, if not close for a full day, during the peak of [the fire]. The air quality was really, really bad in [the community]. I believe it was the worst anywhere in the continental US at one point in that day. We had temporary air quality monitors, so those were really, really helpful… It's tough for people to get in when visibility is bad, brought on by air quality and fires and smoke. It stops people from coming to work, like literally coming into work. And it also, we also face issues with patient access, like patients were unable to come down and visit, and people missing appointments, whether checkups or more urgent care, just because they couldn't drive safely. They weren't comfortable going down to the health center." – Public Health Interviewee [id351] **Q19.** "We evacuated our hospital [due to wildfire] twice last year for the first time in 62 years. So we're seeing a lot of firsts, and a lot of extremes. And the smoke is a part of the problem for sure." – Health System Interviewee [id096]
Improvements to air filtration systems	• Upgrading HVAC systems with HEPA or MERV filters • Purchasing portable air scrubbers • Purchasing or upgrading indoor air quality monitors	**Q20.** "We bought industrial grade air scrubbers… We brought them into our main buildings just to try to do the best we can to keep that air quality internally at some reasonable level… We have also bought generators, because the power supply can be variable in cases of fire and smoke." – Health System Interviewee [id530]

Table 5 (continued): Wildfire smoke impacts to health systems with supporting quotes.

Impact or Responsive Action	Description or Examples	Illustrative quote
Health Systems (continued)		
Staff training	• Additional staff training on wildfire smoke events • Additional training on lung-related issues • Increasing pool of traveler nurses	**Q21.** "When I tell clinicians the action plan and what can be done, it's certainly letting those individuals we know, if it's a pediatric group, letting them know what to do when there's poor air quality days, particularly like wildfire smoke for kids with asthma, adults with other chronic lung conditions and or cardiac conditions. Sort of that counseling component of what to do and what not to do when there's wildfire smoke, I think is probably the most tangible action that we have had for providers." – Health System Interviewee [id996] **Q22.** "We've done a lot of training of our primary care clinicians on lung-related issues, particularly asthma and COPD here, because our referral avenues are really thin. And so we spend a lot of time on medications and patient visits and education and rescue inhalers versus chronic inhalers. You know, those kinds of things that we have to be experts at since we don't really have access to tertiary care services abundantly." – Health System Interviewee [id530]

Table 6: Wildfire smoke impacts to health insurance organizations with supporting quotes.

Impact or Responsive Action	Description or Examples	Illustrative quote
Health Insurance		
Ensuring continuity of care	• Adoption of virtual care • Adjustments of rules for in-network coverage or medication renewable, usually temporary	**Q23.** "Both smoke and wildfire displaced families and individuals that had to leave… We had to change our typical rules around renewal of medication, not just medications for asthma, for displaced individuals and put into place the automatic renewal criteria because they couldn't reach their doctor's offices or couldn't get to the usual pharmacies." – Health Insurance Interviewee [id171]

2.4.3 Health insurance

Health insurance interviewees described their organizations' responses to wildfire smoke events in two main ways: working to ensure continuity of care and supporting emergency response efforts (*Table 6*). It's important to note that for most health insurance interviewees, response to wildfire smoke and response to wildfires themselves were difficult to disentangle.

Several health insurance interviewees described efforts to ensure continuity of care for people displaced by fires or smoke. These efforts included increased adoption of virtual care, and system changes to improve access to healthcare and prescriptions. A few health insurance interviewees also mentioned involvement in emergency response efforts for some of the larger or more disastrous wildfire events in the last few years, including providing emergency services or financial support to emergency response organizations. Several health insurance interviewees also mentioned that wildfire smoke events may have led to increased claims data, but to their knowledge, their organizations were not tracking the potential link. Compared to other sectors, we spoke to relatively fewer representatives of health insurance companies, so there are likely other responses from health insurers in California that we did not capture.

14. **Finding:** Interviewed health insurance groups serving populations in California are responding to wildfire smoke events by ensuring continuity of care when people are displaced by wildfires and sometimes providing financial support to emergency response groups serving their populations.

15. **Finding:** Public health, health systems, and health insurance organizations serving communities located in the Wildland Urban Interface (WUI) are not only impacted by wildfire smoke, but also by wildfires themselves, which can cause emergency evacuations, facility closures, and additional burdens.

16. **Finding:** Interviewed local public health entities and health systems seek more guidance on best practices related to wildfire and wildfire smoke preparedness and response related to communication, appropriate changes to service provision and patient care, and facility management.

Based on Findings 5-16, we conclude:

17. **Conclusion:** Wildfire smoke is a growing problem and is demanding more of the health sector's resources to manage and respond to smoke events. Additional guidance on wildfire smoke response and preparedness for health sector groups is needed.

18. **Recommendation:** To help California health sector organizations proactively prepare for and respond to wildfires and wildfire smoke events, public health and air regulatory agencies should collaborate on developing evidence-based best practices for public communication, facility management, and health care delivery during these events.

2.5 Perspectives on the economic impacts of wildfire smoke on human health and the health sector

Evaluating the economic costs of wildfires—including health-related costs, which are estimated in the billions—is an emerging area of research (Bayham et al. 2022). For example, healthcare-related costs from the 2018 wildfires in California have been conservatively estimated to be $32.2 billion (Wang 2020). Despite new studies estimating these costs, the true economic burden of wildfire smoke events remains largely unknown and likely underestimated. Thus, through our interviews we wanted to better understand the financial implications of the wildfire smoke impacts and responses on health sector organizations as described by interviewees (***Figure 5***).

Here, we explore how interviewees are thinking about costs at the scale of their organization, both in terms of direct costs incurred by preparing and responding to wildfire smoke events and in terms of indirect costs associated with health impacts to the populations they serve. Data resources and studies on the dollar value of health impacts from wildfire smoke are reviewed in ***Chapter 4: Data Resources for Estimating the Health Impacts of Smoke***.

2.5.1 Who bears the costs of wildfire smoke?

To better understand how our interviewees see the distribution of wildfire smoke impacts, we first asked them who bears the costs of wildfire smoke events. Most interviewees identified multiple groups who bear the costs of wildfire smoke events, and interpreted "costs" in different ways, from direct financial costs to indirect impacts of higher health insurance premiums. ***Table A2*** includes quotes illustrating who interviewees view as bearing the costs.

Almost all interviewees mentioned that the brunt of wildfire smoke impacts fall on the individual, the public, or 'everyone.' Many interviewees emphasized that specific vulnerable populations bear the greatest burden from wildfire smoke events. Interviewees highlighted different types of vulnerability, as described in ***In focus: Wildfire smoke impacts on vulnerable populations***.

A few interviewees mentioned specific costs borne by health insurers and health systems in providing additional care, but many of these interviewees also noted that costs borne by health insurers and healthcare facilities are often passed on to the public through increased medical costs or insurance premiums. Others noted that some health systems may monetarily benefit from increased healthcare utilization, depending on the revenue generation model. Some interviewees described other indirect costs of wildfire smoke events, including mental health or chronic health impacts, and future costs associated with patients delaying visits or procedures.

2.5.2 Are organizations tracking the costs of wildfire smoke?

We also asked interviewees if they knew whether their organizations have tracked direct or indirect costs of wildfire smoke events, based on health or organizational impacts.

Almost all interviewees said that their organizations are not calculating costs associated with wildfire smoke events (***Table A3***). Many who said they aren't calculating costs, but particularly those in public health, said that they would like to be able to track costs, but are not sure how or are unable to for various reasons (see ***In focus: Data challenges related to tracking wildfire smoke costs***). Several specifically mentioned that they would find the results interesting and important to their organization. In contrast, a few interviewees expressed skepticism that calculating the costs of wildfire smoke events would motivate any changes at their organization. Least frequently, representatives from health insurance organizations and state agencies said that while they are not calculating costs, they could do so or were hopeful that with additional staff members they could in the future.

A few interviewees, across each of the health sectors, said that their organizations are indeed calculating the costs associated with wildfire smoke events. Of those who *are* tracking costs, most described tracking the costs of emergency activation to respond to wildfire or wildfire smoke, such as billable hours or equipment costs. Only one interviewee described a nascent program to track the impacts of climate events (including wildfire smoke events) on hospital visits through claims data, although this approach still does not capture direct cost estimates.

> 19. **Finding:** Wildfire smoke events lead to financial costs to the general public, vulnerable populations, and health sector organizations, but interviewees reported that these costs are rarely quantified, even by health insurance groups which may have the data to do so.

> 20. **Conclusion:** Interviewed health sector organizations are interested in the financial costs of wildfire smoke events. Quantifying these costs would enable state and local health sector organizations to make more informed decisions regarding budgeting, resource allocation, and response.

> 21. **Recommendation:** California health, emergency response, and research-focused agencies and foundations should work with the health sector to develop procedures to quantify and track the impacts and associated costs of wildfire smoke on their organizations' workforce, operations, and ability to provide services.

> 22. **Recommendation:** Health insurance groups should share sufficiently de-identified datasets on claims and healthcare expenditures to complement healthcare utilization data from health systems to better support tracking the costs of wildfire smoke events.

In focus: Data challenges related to tracking wildfire smoke costs

When asked about whether their organizations are tracking health or organizational costs associated with wildfire smoke, interviewees named several challenges: capacity constraints; data access, quality, and relevance; and methodological challenges (***Table A3***).

Capacity constraints: The most common barrier mentioned by interviewees was a lack of staff capacity or bandwidth to enable cost tracking. This kind of research can be both costly and time-consuming, and many interviewees described data collection and analysis that they would like to undertake but could not do for lack of internal capacity or expertise. Lack of funding for this kind of work was also mentioned. It's worth noting that a substantial portion of our interviewees were from local public health departments, which are often resource and capacity constrained.

Data access, quality, and relevance: A major challenge mentioned by interviewees was accessing sufficient reliable and useful data on air quality and on health impacts. For gathering air quality data, interviewees primarily described efforts and challenges related to measured data, rather than forecasts. Some noted that there were a limited number of air quality monitors available in their communities, constraining the amount of data available on which to base guidance or to study associated health impacts. One interviewee serving a Tribal government shared that the air quality monitors available to them reported PM_{10} but not $PM_{2.5}$, which is currently the more widely used metric. The strength of the relationship between local public health departments and the associated Air Quality Management District (AQMD) or Air Pollution Control District (APCD) varied as well, potentially impacting the perceived availability of air quality information.

Interviewees also described struggles in accessing health data. Some local health departments noted that they serve relatively small communities, reducing the potential sample size for any kind of health impact tracking. Hospitals and health systems noted that they are not uniformly regulated in what health data they track. A few interviewees highlighted that there is no specific code for wildfire smoke-related illness, even when tracking through coding systems in an emergency department, and there may be normative differences in how visits are coded across different hospitals, clinics, or health systems.

Methodological challenges: Many interviewees noted that attributing specific health impacts to wildfire smoke events is complex. The specific health impacts associated with wildfire smoke, such as respiratory or cardiovascular illnesses, have many causes and confounding factors. Some interviewees mentioned the added complexity of factoring in cumulative exposures and long timescales between exposure and observed health impacts. Less frequently, interviewees stated that the infrequency and unpredictability of wildfire smoke events can make it difficult to measure effects while they happen because the infrastructure to quickly collect data is not widespread.

Overcoming challenges: While data challenges are a pervasive issue, interviewees provided evidence of opportunities and new efforts to overcome them. Health insurance organization interviewees were more likely to say that they have the data or could do the analysis to link health outcomes to wildfire smoke events but are not doing it. A few research-focused and public health interviewees described forthcoming or ongoing studies. For example, one public health interviewee described an ad-hoc approach to measuring impacts to inform organizational decision-making:

Q24. "[We] looked at our ambulance and ED data or our EMS 911 calls to see whether or not there was a significant increase in respiratory illness…We wanted to see, what happens to a community of 250,000 people when the air gets bad, in terms of the worst outcomes?… It was surprisingly quiet, actually, the first two days… on day 2, day 3, we started seeing an increase. So it seemed to me like there was this sort of cumulative impact, but we did see a measurable signal in the number of people calling 911." – Public Health Interviewee [id877]

2.6 Summary and discussion

We found that smoke exposure is impacting health sector organizations in California and that these impacts, and therefore the health sector's concern about wildfire smoke, have grown over the past 5 to 10 years, aligning with studies demonstrating an increase in frequency and severity of wildfires and wildfire smoke (C. E. Reid and Maestas 2019). Interviewees identified health impacts of wildfire smoke exposure that align with those well documented in the literature (C. E. Reid et al. 2016; Cascio 2018). They also identified gaps in knowledge about mental and chronic health impacts, although there have been some recent studies attempting to fill this gap (Gao et al. 2023; Eisenman and Galway 2022; Cascio 2018).

Interviewees were concerned about populations that are especially vulnerable to wildfire smoke impacts. Aligning with these concerns, populations with increased wildfire smoke vulnerability have also been identified in the literature (Thilakaratne et al. 2023; Berberian, Gonzalez, and Cushing 2022). Vulnerability to wildfire smoke manifests in multiple domains, including high levels of exposure, sensitivity to exposure, and capacity to recover from health impacts or related disruptions. Certain groups are vulnerable to wildfire smoke in multiple ways. Additional guidance and resources for health sector organizations representing and/or serving vulnerable populations is critical for protecting health outcomes.

We found that wildfire smoke impacts to California's health sector vary across public health entities, health systems, and health insurers, but appear more pronounced for organizations serving populations in fire-prone areas, the WUI, or areas that experience air quality issues even without wildfire smoke. Wildfires and wildfire smoke events can not only exacerbate health outcomes for already vulnerable populations, but also impact the ability of health organizations to provide services to these groups, including when wildfires and smoke impact staff and facilities. Overlapping events, including COVID and extreme heat, have amplified these health and organizational impacts and created additional challenges for the health sector.

We asked our health sector interviewees if their organizations are translating the health and organizational impacts they described in the first section of the interview into costs or financial impacts. We found that the health sector is largely not aware of or tracking these costs. As described above, interviewees provided several reasons why their organizations are not currently tracking these costs. For some of the most wildfire smoke-impacted health sector organizations and the communities they serve, the challenges of responding to frequent and severe wildfire smoke events and other health challenges with limited resources take precedent. Even though there may be interest in understanding these costs, these organizations must first take care of their staff, their facilities, and the populations they serve.

A potential resource for future research on the health costs of wildfire smoke events is the recently established California Department of Health Care Access and Information (HCAI) Health Care Payments Data (HPD) program, a database of healthcare claims and encounter data for over 30 million Californians (California Department of Health Care Access and Information 2023), assuming data is available to identify health care utilization associated with wildfire smoke exposure and isolate geographies and time periods associated with smoke events.

Although it was not an intended focus of our interviews, we heard from interviewees that they are interested in additional resources, guidance, and information on wildfire smoke impacts, preparedness, and response (discussed further in ***Chapter 3: Perspectives on the Connections Between Forest Health and Human Health***). Addressing the needs identified by these interviewees is a necessary first step to enable future collaborations between the health sector and land managers.

Chapter 3: Perspectives on the Connections Between Forest Health and Human Health

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Many health sector organizations see value in future engagement with forest management to meet shared goals but require avenues for collaboration and more information on the potential health benefits.

After hearing from our interviewees that wildfire smoke is a health sector concern and that wildfire smoke events have led to human health and health sector organizational impacts, we transitioned to asking about health sector perspectives on forest management. Forest management is used here to collectively refer to forest restoration and fuels reduction activities, which may include beneficial fire and/or thinning (see ***Definitions Box 3. Forest Management and Treatment Activities***). We focused on exploring forest management as a potential way to mitigate the risk of catastrophic wildfires, wildfire smoke events, and associated population exposure, health outcomes, and financial costs to the health sector (***Figure 4***). If accelerated forest management can deliver those benefits, there may be an opportunity for some in the health sector to collaboratively engage with land managers to further advance forest management, to the mutual benefit of both parties. This collaborative engagement or participation could take several forms, including advocacy, community outreach, funding partnerships, multidisciplinary research, and considering health tradeoffs in forest management planning and implementation.

For more detailed information on our interview methodology, refer to ***section 2.1***.

3.1 Familiarity with forest management among health sector interviewees

When asked about their familiarity with forest management as a way to decrease the risk of catastrophic wildfires, almost all interviewees said they were generally familiar with the concept, but many were quick to note that they were not experts (***Table 7***). Many were familiar with forest management due to their personal experience of living in California and sometimes from a past educational or professional experience. A higher level of familiarity was typical of interviewees who lived in or served populations in fire-prone and/or WUI areas and had experienced catastrophic wildfire in recent years. These interviewees more frequently expressed a need for increased forest management to mitigate wildfire risk. Some interviewees described forest management as a controversial and political topic in their community—based on their experiences hearing debates about forest management approaches and tradeoffs—and expressed a lack of clarity on what responsible forest management means. No interviewees tied their awareness of forest management to their professional experiences in the health sector.

Climate change was also frequently discussed, as both a driver of wildfires and wildfire smoke and as a broader issue of which wildfires are only one part. Linking wildfire smoke to climate change was more common among interviewees who either: (1) reported less direct impacts of wildfire in their communities, or (2) represented organizations with a state-wide or multi-state scope. These interviewees often had less personal experience with wildfire smoke exposure and its impacts on their communities and operations. When interviewees made this link, they typically did so in one of two ways: (1) some pointed to the scale of climate change to describe the challenges of addressing such a wide-reaching phenomenon, while (2) others described their engagement with climate impacts that they considered to be more salient concerns than wildfire smoke (e.g., sea level rise) or as examples of environmental initiatives to which their organizations were already contributing (e.g., facility decarbonization).

> 23. **Finding:** Interviewed health sector professionals generally have a basic familiarity with the concept of forest management and recognize its role as a tool to reduce the risk of catastrophic wildfires.

> 24. **Finding:** The degree to which interviewed health sector professionals recognize forest management's role in wildfire risk reduction varies based on where they live, where their organizations operate, and their past experiences with wildfire and wildfire smoke.

Table 7: Quotes from health sector interviewees on forest management.

Theme	Illustrative quote(s)
Health Sector Awareness of Forest Management	
On their general awareness of forest management	**Q25.** "I would say it's safe to assume as members of the general public that they are aware of the principles of [forest management]. But from a kind of public health specialty, I don't think there's anybody [in my organization] that is focused on that particular issue." – Public Health Interviewee [id795]
On using beneficial fire, smoke, and health	**Q26.** "The levels of smoke people are seeing in the past five years, throughout the state of California and other places throughout the nation are really things we've been living with for decades. But, you know, we don't typically attribute that to the fact that there is fire occurrence; we attribute that to the fact that people have taken fire from the systems. … We are enacting solutions by ramping up our prescribed fire and cultural burning activities to reduce the emission potential for these major wildfire events in the worst conditions." – Interviewee serving Tribal government [id896] **Q27.** "The problem that we always have is people complain about the air quality when they do prescribed burns, which are generally done in the winter, which is normally when our inversions are the worst from a weather phenomenon standpoint. So, it's kind of a no-win situation from the forest management perspective. But, you know, people need to take into account that slightly worse, air quality is better than having the worst AQI in the world for several days." – Health System Interviewee [id303]

3.2 Perspectives on the connections between forest health and human health

Many interviewees explicitly recognized that human health is directly impacted by the environment. About half of the interviewees discussed the connection between forest management practices and potential impacts on human health. Those who did make this connection live in or provide services to people in more forested, wildfire-prone areas. Many interviewees recognized that proactive forest management would likely yield human health benefits, but very few indicated that they are actively considering forest management as a tool to improve human health outcomes for their communities.

A few interviewees pointed out that forest management may be too far upstream of a health determinant for the health sector to conceptualize in a meaningful way. Some interviewees directly drew parallels between forest health and social determinants of health, which are non-medical factors that influence health outcomes, such as income, education, housing, and food security (WHO 2023).

Some interviewees brought up prescribed fire or cultural burning, noting benefits such as reduced wildfire risk, improved forest health, or a return to the way land was managed by Indigenous people (***Table 7***). Interviewees serving Tribal communities emphasized the importance of burning as a cultural practice and a land management tool. Some interviewees brought up concerns from community members about smoke impacts from prescribed fires and noted the need for better communication from public and private land managers to alleviate anxiety from community members around smoke due to prescribed burns. No interviewees described prescribed burning in a solely negative way.

> 25. **Finding:** Many interviewed health sector professionals recognize that proactive forest management has the potential to deliver benefits to public health and the health sector.

> 26. **Finding:** Interviewed health sector professionals who live in rural, fire-prone areas are more likely to: (1) be familiar with forest management, (2) make the connection between forest health and human health, and (3) recognize that both could be improved by proactive forest management.

3.3 Opportunities for health sector engagement with forest management

3.3.1 Potential avenues for engagement

To better understand the potential for collaborative engagement between health sector organizations and land managers, we asked interviewees to share their perspectives and ideas on what health sector engagement with forest management could look like in the future for their organization.

Almost all interviewees said that participation in forest management through community engagement or advocacy would be of interest to their organizations. Interviewees had varying perspectives about the potential for their organizations to participate through cost-sharing. Other ideas that came up included multidisciplinary research collaborations or providing perspectives to ensure forest management incorporates health trade-offs as an input.

Community engagement was the most interesting avenue for forest management engagement to interviewees, and many said that partnerships focused on engagement and outreach are both possible and important for the communities they serve. Commonly, interviewees mentioned ideas for partnership that centered on collaborative work between various health sector and land management groups, often either in the context of better community education or advocacy. Many interviewees said that state and federal land managers, public health, private health systems, universities, Air Quality Management Districts, and Indigenous groups should come together to provide interdisciplinary guidance on wildfire smoke preparedness and mitigation. Others had similar recommendations—but at the local level—to share information about planned treatments and the benefits of forest management with impacted communities. The few interviewees who expressed less interest in partnership provided specific reasoning for their hesitation, such as a sense that it wasn't their organization's place to participate and that other health sector organizations might be better suited to this collaboration.

When we asked whether opportunities or interest might exist for the health sector to financially contribute to forest management, most interviewees noted that this contribution was likely not feasible currently. Most of these interviewees expressed interest in the concept and some understanding of the benefit that forest management might have for their populations. However, many highlighted barriers that would preclude their organization from contributing funding, particularly resource constraints among organizations in all health sector groups. A few others said they did not see a role for their organization or for others in the health sector, citing a view that it is not the role of the health sector to contribute to forest management.

Interviewees had many ideas about which other health sector organizations could more feasibly contribute, including state or federal public health agencies, large hospital systems, large insurers, and foundations. Multiple interviewees also mentioned ideas for how health sector organizations could pool smaller funding contributions for forest management projects. For example, several interviewees raised the idea of hospital community benefit programs paying into forest management work. Others mentioned that funding should come from the state or federal government given their scope and responsibility. Some interviewees referred to policies that require health systems or insurers to devote some amount of funding each year to upstream determinants of health as a possible means of financial contribution.

A small number of interviewees described current or prior engagement between their organizations and the land management sector. Most of these interviewees represented Tribal communities and public health entities, as well as one interviewee from a rural health system. The level and types of involvement ranged widely and included:

- Communicating the smoke tradeoffs of prescribed burning and sharing information about the health impacts of wildfire smoke exposure with members of the public.
- Health sector participation in the planning of forest management projects by providing a public health lens.
- Collaborating on research projects to better understand wildfire and prescribed burning smoke impacts and develop best practices for response to smoke events.

These examples illustrate that collaboration between the land management and health sectors is viable. However, most interviewees did not report such collaboration existing currently, indicating that most health sector organizations are not currently engaged in forest management, despite seeing the value of doing so.

> 27. **Finding:** Many interviewed health sector professionals see value in the health sector engaging with forest management but aren't currently doing so and do not see a path for their organization to participate.

3.3.2 Motivations for engagement

We asked interviewees to outline major motivations that could potentially facilitate health sector participation in forest management through community engagement, advocacy, cost-sharing, or other avenues. The most frequently mentioned motivations were demonstrated health benefits; alignment with their organization's interest in supporting climate related initiatives; demonstrated financial return; and fit with the organization's mission to provide care and protect vulnerable populations. ***Figure 7*** outlines the primary motivations and barriers, and ***Table 8*** provides illustrative quotes.

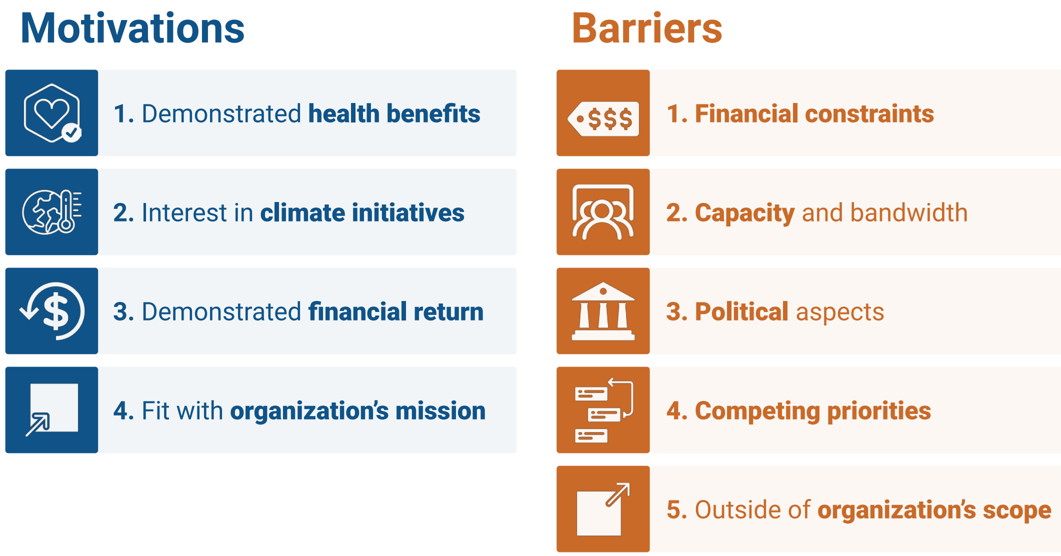

Figure 7. Motivations and barriers for health sector engagement with forest management. Interviewees described an array of potential motivations and barriers for greater engagement from their organizations with forest management. They also described information needs and institutional structures that could help to bolster motivations or overcome barriers.

Demonstrated health benefits

The most common motivator identified by interviewees was evidence of health benefits to the populations they serve due to forest management. Many interviewees from each health sector (public health, health systems, and health insurers) stated that their organization's focus is on protecting the health and well-being of their populations, so demonstrating a benefit to community health would be particularly motivating. Several of these interviewees also indicated that information demonstrating a beneficial relationship between forest management and human health does not exist yet, or is not widely available or recognized, and expressed the need for more and better information and dissemination.

Alignment with the organization's interest in supporting climate-related initiatives

Second, interviewees mentioned a sense of urgency about climate change that could motivate their organization's engagement with forest management. These interviewees often cited the worsening effects of climate change as part of that motivation, and some also described a growing recognition in the health sector of the connection between climate change and human

Table 8: Quotes from interviewees on motivations for health sector engagement with forest management.

Theme	Illustrative quote(s)
Motivations for Health Sector Engagement with Forest Management	
Demonstrated health benefits	**Q28.** [On advocacy] **"**We focus on health plan policies, and then public health. And so through the lens of public health, we really look and say, Okay, does this improve public health? So the baseline is sort of understanding [the policy] and then how it intersects with our public health goals.**"** – Health Insurance Interviewee [id845] **Q29.** **"**If we identified wildfire smoke as being a significant health risk on a continual basis, then we would place it at a higher ranking [level of concern]… It would have to be a continual exposure risk that would drive us to be more involved in that sort of upstream effect of land management.**"** – Public Health Interviewee [id795]
Alignment with the organization's interest in supporting climate related initiatives	**Q30.** **"**When we think back to these recent years when we've been shrouded in [smoke where you] can't see in the daytime, you know, for sometimes weeks. It causes impacts, and it causes action. I mean, it's been one of the better motivators [for commitments to climate action], I would say. And I don't mean to make that sound like it's a good thing. But in terms of climate action, I think it has been compelling because it's so difficult to live with.**"** – Health System Interviewee [id229]

Table 8 (cont.): Quotes from interviewees on motivations for health sector engagement with forest management.

Theme	Illustrative quote(s)
Motivations for Health Sector Engagement with Forest Management (continued)	
Demonstrated financial return	**Q31.** "I've had many discussions with [leadership]… about climate change and health and healthcare decarbonization. And the first thing they said was, you've got to show us that it's economically profitable, that it's economically feasible to do that." – Health System Interviewee [id584] **Q32.** "I can see it happening with a specific organization...that is very focused on this, that has done the work to convince their leadership that not only is this really relevant for people's lives, but it's actually affecting our bottom line, and we have a very firm idea of what these numbers are, and we think that if we spent this money, we would be able to prevent some of this." – Health Insurance Interviewee [id575] **Q33.** "From where I sit… for the healthcare side, there always has to be the return on investment data… The healthcare system, and probably public health too… really needs that clear, financial line of like, 'okay, we invest in these land management practices, and we're likely to see a reduction in the number of folks coming to the ER, during a wildfire smoke event, because it's not as severe can get under control faster'." – Public Health Interviewee [id626]
Fit with the organization's mission to provide care and protect vulnerable populations	**Q34.** "I think it's the values of the people who are involved, and how we think about equity and who is most affected by natural disasters, that helps us to think about where to invest funding… We have a very strong focus and mission on supporting our most vulnerable members" – Health Insurance Interviewee [id802]

health. A few interviewees further recognized that the health sector itself contributes to climate change and suggested that some health organizations may be motivated to engage with forest management due to a sense of responsibility to help mitigate their contribution to climate impacts.

Demonstrated financial return

Some interviewees said that a demonstrated financial return or cost savings would be motivating for their organization or other similar organizations to participate in forest management, particularly when asked about funding or cost sharing. Interviewees who mentioned financial returns often highlighted that healthcare organizations are businesses, and a calculated financial return would be required to consider sharing costs for forest management.

Fit with the organization's mission to provide care and protect vulnerable populations

A few interviewees highlighted that their organization would be motivated to participate because contributing to efforts like forest management and serving vulnerable populations align with their mission (see ***In focus: Wildfire smoke impacts on vulnerable populations***). Others mentioned that interest in environmental health is increasing in the public health sector.

> 28. **Finding:** Interviewees reported motivations for health sector organizations to engage with forest management including (in order of frequency mentioned): (1) demonstrated health benefits, (2) alignment with their organization's interest in supporting climate related initiatives, (3) demonstrated financial return, and (4) fit with the organization's mission to provide health care and protect vulnerable populations.

3.3.3 Barriers to engagement

We also asked interviewees to outline the primary barriers that would prevent their organizations or others like them from participating in forest management through community engagement, advocacy, cost-sharing, or other avenues. The common barriers identified by interviewees fell into five categories: financial constraints; capacity and bandwidth; perceived political aspects; competing priorities; and forest management being outside of the organization's scope. ***Figure 7*** outlines the primary motivations and barriers, and ***Table 9*** provides illustrative quotes.

Financial constraints

Financial constraints were the most frequently mentioned barrier to health sector engagement with forest management. The lack of available funding was an especially common concern among public health interviewees, but inability to participate due to financial constraints was a response we heard from interviewees across all sectors. Public health interviewees often expressed that they felt other health sector groups, like large health systems and health insurers, were more likely to have funds to contribute to forest management. These groups, in turn, also expressed limitations caused by a lack of funding, or shared that their organizations' available funding would likely go to other organizational priorities before forest management.

Capacity and bandwidth

Capacity or bandwidth to engage in a new issue was mentioned by interviewees from all health sector organization types. Several interviewees noted that capacity is generally low across the health sector due to burnout and high rates of attrition from health professions due to the COVID pandemic. Additionally, interviewees from organizations located in rural, wildfire-prone communities shared that repeated wildfire exposure incentivized people to move away from these communities and made hiring and retention of staff more difficult. Some interviewees also noted that the barriers of capacity and competing priorities are often intertwined. With the COVID pandemic and other critical public health needs competing for limited resources, other determinants of health, such as the physical environment, receive limited attention.

Political aspects

The third-most common barrier that interviewees mentioned was the political aspects of public health or forest management. This barrier arose in two distinct contexts: the sense that forest management and climate change are politicized and controversial; and that trust in governmental entities like public health departments is currently low. Interviewees commonly mentioned that they have heard of controversies regarding forest management or varying opinions among their communities. Additionally, interviewees representing public health organizations often stated that the politicization of COVID has led to low trust in public health, limiting their ability to introduce new programs or engage their communities.

Competing priorities

Competing priorities as a barrier to participation was mentioned by some interviewees, often associated with capacity and financial constraints. Interviewees mentioned competing priorities in terms of other priority health concerns (e.g., COVID or drug overdoses) or in terms of other climate or environmental hazards they considered more pressing (e.g., extreme heat). Ultimately, many said that other initiatives would take priority, particularly when considering cost-sharing.

Table 9: Quotes from interviewees on barriers to health sector engagement with forest management.

Theme	Illustrative quote(s)
Barriers to Health Sector Engagement with Forest Management	
Financial constraints	**Q35.** "We don't have enough money for ourselves…cost sharing would be on the insurance, it would be on the healthcare side, whatever – if you can convince them that the prevention is good for them. Good luck. We've been trying for decades." – Public Health Interviewee [id877] **Q36.** "Hospitals are already being pulled in a thousand different directions, and it costs so much money – especially in this area – to operate a hospital, that even with the great financial resources that we have at [this organization], I still can't get projects funded… Land management and forest management wouldn't make the cut." – Health System Interviewee [id596] **Q37.** "The health sector, they're under so much financial pressure all the time… Especially these critical access hospitals in these rural areas, they just struggle to keep the doors open. So from a financial standpoint, at least in our rural setting, I don't see any real engagement opportunities." – Health System Interviewee [id303]
Capacity and bandwidth	**Q38.** "If you're talking about adding on actions to [public health], they need to come with resources for more staff and more oversight." – Public Health Interviewee [id572] **Q39.** "It's bandwidth… We're just exhausted… We have to get on our feet again to be an effective partner, but it doesn't mean we can't play some role and we can't get momentum started." – Health System Interviewee [id530]

Table 9 (cont.): Quotes from interviewees on barriers to health sector engagement with forest management.

Theme	Illustrative quote(s)
Barriers to Health Sector Engagement with Forest Management (cont.)	
Perceived political aspects	**Q40.** "[For] health systems, it's always a matter of what the local environment is, and whether or not you're aligning yourself with the local city council, local board of supervisors, or regulatory agency. You're going to run into all the questions about who's supporting which side and what the political landscape is." – Health System Interviewee [id996] **Q41.** "This would be more of a public health measure, except that public health… is not as strong or as listened to as they once were." – Health System Interviewee [id530] **Q42.** "I hear different opinions about what responsible forest management would look like, and that's actually a very heated argument here… currently, you know, even people that really care and want to do the right thing, like myself, are genuinely confused about what the way forward should be." – Public Health Interviewee [id880]
Competing priorities	**Q43.** "With the disparities that we see in our county, we have other priorities, [so] if we do have a little extra bandwidth and a little extra money, where is it going to go? It's probably going to go to try to eliminate or decrease those disparities that exist. Equity is definitely one of our top priorities these days." – Public Health Interviewee [id024] **Q44.** "We know that there's a significant amount of COPD and asthma in our community and cardiovascular disease. I don't have the numbers, but… they're not astronomical. What's astronomical is drug deaths, overdose deaths. That's what has occupied our attention probably most from a health statistics point of view" – Public Health Interviewee [id208]

Table 9 (cont.): Quotes from interviewees on barriers to health sector engagement with forest management.

Theme	Illustrative quote(s)
Barriers to Health Sector Engagement with Forest Management (cont.)	
Forest management outside of the organization's scope	**Q45.** "Some of these issues of air quality might be actually good to address at the statewide level. Because the solutions aren't just in our geographic area. I think they're broader. I mean, wildfires have affected the air quality in Chicago and New York. What happens here is really a national problem… It has to be more than just… the county level." – Public Health Interviewee [id900] **Q46.** "I really don't think it's the role of public health to pay for [forest management]… Maybe county government above us should be doing that. But it just really depends on who's doing land management. Is it the [federal government]? Is it the state? Is it the county?" – Public Health Interviewee [id208]

Forest management being outside of the organization's scope

Another barrier mentioned by some interviewees was a sense that engagement with forest management is not the responsibility of their organization, other similar health organizations, or the health sector in general. Some interviewees, especially those working at the local level, thought that wildfire smoke interventions and forest management should be addressed at a state or federal level due to the diffuse nature of wildfire smoke events. A few others felt that, as non-experts, health professionals were unlikely to have any influence among the land or forest management communities. For some, the connections between forest health, wildfire smoke, and human health were not sufficient to motivate engagement with forest management activities.

> 29. **Finding:** Interviewees reported barriers for health sector organizations to engage with forest management including (in order of frequency mentioned): (1) financial constraints, (2) capacity constraints, (3) political aspects of public health or forest management, (4) competing priorities, and (5) the work being outside their scope.

3.4 Enabling conditions: institutional structures and information

We heard from most interviewees that while they see value in participating in forest management given the potential human health and health sector benefits, additional institutional structures and information are critical enabling conditions.

3.4.1 Institutional structures

Despite interest in engagement, many interviewees noted that more institutional structures and examples of avenues for engagement or models of collaboration are needed. Interviewees described concerns around three areas:

1. Ambiguity in roles and responsibilities to facilitate collaboration.
2. A lack of policy mandates that enable and encourage health sector entities to expand their scope to encompass upstream determinants of health.
3. A lack of platforms or opportunities through which to begin engaging with forest and land managers.

Interviewees highlighted a need for more and better institutional structures to encourage engagement with forest management due to a sense of ambiguity in roles and responsibilities. This ambiguity came up in two dimensions: sector and scale. Interviewees noted that different parts of the health sector often operate in silos, and for emerging, multifaceted health threats exacerbated by climate change (like wildfire smoke), greater cooperation within the health sector, and across sectors, may be necessary. Many interviewees also noted that the impacts of smoke from fires that occur in potentially distant locations can accumulate within the communities served by their organization. This dichotomy of scale prompted some interviewees to speculate what scale of health sector organization (federal, state, or local) should be responsible for greater engagement with forest management.

Q47. "You know, we've had these forays in talking with forest science and public health, but that needs to be more deliberate… The question is, who at a policy level drives that? Is it the [federal government]? Is it the state? Is it like the CSAC, California [State] Association of Counties? Is it RCRC, which is the [Rural County Representatives] of California? Who drives this conversation and brings in the policymakers? Because you can have the science, you can have the public health, if you don't have policy driving it, then we'll end up raking forests." – Public Health Interviewee [id850]

A particular challenge related to the ambiguity in roles noted by interviewees was the lack of clear mandates or directives encouraging health sector entities to engage with new issues. As climate-related health crises become more frequent, health sector organizations—particularly public health entities—are increasingly stretched beyond their historic scope. Pervasive, wide-reaching health crises such as those posed by climate change, including wildfires and wildfire smoke events, transcend the original mandates of health sector organizations. While action to address crises like wildfires and wildfire smoke events is becoming increasingly necessary, interviewees pointed out that it is not clear which health sector organizations should act and what those actions should be. Some interviewees stated that they felt requirements from higher levels of government or outside policies would be necessary to facilitate health sector engagement with forest management because these policies would provide a clear avenue for that participation. Formal encouragement in the form of mandates or directives could empower health sector organizations to act.

Q48. "The historical responsibility of public health [is] mostly communicable diseases… Climate change-related threats are sort of [where] we're a square peg [and] there's a round hole. You're going to find different health departments in different stages of understanding [climate change-related threats] as a part of public health or not [and asking,] is this my job or not? And then, for those that recognize it as part of their role, kind of how far they've gone in terms of building operations and infrastructure." – Public Health Interviewee [id877]

Interviewees also identified a lack of platforms or opportunities to initiate engagement with forest management. Frequently, interviewees expressed confusion over how to begin engagement with forest management, should they want to, citing a lack of examples of this kind of cross-sector engagement. These interviewees highlighted a need for models of collaboration and the development of platforms through which to engage with forest management. Interviewees raised the idea of coalitions or groups of multiple health sector organizations participating jointly in forest management, saying that joining a coalition of diverse but similarly interested groups might be more empowering than being asked to act alone.

Q49. "Prevention of wildfires is by far and away the best approach [to reduce health impacts from wildfire smoke], but the problem is public health has no real influence there [in forest management]." – Public Health Interviewee [id922]

Institutional structures may alleviate these concerns and reduce barriers to health sector participation in forest management. Models of collaboration, policy directives, and other institutional structures can make collaboration easier (reducing financial and capacity inputs needed) and more legitimate (assuaging some concerns around political aspects, competing priorities, and new collaborations being outside scope) while providing structure and support for health sector organizations to act on their motivations for engagement.

3.4.2 Information

The importance of access to accurate, reliable information emerged as a common theme throughout our interviews. Interviewees expressed that information is most helpful when it is available at spatial scales relevant to their organizations. More geographically specific information is important for contextualizing impacts and outcomes for their population and supports better decision-making. Additionally, some interviewees stressed the importance of making research results tangible for the public and for policymakers by translating research findings into more accessible language, creating user-friendly tools with locally-specific information, and developing better guidance for air quality standards and other best practices. When filling knowledge gaps, ensuring information is available at various spatial scales and accessible to diverse audiences is key.

The most frequently mentioned information gaps are in the following categories (***Table A4***):

1. Information about the impacts of wildfire smoke on health and organizational outcomes.
2. Information about forest management and evidence that it will lead to improved health and organizational outcomes.
3. Evidence that health sector engagement with forest management will help realize those outcomes.

Most commonly, interviewees expressed a need for more information about the impacts of wildfire smoke on human health, saying that the health sector currently has an incomplete understanding of the connections between wildfire smoke and health outcomes. Several interviewees noted that while there is much research demonstrating the acute physical health impacts of wildfire smoke, there are few formal studies illustrating the non-acute impacts or impacts on mental and behavioral health. Beyond the acute effects of wildfire smoke exposure, interviewees identified a need for studies exploring the effects that emerge over time (chronic) or due to repeated exposures (cumulative), especially for vulnerable groups and as wildfires become more frequent and severe.

Some interviewees wanted information on the impacts of wildfire smoke and forest management on organizational or community resources. Interviewees often felt that health sector organizations may be motivated to participate in forest management if research showed that there are financial benefits of participation, for example through cost savings or reduced risk related to decreased wildfire smoke exposure. Less frequently, the topic of organizational outcomes referred to non-financial organizational resources, such as capacity in Emergency Departments during wildfire or wildfire smoke events.

Interviewees also desired better information about methods of wildfire smoke mitigation. Most commonly, they described a lack of clarity on which (and how) forest management techniques best protect public health through wildfire smoke risk reduction, and how the techniques compare to wildfire smoke exposure without forest management. Several interviewees explicitly requested comparative studies of the smoke impacts of wildfires versus forest management techniques like prescribed burns, highlighting research gaps as well as opportunities for existing information to be better disseminated to health professionals. Common threads were the need for the health sector and the public to better understand forest management objectives and activities and the need for the health sector to see information that shows how engagement in forest management could facilitate wildfire smoke risk reduction. For example, cost estimates of health and organizational impacts of wildfire smoke from an untreated forest versus a treated forest—with financial participation from the health sector—could demonstrate a positive return on investment.

Ensuring the health sector has access to new and existing information may help to address the key motivations and barriers interviewees identified for health sector engagement with forest management. Interviewees stated that filling key information gaps could help to support health sector participation in forest management. For example, information about the impacts of wildfire smoke on human health may elevate wildfire smoke to higher priority for health sector organizations and assuage some of the political aspects they perceive, and understanding the impacts on organizational resources may aid in resource allocation among competing demands. Evidence that forest management can lead to improved health and organizational outcomes may alleviate concerns about financial constraints and support motivations by demonstrating health and financial benefits. Lastly, information that demonstrates that health sector engagement with forest management could help realize positive health and resource outcomes may assuage health sector organizations' stated concerns about political aspects of forest management or public hesitance. This information could also illustrate how health sector involvement in mitigating upstream health determinants could lead to both improved health and financial outcomes.

> 30. **Finding:** Interviewed health sector organizations seek institutional structures and models of collaboration to address ambiguity about roles and a lack of clear directives or platforms through which to engage with forest management.

> 31. **Finding:** To inform potential engagement with forest management, health sector interviewees seek information in three categories, each at actionable levels of spatial resolution for their service area: (1) the quantified impacts of wildfire smoke on health and organizational (human resource, operational, and financial) outcomes, (2) evidence that forest management will lead to improved health and organizational outcomes, and (3) evidence that health sector engagement in forest management will help realize those outcomes.

Based on Findings 25-31, we conclude:

> 32. **Conclusion:** Interviewed health sector organizations are interested in exploring opportunities for engaging with forest management but require avenues for collaboration, policies to motivate and enable participation, and more research into health and the health sector benefits of forest management.

> 33. **Recommendation:** California and federal agencies responsible for forest management, environmental regulation, and health research should continue to fund and support multidisciplinary research that demonstrates how forest management could change wildfire smoke risk and its subsequent impacts on human health and the health sector, at actionable levels of spatial resolution.

> 34. **Recommendation:** California and the federal government should further prioritize health sector interested parties' participation in forest management advisory bodies (e.g., California Wildfire & Forest Resilience Task Force, Forest Service Wildfire Crisis Strategy) to strengthen the linkages between public health and forest management planning and practice.

3.5 Summary and discussion

Given that wildfires and associated smoke events are expected to become more frequent and severe, taking a long-term view on how health and the physical environment are interconnected is critical but challenging. We wanted to understand the extent to which health sector groups may already be taking this view, as it relates to wildfire smoke and forest management.

We found that the level of familiarity with forest management and the degree to which interviewees saw a link between forest health and human health varied. Interviewees living in fire-prone and/or WUI communities who had experienced wildfires were more familiar with forest management, which may be expected given these communities have a greater risk of exposure to catastrophic wildfire and wildfire smoke (G. C. L. Peterson, Prince, and Rappold 2021). Many interviewees also expressed some familiarity with prescribed fire or cultural burning.

Often this familiarity was nuanced, including recognition of the benefits of beneficial fire as well as potential concerns about smoke exposure. Many agreed that forest management has potential implications for human health but did not indicate that this connection is one they are considering in their professional capacities. The exception was interviewees serving more rural, forested, and wildfire-prone communities, who tended to more thoroughly describe the connection between improved forest health and the potential for reduced wildfire smoke-related health outcomes.

Interviewees who linked forest health and human health also tended to describe their organizations as overburdened and overwhelmed by wildfire smoke impacts. We recognize that for these groups, making the connection between forest health and human health may not be enough to lay the foundation for cross-sector collaboration; these groups need additional support to prepare and respond to the wildfire smoke events that disproportionately affect their organizations, staff, facilities, and the populations they serve.

Yet, there are opportunities for health sector organizations to engage with forest management in the pursuit of mutual benefits for both land managers and human health. The goals of this participation would be to improve health outcomes which could potentially decrease health sector costs associated with wildfire smoke. This would likely require more resources in the beginning as a long-term strategy for preventative healthcare that could be coupled with outreach and efforts to help residents live with fire.

We found that most interviewees see the value of health sector participation in forest management to mitigate wildfire smoke, but many do not think their particular organization is the appropriate one to participate. This sentiment is common for many public goods (Charnley, Kelly, and Fischer 2020). Our interviews revealed a variety of potential avenues for health sector participation, including (but not limited to) community engagement, advocacy, and cost-sharing. Examples could include a more holistic analysis of smoke-related health impacts in both environmental and public health planning and implementation; education and awareness campaigns about wildfire smoke risk and protection measures; cost-sharing forest restoration projects; and advocacy to state regulators to expand prescribed burn windows to accelerate the pace and scale of work.

Our interviews also uncovered potential motivations and barriers for this engagement, which largely hinge on better information and institutional structures that do not currently exist. More interdisciplinary research on the links between forest management, wildfire smoke exposure, and human health outcomes, including guidance and information on the true costs of wildfire smoke impacts to health and health sector organizations, could help bring the health sector to the table. Some examples of this type of collaboration do exist. NASA's Health and Air Quality Applied Sciences Team (HAQAST) established a multidisciplinary coalition of researchers to assess the effects of wildfire smoke on air quality and human health to better inform emergency response planning (O'Neill and Diao 2018). This model could be replicated to generate needed insights on human health impacts of different forest management scenarios. In ***Chapter 4: Data Resources for Estimating the Health Impacts of Smoke*** and ***Chapter 5:***

Evidence that Forest Management can Benefit Human Health, we evaluate the existing data resources and research on the potential health benefits of forest management.

Given the impossibility of a smoke-free future, including the health sector in existing decision-making bodies could provide a venue for elevating these issues and taking a more holistic approach to protecting public health. These efforts have begun but are still in their infancy. One example is research by CDPH to uncover community attitudes and perspectives on prescribed burning in El Dorado and Nevada Counties, funded in part by the California Department of Forestry (Hoshiko et al. 2021). Another example is the interdisciplinary Science for Nature and People Partnership (SNAPP) working group on wildfires and human health, which has produced research and guidance on responding to the need for greater interdisciplinary partnerships across forest health, wildland fire, and public health sectors (Haugo et al. 2023; D'Evelyn et al. 2023).

Even as this opportunity for greater cross-sector collaboration grows, we recognize that an investment in forest health to benefit human health is a long-term investment, with decreased smoke exposure and any subsequent protection of human health accumulating over decades and after repeated, large-scale forest management. Other high-priority, immediate needs face the health sector. We heard from our interviewees that COVID, overdoses, and other health crises are very real concerns to which these organizations must devote their limited resources before they can invest in gathering information about wildfire smoke impacts and what investment in forest health might mean for them. Health impacts and organizational impacts from wildfire smoke manifest primarily as equity and access issues, frequently felt most intensely in rural, remote, or resource-constrained communities for whom wildfire smoke impacts simply compound very real, already imminent challenges. When advocating for increased engagement between the forest management and health sectors, it is critical to recognize the intersections and hierarchies of needs at play.

Part II: Literature Review of Smoke Data Resources and Smoke Tradeoffs of Forest Management

Chapter 4: Data Resources for Estimating the Health Impacts of Smoke

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Comprehensive statewide or locally specific information on the adverse human health impacts of wildfire smoke are not readily available, but could be generated from additional analysis of existing data resources.

Ready access to wildland fire smoke data for a particular region can help the health sector better understand the health risks of the populations they serve, and better help populations prepare for harmful levels of smoke to reduce the risk of adverse health outcomes. Smoke impact data that additionally traces a region's smoke exposure back to source fires can help land managers evaluate the tradeoffs of alternative forest management strategies and to develop forest treatment prescriptions that minimize the net harm to human health from wildland fire smoke.

To evaluate the adverse health impacts of smoke and the potential human health benefits of improving forest health, researchers need access to both: (1) high-quality, comprehensive data products that retroactively track the historical smoke impacts from wildland fires that have occurred in the past, and (2) modeling tools to forecast the smoke impacts of fires expected to occur in the future or to simulate the smoke impacts of fires that could occur under different forest management scenarios. Tracking smoke metrics of fires that have occurred in the past provides insight on how smoke has been impacting populations across California. Smoke forecasts for actively burning fires provide information on how smoke is expected to impact populations in the near future. Smoke metrics for simulated fires that could occur are a critical input for evaluating the expected smoke tradeoffs of alternative proposed management strategies.

Here we review publicly available data products for historical tracking, forecasting, or simulating smoke metrics relevant for quantifying adverse health outcomes attributable to wildland fire smoke in California.[2] We categorize data products into three types:

- **Data Inventories** – regularly updated datasets that provide systematic, ongoing tracking of smoke metrics, and typically published and maintained by a government agency to facilitate further analyses.
- **Datasets** – one-time, static datasets of smoke metrics, typically published as part of a completed research project to facilitate future analyses.
- **Dashboards –** interactive portals to convey the results of smoke metrics analyses in an easily-digestible format, which may or may not be regularly updated depending on source of data.

4.1 A framework for estimating health impacts of smoke

Wildland fires produce smoke that can travel far beyond a fire's footprint and expose populations to harmful levels of air pollution (Long, Tarnay, and North 2018; U.S. EPA 2021; Williamson et al. 2016). All wildland fires are expected to incur at least some smoke-related adverse health impacts, but different fires can have very different health impacts depending on where and how they burn (Cahill 2009; Mueller et al. 2020). Long et al. (2018) proposed a framework for evaluating the health impacts of wildland fire smoke (***Figure 8***). The extent to which smoke from any given wildland fire impacts human health can vary greatly depending on three main factors:

- **Smoke Emissions** – the composition and amount of air pollutants in the smoke of wildland fires.
- **Smoke Dispersion** – how smoke plumes spread across the landscape and the resulting concentration of smoke air pollutants in affected regions over time.
- **Population Exposure** – the size and vulnerability of the population(s) exposed to the smoke.

The combination of these three factors contribute to **Health Impacts** – the number of cases or the dollar value costs of adverse health outcomes attributable to smoke exposure in a population. The long-term and cumulative health impacts of wildland fire smoke can additionally depend on the frequency and duration of successive fire events.

2 The many other costs associated with wildland fire smoke are beyond the scope of this study, including impacts to tourism, the local economy, the built environment, agriculture, ecosystems, and carbon emissions.

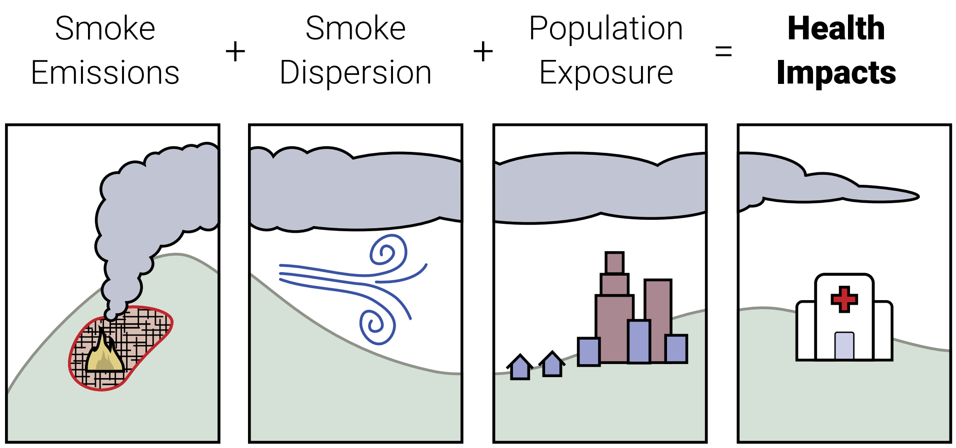

Figure 8. Framework for estimating the health impacts of wildland fire smoke. The number of adverse health outcomes attributable to smoke depends on: **(1)** Smoke Emissions - the composition and amount of air pollutants in the smoke of wildland fires, **(2)** Smoke Dispersion - how the smoke plumes spread across the landscape and the resulting concentration of air pollutants over time, and **(3)** Population Exposure - the size and vulnerability of the population(s) exposed to the smoke. Adapted from Figure 1 from Long, Tarnay, and North (2018).

4.2 Smoke plume processes

Wildland fires burn vegetation, trees, and other biomass when they spread across natural and working lands. And, with increasing frequency, wildland fires also burn homes, cars, and other human-made materials when they spread into developed areas of the wildland-urban interface (WUI). Wildland fire smoke contains many types of air pollutants that are harmful to human health including fine particulate matter ($PM_{2.5}$), coarse particles, black carbon, volatile organic compounds (VOC) such as benzene, nitrous oxides (NOx), ozone (O_3), polycyclic aromatic hydrocarbons (PAHs), and heavy metals such as lead (Jaffe et al. 2020; D. L. Peterson, McCaffrey, and Patel-Weynand 2022; Long, Tarnay, and North 2018). Some of these air pollutants are emitted directly by the fire as a product of combustion (primary pollutants), whereas others are created within the smoke plume as a result of further chemical reactions (secondary pollutants) (Brey and Fischer 2016; Jaffe and Wigder 2012). Most studies focus on $PM_{2.5}$ when assessing the human health impacts of smoke (Jaffe et al. 2020; H. Chen et al. 2021). The composition and amount of air pollutants in wildland fire smoke emissions depends on many factors, including: the number of acres burned; the duration; the severity of the fire; the type of fuels burned (e.g., grasses, trees, or human-made materials); fuel moisture; and fuel load (Jaffe et al. 2020; D. L. Peterson, McCaffrey, and Patel-Weynand 2022; J. S. Reid et al. 2005).

Wildland fire smoke plumes can spread beyond the footprint of the fire's flames and disperse air pollutants across the landscape and far from the fire through transportation and dispersion processes (Jaffe et al. 2020; D. L. Peterson, McCaffrey, and Patel-Weynand 2022; Long, Tarnay, and North 2018). During the dispersion process, secondary pollutants such as ozone form as a result of chemical reactions (Jaffe and Wigder 2012). The extent to which smoke disperses away from a wildland fire or lingers over a particular region depends on the amount of emissions, the vertical plume extent, and the winds driving the smoke dispersion (Y. Liu et al. 2019). The amount of emissions and their lofting due to the heat generated by fires are impacted by a number of factors including the prevailing weather conditions (winds and atmospheric stability), the intensity of the fire, and the topography of the landscape (Jaffe et al. 2020; D. L. Peterson, McCaffrey, and Patel-Weynand 2022; Long, Tarnay, and North 2018). Because the atmospheric properties such as winds change with height, the vertical extent of the smoke column (called the smoke injection height) is one of the key parameters controlling the fate of smoke emissions in the atmosphere (Martin et al. 2010; Mallia et al. 2018).

4.3 Smoke emissions

Smoke emissions metrics measure the amount by weight of the various air pollutants that make up the wildland fire smoke plumes (Jaffe et al. 2020; D. L. Peterson, McCaffrey, and Patel-Weynand 2022). For historic fires, forecasts of actively burning fires, and simulated fires, smoke emissions data are typically derived from models that estimate the amount of pollutants based on inputs of fire size, intensity, and type of fuels burned (Ottmar 2014). Emissions from small, short-lived burns of known size can be estimated using modeling tools such as the U.S. Department of Agriculture, Forest Service, First Order Fire Effects Model (FOFEM) or CONSUME (USFS 2023b; Prichard, Ottmar, and Anderson 2007). For larger and long-lasting wildland fire events, modeling frameworks such as BlueSky leverage satellite fire observations to assess daily fire growth, and estimate hourly emissions based on typical daily fire activity (USFS 2023a). Wildland fire emissions are an important input for models that estimate smoke plume dispersion and air pollutant concentrations. Output from frameworks such as BlueSky are used as an input into chemical transport models such as CMAQ or WRF-CHEM used for air quality simulation and forecasting (U.S. EPA 2023c; NOAA 2021).

The U.S. Environmental Protection Agency (EPA) National Emissions Inventory (NEI) (U.S. EPA 2023e) and the California Air Resources Board (CARB) Wildfire Emissions Inventory (CARB 2023a) retrospectively track emissions of various air pollutants for individual wildland fires (***Table 10***). The EPA inventory includes daily emissions estimates for more than 40 air pollutants, including $PM_{2.5}$ for individual wildfires, prescribed fires[3], and agricultural fires (U.S. EPA 2023a). The CARB inventory includes total emissions estimates of $PM_{2.5}$, PM_{10}, and CO_2 for the 20 largest wildfires in California each year. Several other retrospective emissions datasets that cover the U.S. over specified time periods have been published in the literature, see Urbanski et al. (2018) and references therein.

The available wildland fire emissions data products (e.g., the NEI) only include estimates for burned wildland vegetation—including grasslands/pasture/rangeland—but do not include emissions from burned human-made fuels in developed areas (Baker et al. 2020; Larkin et al. 2020). Consequently, the available smoke emissions data products underestimate the total amount of emissions from catastrophic wildfires that burn into the WUI (Jaffe et al. 2020). The lack of emissions estimates for human-made fuels (e.g., structures and vehicles) is in part due to a lack of knowledge of what is in the smoke of wildfires that burn into an urban landscape (NASEM 2022a), a gap that CARB and the National Institute of Standards and Technology (NIST) have proposed to address with new research (CARB 2023c). Another reason for this limitation is the relatively coarse spatial resolution of satellite fire detections used as an input into emission estimates, which makes it difficult to differentiate between the emissions coming from combustion of various materials burning within one satellite pixel often as large as 2 kilometers by 2 kilometers (Shi et al. 2015; T. Liu et al. 2020).

Although smoke emissions are directly linked to fire activity, which varies daily, most forecasting models project past satellite observations to the future using the so-called persistence assumption (Ye et al. 2021; Jaffe et al. 2020). This widely used approach does not allow models to resolve day-to-day changes in fire activity and their impact on the emissions, because it assumes that the most recent day of observed fire growth can be used as a proxy for the next day's predicted fire growth. Although a new integrated approach to computing emissions has been proposed (Kochanski et al. 2015), it hasn't yet been widely adopted by air quality agencies.

4.4 Smoke dispersion

Smoke dispersion is typically measured over a specified area and period of time using several different metrics including: (1) the overall density of the smoke plume as a whole, (2) the concentration ($\mu g/m^3$) of individual air pollutants, or (3) the prevalence of significant smoke events (Long, Tarnay, and North 2018; Henderson et al. 2011; Koman et al. 2019). For historic fires and actively burning fires, smoke dispersion metrics can be estimated using observational

3 The NEI prescribed fires category includes only broadcast burns and does not include emissions from pile burns. The EPA is working to develop standardized methods for estimating emissions from pile burns. (U.S. EPA 2023a)

Table 10: Publicly available data products of wildland fire smoke metrics in California.

	Metric	Name	Data Product Type	Region	Timespan	ID by Source Fire?	Description
Smoke Emissions	Smoke Emissions	EPA National Fire Emissions Inventory	Inventory	US	2008 – present	YES	Retrospective estimates of daily emissions by weight of $PM_{2.5}$ and 40+ other air pollutants by individual fire event (wildfire and prescribed fire) across the U.S. Updated every three years. https://www.epa.gov/air-emissions-inventories/national-emissions-inventory-nei
Smoke Emissions	Smoke Emissions	CARB Wildfire Emissions Inventory	Inventory	CA	2020 – present	YES	Retrospective estimates of total emissions (tons) of $PM_{2.5}$, PM_{10} and CO_2 for the top 20 largest wildfires by area in California. Updated annually. https://ww2.arb.ca.gov/wildfire-emissions
Smoke Emissions	Smoke Emissions	Missoula Fire Lab Emission Inventory (MFLEI)	Data Set	US	2003 – 2015	YES	Retrospective estimates of daily emissions by weight of $PM_{2.5}$, CO_2, CO, and CH_4 by area burned across the U.S. at a spatial resolution of 250 m. https://data.nal.usda.gov/dataset/missoula-fire-lab-emission-inventory-mflei-conus
Smoke Dispersion	Smoke Plumes	NOAA HMS Smoke	Inventory	US	2003 – present	NO	Retrospective maps of daily smoke plume spatial footprints and optical density (light, medium, heavy). Smoke plumes represent cumulative contribution of one or more fires. Updated daily. https://www.ospo.noaa.gov/Products/land/hms.html
Smoke Dispersion	Smoke Plumes	U.S. EPA Air Now Fire and Smoke Map	Dashboard	US	current	NO	Interactive map of current HMS smoke plumes, fire detections, and air quality measurements. https://fire.airnow.gov
Smoke Dispersion	Smoke Concentration	NOAA High-Resolution Rapid Refresh (HRRR) Smoke Product	Inventory	US	2020 – forecast	NO	18- or 48-hour forecast maps of wildland fire smoke $PM_{2.5}$ concentrations at 3 km grid for the U.S. Updated hourly. Additional forecasts from the Experimental HRRR available since 2016. https://rapidrefresh.noaa.gov/hrrr/HRRRsmoke/
Smoke Dispersion	Smoke Concentration	Childs et al. 2022	Data Set	US	2006 – 2020	NO	Retrospective estimates of daily wildland fire smoke $PM_{2.5}$ concentrations over a 10-km grid. https://www.stanfordecholab.com/wildfire_smoke
Smoke Dispersion	Smoke Concentration	Aguilera et al. 2023	Data Set	CA	2006 – 2020	NO	Retrospective estimates of daily wildland fire smoke $PM_{2.5}$ concentrations by zip code. https://github.com/benmarhnia-lab/Wildfire_PM25_California_ZIP
Smoke Dispersion	Smoke Events	Capital Public Radio Wildfire Smoke Exposure Map	Dashboard	US	2009 – 2020	NO	Average number of smoke days a year by zip code across the U.S. for two time periods: 2009-2013 and 2016-2020. https://www.capradio.org/articles/2021/09/28/dangerous-air-we-mapped-the-rise-in-wildfire-smoke-across-america-heres-how-we-did-it/
Population	Smoke Exposure	Vargo 2020	Data Set	US	2010 – 2019	NO	Retrospective estimates of daily population exposure to HMS Smoke Plumes by US Census Blocks. https://dataverse.harvard.edu/dataset.xhtml?persistentId=doi:10.7910/DVN/CTWGWE
Population	Smoke Vulnerability	-	-	-	-	-	No known data products specifically designed for wildland fire smoke
Health Impacts	Health Outcomes (number of cases)	-	-	-	-	-	No known data products. See Table 11 for California studies.
Health Impacts	Health Outcomes (dollar value costs)	-	-	-	-	-	No known data products. See Table 11 for California studies.

data from satellite sensors or ground-based air quality sensors. For historic fires, forecasted fires, and simulated fires, smoke dispersion metrics can also be estimated from modeling tools based on inputs of weather and smoke emissions data. Estimates of $PM_{2.5}$ concentrations attributable to wildland fire smoke is an important input for modeling tools that estimate adverse health outcomes due to smoke exposure.

4.4.1 Smoke observations

The National Oceanic and Atmospheric Administration (NOAA) Hazard Mapping System (HMS) Fire and Smoke Product retrospectively tracks the spatial footprint and density (light, medium, heavy) of wildland fire smoke plumes daily across the U.S. (NOAA 2023a) (***Table 10***). The smoke plumes are optically detected by trained analysts from satellite data and therefore include smoke present at any height in the atmosphere but not smoke that is obscured by clouds (Rolph et al. 2009). Thus, the presence or absence of a smoke plume based on satellite data does not necessarily reflect on-the ground conditions where people are breathing (Vargo 2020). Some research has been conducted to develop functions for estimating ground level air pollution concentrations based on the HMS smoke plume data product (Larsen et al. 2018; Preisler et al. 2015; Fadadu, Balmes, and Holm 2020; Diao et al. 2019). The HMS data product includes information on the position of fires detected by satellites, but otherwise does not explicitly attribute smoke plumes to individual fires. Some researchers have manually validated the HMS data to attribute smoke plumes to individual wildland fires (Schweizer, Preisler, and Cisneros 2018). The EPA Air Now Fire and Smoke Map dashboard maps current smoke plume and fire locations, ground-level air quality readings, and recommendations for actions individuals can take to protect their health from smoke exposure (U.S. EPA 2023b) (***Table 10***).

While satellite data provide estimates of the entire smoke column in the whole atmosphere, EPA monitoring stations track ground-level concentrations of $PM_{2.5}$ and other air pollutants commonly found in smoke. Additionally, the high-density networks of PurpleAir and other low-cost sensors measure $PM_{2.5}$ concentrations at many more locations than the EPA stations, but these sensors can be less accurate than regulatory monitors (Holder et al. 2020). Ground-based monitors are primarily located in larger population centers with high levels of anthropomorphic air pollution, and many smaller or more remote communities that are more regularly affected by smoke lack local measurements of air pollution (U.S. EPA 2021).

Many of the air pollutants common to wildland fire smoke are also found in the emissions of other sources of air pollution, such as the combustion of fossil fuels (U.S. EPA 2021). The inventories of ambient air pollutant concentration data produced by the EPA and commercial monitoring networks represent the total cumulative concentration of air pollutants from all sources, and do not discriminate between non-fire and fire-specific sources of air pollution.

To derive estimates of 'smoke' $PM_{2.5}$ concentrations attributable to wildland fires, researchers combine data from ground-level air monitoring and satellite smoke plume datasets using a variety of models and methods (A. L. Johnson et al. 2020; Mueller et al. 2020; O'Dell et al. 2019; Mallia et al. 2014; Childs et al. 2022).

There are no regularly updated data inventories retroactively tracking smoke $PM_{2.5}$ concentration within the U.S. or California. Childs et al. (2022) and Aguilera et al. (2023) provide retrospective datasets of daily smoke $PM_{2.5}$ ($\mu g/m^3$) attributable to wildland fires from 2006 to 2020 (***Table 10***). Childs et al. (2022) reports smoke $PM_{2.5}$ over a 10-kilometer grid across the contiguous U.S., whereas Aguilera et al. (2023) reports smoke $PM_{2.5}$ concentrations by California zip code. There appear to be no data products tracking concentration of other air pollutants aside from $PM_{2.5}$ attributable to wildland fires.

4.4.2 Smoke modeling

Smoke transport, dispersion, and impact on ground-level concentrations of air pollutants can be estimated from smoke emissions and weather data using a wide range of modeling tools (Long, Tarnay, and North 2018). Examples include:

- particle dispersion models such as HYSPLIT (NOAA 2023c) or STILT (Lin et al. 2003)
- chemical transport models such as CMAQ (U.S. EPA 2023c) or WRF-CHEM (NOAA 2021)
- systems integrating fire, weather, and chemical transport models such as WRF-SFIRE-CHEM (Kochanski et al. 2015).

Smoke emissions are included in the air quality forecasts run by the EPA and available at AIRnow; however, these forecasts reflect the combined impact of air pollutants from smoke and other sources. The NOAA High-Resolution Rapid Refresh (HRRR) Smoke Product provides hourly forecasts with 18- or 48-hour lead time of smoke $PM_{2.5}$ concentrations ($\mu g/m^3$) from satellite detected wildland fires across a 3-kilometer grid of the continental U.S. (NOAA 2023b) (***Table 10***). Smoke forecasts have been included as part of the operational HRRRv4 since December 2020, with additional forecasts intermittently available from the Experimental HRRR since April 2016. In the absence of empirical, retrospective data products of observed historic wildland fire smoke $PM_{2.5}$, some researchers have used the HRRR forecasts as a proxy estimate of smoke $PM_{2.5}$ from fires that occurred in prior years (Rosenthal et al. 2022; M. M. Johnson and Garcia-Menendez 2022).

New integrated coupled fire-atmosphere models such as WRF-SFIRE (Mandel, Beezley, and Kochanski 2011) simulate both fire progression and smoke processes at regional scales. They integrate predictive fire spread models and numerical weather prediction models to simulate and forecast fire propagation in-line with the plume rise and smoke dispersion, either as standalone systems or as components of regional air quality systems such as AIRPACT (Kochanski et al. 2021). Although the operational models used by air quality agencies do not easily isolate the air quality impacts of particular fires, some of them (e.g., WRF-SFIRE, HYSPLIT or STILT) can be executed to assess the smoke impacts of a given fire (Mallia et al. 2020) or to investigate the individual contribution of emissions from multiple fires impacting the air quality at a given location (Mallia et al. 2014). Coupled fire-atmosphere models such as WRF-SFIRE can provide smoke forecasts and historical reconstructions at high spatial resolutions (typically around 500 meters), but they are only carried out for selected fire events.

4.4.3 Characterization of smoke events

Many anthropogenic activities that produce air pollutants (e.g., fossil fuel combustion) occur consistently year-round and are commonly reported as annual mean statistics. However, many wildland fires are intermittent events that result in extremely large but relatively short-lived pulses of increased air pollution, which can be obscured in annual mean statistics. To better study the prevalence of significant smoke events, researchers have developed the concepts of "smoke days" and "smokewaves" analogous to heatwaves (Koman et al. 2019; Errett et al. 2019; J. C. Liu, Mickley, Sulprizio, Dominici, et al. 2016). A smoke day is defined as a day in which wildland fire smoke exceeds a specified threshold value (e.g., plume density or smoke $PM_{2.5}$ concentration). Similarly, a smokewave is defined as two or more consecutive days with wildland fire smoke above a specified threshold value. Smoke days and smokewaves help researchers, managers, regulators, and communities better understand how often wildland fires are driving air pollution concentrations to levels high enough to be harmful to human health, and the cumulative impacts of smoke on populations.

The threshold smoke value used to define a smoke day or smokewave is not standardized and varies from study to study. Several papers have defined smokewaves as periods in which wildfire attributable $PM_{2.5}$ concentration exceeds the EPA National Ambient Air Quality Standard (NAAQS) of 24-hour $PM_{2.5}$ levels greater than 35 $\mu g/m^3$ (Koman et al. 2019; 2022). Other papers defined the threshold relative to their specific region and time period of study. For example, one study defined smokewaves as "periods in which wildfire attributable $PM_{2.5}$ concentration exceeded the 98^{th} or greater quantile of the distribution of daily wildfire attributable $PM_{2.5}$ values in the modeled present-day years, on average across the study area" (J. C. Liu, Mickley, Sulprizio, Dominici, et al. 2016). The threshold value used to define a smokewake varies greatly between studies from 6 $\mu g/m^3$ to 37 $\mu g/m^3$ (J. C. Liu, Wilson, Mickley, Ebisu, et al. 2017; J. C. Liu, Wilson, Mickley, Dominici, et al. 2017; Rosenthal et al. 2022; J. C. Liu and Peng 2019; J. C. Liu, Mickley, Sulprizio, Dominici, et al. 2016).

Smoke events are not systematically tracked across the U.S. or California, and there are no readily accessible retroactive inventories or datasets. However, when using a standard numeric value for the threshold (e.g., the NAAQS 24-hour $PM_{2.5}$ level of 35 $\mu g/m^3$), smoke events could be easily derived from datasets that track daily or hourly averages of air pollutant concentrations attributable to wildland fire smoke. National Public Radio's California Newsroom has published an online dashboard that reports average number of smoke days a year by zip code across the U.S. for two time periods—2009 to 2013 and 2016 to 2020 (Saldanha 2021). The dashboard defines smoke days as days in which a zip code intersected a NOAA HMS smoke plume.

4.5 Population exposure

Populations of people residing or working within the footprint of a wildland fire smoke plume are at risk of exposure to harmful levels of smoke that can lead to adverse health outcomes (Long, Tarnay, and North 2018; J. C. Liu, Wilson, Mickley, Dominici, et al. 2017; C. E. Reid et al. 2016; Gan et al. 2017). Population exposure metrics measure the size and vulnerability of populations exposed to wildland fire smoke. Because smoke typically spreads beyond the fire footprint, the population exposed to smoke can be much larger than the population exposed to the flames of the fire and can include people that are very far away from the fire footprint (Burke et al. 2021). Population vulnerability to smoke is dependent on the likelihood of smoke exposure, likelihood of negative health outcomes when exposed to smoke, and the likelihood or ability to take mitigating actions to reduce smoke exposure. These factors can be related to demographic indicators such as age, race, immigration status, income, occupation, and pre-existing health conditions (Rappold et al. 2017; D'Evelyn et al. 2022; Davies et al. 2018). Population exposure metrics are an important input for estimating counts of adverse health outcomes attributable to wildland fire smoke. ***In focus: Wildfire smoke impacts on vulnerable populations*** provides a discussion of vulnerability to health impacts from wildfire smoke as described in interviews with California health sector interviewees.

4.5.1 Population size

Population size metrics measure the number of people within the spatial footprint of a smoke event and is typically measured as person-days of exposure to smoke (OEHHA 2022). Population size represents the total maximum number of people that could be exposed to a given threshold amount of smoke. The actual number of people that are exposed to smoke could be much less depending on the extent to which a population takes action to reduce their exposure to smoke (Long, Tarnay, and North 2018).

The population being measured can vary depending on the focus of the study. Some studies use U.S. Census Bureau data products or the Gridded Population of the World census to estimate the size of the general population residing within the footprint of a smoke plume (Rosenthal et al. 2022; Hu et al. 2008; Long, Tarnay, and North 2018; Schweizer, Preisler, and Cisneros 2018; Gan et al. 2020). Another study used data from the California Employment Development Department (EDD) Labor Market Information Division public databases to estimate the population of agricultural workers exposed to smoke (Marlier et al. 2022).

The threshold definition of a high smoke event used for estimating person-days of exposure also varies by study. Examples include:

- exposure to medium and high-density smoke plumes identified by the NOAA HMS product (Schweizer, Preisler, and Cisneros 2018; Long, Tarnay, and North 2018);
- exposure to smokewaves in which smoke $PM_{2.5}$ higher than the 98^{th} quantile of wildfire $PM_{2.5}$ concentrations between 2004 to 2009 (Marlier et al. 2022); and
- exposure to $PM_{2.5}$ concentrations greater than specified Air Quality Index (AQI) thresholds (Marlier et al. 2022).

There are no regularly updated data inventories retroactively tracking person-days of exposure to smoke within California or the U.S. Vargo (2020) provides a historical dataset of U.S. population exposure to wildfire smoke plumes between years 2010-2019 (***Table 10***). The dataset combines data from the NOAA HMS Smoke Product and the United States Census Block Group Centers of Population to estimate potential exposures to light, medium, and heavy categories of wildfire smoke (Vargo 2020).

4.5.2 Population vulnerability

Populations can vary in their risk of smoke exposure and can vary in their risk of adverse health outcomes when exposed to a given amount of smoke. Research has found that some populations experience a disproportionately greater number of adverse health outcomes when exposed to the same amount of smoke, including children, the elderly, those who are pregnant, and those with pre-existing health conditions (D'Evelyn et al. 2022). Populations can also vary in the likelihood that individuals take mitigating actions to reduce their smoke exposure, which depends on their access to information on what actions to take (e.g., public health announcements), their willingness to take actions, and their access to resources necessary to take action (U.S. EPA 2021; Masri et al. 2023). Examples of actions that help reduce smoke exposure include reducing activity levels, using a mask, staying indoors, running portable air cleaners or HVAC systems equipped with high-efficiency filters to create a clean-air indoor space at home, or spending time at a community-designated clean air space (Fisk and Chan 2017; U.S. EPA 2021). Research has found that some populations have relatively lower ability to reduce their exposure to smoke, including lower-income communities, outdoor workers, unsheltered people, and people unable to access public health announcements due to language or resource barriers (D'Evelyn et al. 2022). Moreover, there is an expectation that population vulnerability to smoke could also vary depending on the type of wildland fire producing the smoke (U.S. EPA 2021). For example, because many beneficial fires are planned well in advance, people could potentially better prepare to reduce their smoke exposure, resulting in lower vulnerability than during unexpected wildfires (U.S. EPA 2021).

There are no data products tracking population vulnerability specific to wildland fire smoke across the U.S. or California (***Table 10***). Studies investigating the relationship between population vulnerability and wildland fire smoke exposure have used various metrics to measure population vulnerability. Some studies have relied on existing metrics of general vulnerability, including the CDC 2016 social vulnerability index (SVI) (Afrin and Garcia-Menendez 2021) or the California Office of Environmental Health Hazard Assessment CalEnviroScreen 4.0 (Rosenthal et al. 2022; Kramer et al. 2023). Other studies have developed their own custom indices to measure vulnerability specific to wildland fire smoke (Rappold et al. 2017; Gaither et al. 2015). Rappold et al. (2017) developed a Community Vulnerability Index metric that characterizes a population's risk to adverse health effects when exposed to wildland fire smoke based on representative measures demonstrated to modify the risk of smoke-related outcomes. These measures include prevalence for diabetes, hypertension, asthma, chronic obstructive pulmonary disease (COPD), percent of population over 65 years of age, household income, education, rates of poverty, and unemployment. Similarly, Gaither et al. (2015) developed a social vulnerability index for wildfires using the following eight factors: individuals greater than 65 years old; less than 15 years old; American Indian/Alaskan Native; African American; Hispanic; renters; poverty status; and persons 25 or over without a high school diploma.

4.6 Health impacts

Population exposure to the air pollutants in wildland fire smoke can result in a variety of adverse health outcomes including respiratory illness (e.g., asthma attacks and chronic obstructive pulmonary disease (COPD)), cardiovascular illness (e.g., heart attack), stroke, premature birth, low birth weight, and death (Amjad et al. 2021; Aguilera, Corringham, Gershunov, and Benmarhnia 2021; Stowell et al. 2019; Heft-Neal et al. 2022; Doubleday et al. 2020; Cascio 2018). Research on the links between ambient air pollution and health suggests that wildfire smoke exposure could also lead to adverse mental health outcomes (Bastain et al. 2021; Sheffield et al. 2018) and to long-term chronic health impacts, especially among populations with repeated exposures over time (Grant and Runkle 2022). Health impacts attributable to wildland fire smoke are typically measured as: (1) the number of excess cases of adverse health outcomes, or (2) dollar value costs of adverse health outcomes.

4.6.1 Methods for estimating excess adverse health outcomes

When smoke exposure causes a direct impact to health (e.g., irritation to the eye, throat, or respiratory tract), cases of adverse health outcomes attributable to a smoke event can be directly counted (Shusterman, Kaplan, and Canabarro 1993). However, smoke exposure can also indirectly impact health by contributing to the occurrence of many other adverse health outcomes (e.g., asthma or heart attacks). Indirect health outcomes cannot be individually counted, and cases are instead quantified from population-level estimates of excess adverse health outcomes attributed to a smoke event using statistical methods (NASEM 2020).

Excess cases of indirect adverse health outcomes attributable to wildfire smoke can be estimated in one of two ways: (1) an epidemiological study, or (2) a health impact assessment (Cleland et al. 2021). Epidemiological studies commonly employ a time-series analysis design that uses empirical health outcome datasets (such as total cases of heart attacks before, during, and after a smoke event) to estimate the number of health outcomes that occurred during a wildfire smoke event in excess of the expected background rate (Heft-Neal et al. 2022; Parthum, Pindilli, and Hogan 2017; Kochi et al. 2016; 2012; Delfino et al. 2009; G. Chen et al. 2021). Health outcome datasets are typically sourced from state or federal data products such as Vital Records from the California Department of Health, or Patient Discharge Data and Emergency Department Data provided by the California Department of Health Care Access and Information. Epidemiological studies can only be conducted retroactively for fires that have occurred in the past once the corresponding health outcome datasets are made available, resulting in a lag time of months or years from the fire event.

The results from past epidemiological studies can be used to derive concentration-response functions (CRFs) that describe the relationship between population smoke exposure and consequent health impacts. Health impact assessments use data on smoke concentrations and populations exposed with previously derived CRFs to estimate the excess cases of adverse health outcomes attributable to wildland fire smoke (Burke et al. 2021; U.S. EPA 2021; O'Neill et al. 2021; Jones and Berrens 2017; Cleland et al. 2021). Because wildfire smoke is composed of a mixture of many harmful gaseous and particle pollutants that are hard to quantify, studies usually rely on measures of an indicator pollutant to serve as a surrogate to represent exposure to all harmful smoke pollutants. Wildfire smoke studies often rely on measures of $PM_{2.5}$ to serve as the exposure indicator for estimating the health impacts of wildfire smoke because $PM_{2.5}$ has been shown to adversely affect many health outcomes, is regulated as a criteria air pollutant by the EPA, and is routinely monitored by the government monitoring networks (U.S. EPA 2021). CRFs for $PM_{2.5}$ are available in the literature or through the U.S. EPA's Environmental Benefits Mapping and Analysis Program – Community Edition platform (BenMAP–CE) (U.S. EPA 2023d). Health assessment studies can be conducted for historic or currently burning fires, forecasted fires, or simulated fire.

There is no standardized methodology for estimating the health impacts of wildfire smoke, and there are many $PM_{2.5}$ CRFs available in the literature that can be used to conduct a health assessment (Cleland et al. 2021). Depending on the CRF choice used for an analysis, estimates of adverse health outcomes attributable to a particular smoke event can vary by as much as an order of magnitude (M. M. Johnson and Garcia-Menendez 2022; Afrin and Garcia-Menendez 2021; Burke et al. 2021). The large variation in estimates depending on choice of CRF suggests that health impact results are not generally comparable across studies without careful review of the methods used in the analysis.

The large variation in health impacts estimates depending on choice of CRF also suggests that there are significant differences in the toxicity of $PM_{2.5}$ depending on the source of the smoke. Many of the available CRFs that relate $PM_{2.5}$ concentrations to health outcomes come from epidemiological studies of ambient air pollution (Cleland et al. 2021). However, growing convergent evidence from epidemiological and toxicological studies suggests that wildland fire smoke is more harmful than ambient air pollution at the same concentration of $PM_{2.5}$ (Aguilera, Corringham, Gershunov, Leibel, et al. 2021; Aguilera, Corringham, Gershunov, and Benmarhnia 2021; Wegesser, Pinkerton, and Last 2009; Migliaccio et al. 2013; K. M. Williams, Franzi, and Last 2013; Dong et al. 2017). This suggests that CRFs derived from studies of ambient air pollution are likely to underestimate the health impacts when used to assess wildland fire smoke.

Moreover, there is growing evidence that smoke toxicity can also vary between different types of wildland fire. Studies have found that smoke toxicity for a given concentration of $PM_{2.5}$ can vary depending on how a fire burns (e.g., smoldering vs. flaming) or what fuels a fire burns (e.g., vegetation vs. human-made materials), likely because how or what a fire burns can affect the chemical composition of air pollutant mixtures in the smoke plume (Kim et al. 2021; 2018). And smoke from prescribed fires may be less toxic than wildfires (Prunicki et al. 2019). Additionally, as smoke ages, the composition of constituent air pollutants changes as a result of ongoing chemical processes, which can also affect the relative toxicity of a smoke plume over time (O'Dell et al. 2020; Hodshire et al. 2019). These results collectively suggest that separate CRFs for different sources of $PM_{2.5}$ (ambient air pollution vs. fire smoke), for different types of fires (prescribed fire vs. wildfire), or even different ages of smoke may be warranted to ensure more accurate estimates of the health impacts from wildland fire smoke (M. M. Johnson and Garcia-Menendez 2022; Afrin and Garcia-Menendez 2021). Additional research on how the many constituents of wildland fire smoke vary across different fires and over time would facilitate the development of improved CRFs.

Although there is growing evidence that the health impacts of wildland fire smoke depend in part on a population's vulnerability to smoke exposure, there appear to be no available functions to account for this effect in estimates of adverse health outcomes (U.S. EPA 2021). The EPA's 2021 case study provides an example of how accounting for the adaptive capacity of populations to reduce their smoke exposure when calculating the smoke-related health costs of wildland fires can result in meaningful differences in the estimated number (U.S. EPA 2021). However, the study authors caution that their analysis is not based on rigorously developed vulnerability metrics and is presented only to illustrate the importance of accounting for population vulnerability when estimating smoke health costs.

4.6.2 Cases of health outcomes

There are no data products retroactively tracking the estimated number of cases of adverse health outcomes attributable to wildland fire smoke exposure in the U.S. or California. The California Department of Forestry and Fire Protection (CAL FIRE) wildfire incident inventory includes the number of injuries and fatalities directly attributed to wildfire exposure (e.g., burns from flames) but does not include cases of indirect health outcomes from smoke exposure (e.g., respiratory illness) (CAL FIRE 2023). A small, but growing, body of research studies estimate the number of cases of health outcomes attributable to smoke for select wildfires in California (***Table 11***)[4]. The studies focus on short-term physical health impacts that present either during or immediately after a smoke event and typically do not investigate delayed or chronic health outcomes that present long after a smoke event or mental health impacts. Thus, the available assessments of health impacts likely underestimate the total human health impacts of wildfire smoke over longer time frames.

The available studies report estimated cases of the cumulative health outcomes for all concurrently burning wildland fires that occurred within the study region and timespan, except for the U.S. EPA (2021) study, which reports estimated health outcomes for the 2015 Rough Fire in Fresno County. The U.S. EPA (2021) study also reports health outcome estimates for the hypothetical Boulder Creek prescribed fire that was planned but never implemented in Fresno

4 Table 11 includes only studies that report population-level estimates of health outcomes attributable to wildland fires that have occurred in California. Not included are the many studies that investigate the many ways smoke exposure can impact the health of individuals, or studies that estimate the relationship between smoke exposure and a health impact (e.g., an X% increase in respiratory hospitalizations per unit increase in smoke exposure). For reviews of the large body of literature discussing the health impacts of wildfire smoke see (Hill, Jaeger, and Smith 2022; Jaffe et al. 2020; U.S. EPA 2021; D'Evelyn et al. 2022; Cascio 2018) and for the smaller body of literature specifically focused on prescribed fire smoke see (Hill, Jaeger, and Smith 2022).

Table 11: Studies estimating the adverse health impacts from wildland fire smoke in California.

Study Name	Health Metric	CA Counties	Timespan	Health Impact
Adverse Health Outcomes (Number Of Cases)				
Heft-Neal 2022	Preterm Birth	All	2007-2012	6,974 (95 % CI: 5,513–8,437) excess preterm births attributable to wildfire smoke exposure 2007–2012.
O'Neill 2021	Deaths	All	October 2017 Wine Country wildfires	"Without the wildland fires, mortality due to $PM_{2.5}$ exposure was estimated as 44 deaths (95% confidence interval: 0, 105). Including the Wine Country wildfires and other smaller wildland fires increased the estimated mortality to 83 (95% confidence interval: 0, 196), almost doubling the number of deaths... It should be noted that a mortality of 83 is within the 95% confidence interval of the No Fires case and thus a possible outcome for that case as well."
Cleland 2021	Illness	All	October 2017 Wine Country wildfires	"We estimate there were an excess 240 (95% CI: 114, 404), 68 (95% CI: −10, 159), and 45 (95% CI: 18, 81) respiratory, cardiovascular, and asthma hospital admissions, respectively, attributable to fire-originated $PM_{2.5}$ exposure between October 8 and 20."
O'Dell 2021	Illness	All	2006-2018	"Asthma ED visits attributable to smoke $PM_{2.5}$ in the U.S. range from approximately 1,300 to 5,900 visits per year, or 0.07%–0.33% of all asthma ED visits. We estimate long-term exposure to smoke $PM_{2.5}$ leads to 6,300 (CI: 4,800–7,800) additional deaths per year, 3% of all $PM_{2.5}$ mortality in the contiguous U.S."
Adverse Health Outcomes (Dollar Value Costs)				
US EPA 2021	Illness and Deaths	Fresno	2015 Rough Fire	$3 billion (0.26 - 7.9) total for morbidity (cardiovascular and respiratory) + mortality.
Wang 2020	Illness and Deaths	All	2018	$32.2 billion for mortality (3,652 deaths) + $210 million for cost of illnesses
Jones 2017	Illness and Deaths	All	2005-2015	"On average, wildfire smoke in the Western U.S. creates $165 million in annual morbidity and mortality health costs."
Kochi 2016	Illness	Los Angeles, Riverside, San Bernardino, San Diego, Santa Barbara, Ventura	2007 Southern CA wildfires	"Specifically, we found approximately 80 excess respiratory-related hospital admissions, 26 excess acute cardiovascular-related hospital admissions, nearly 760 excess respiratory-related emergency department visits, and 38 excess acute cardiovascular-related emergency department visits. We estimated that the associated medical costs were over $3.4 million."
Kochi 2012	Deaths	Los Angeles, Riverside, San Bernardino, San Diego, Santa Barbara, Ventura	2007 Southern CA wildfires	"We identify 133 excess cardiorespiratory-related deaths caused by wildfire-smoke exposure. The mean estimated total mortality-related cost associated with the 2003 southern California wildfire event is approximately one billion U.S. dollars."

County, CA, and for several actual prescribed fires that occurred in Oregon. There appear to be no other studies that have estimated cases of adverse health outcomes attributed to real individual prescribed fires that have occurred in California (Hill, Jaeger, and Smith 2022).

All of the available studies focus on the general population residing in the study area. There appear to be no studies to date that estimate health outcomes for different sub-populations expected to be disproportionately impacted by wildland fire smoke. In particular, wildland firefighters, emergency responders, and other support staff deployed to wildland fires are expected to be exposed to higher concentrations of smoke at increased frequency over the course of their careers than the general population (Domitrovich et al. 2017). Although there is a body of literature studying physiological response (e.g., lung function) to occupational smoke exposure in individuals (for recent reviews see (U.S. EPA 2021; Navarro 2020; H. Chen et al. 2021; CCST 2020)), there appear to be no population-level studies estimating cases of adverse health outcomes of smoke exposure for firefighters and other fire emergency responders.

4.6.3 Costs of health outcomes

Health cost metrics estimate the dollar value costs of adverse health outcomes attributable to wildland fire smoke. Studies typically rely on Value of a Statistical Life (VSL) metrics to value excess mortality and Cost of Illness (COI) metrics to value excess health care treatments. Many studies rely on standardized VSL and COI metrics recommended in protocols developed by the EPA (U.S. EPA 2021; Neumann et al. 2021; Wang et al. 2020; Fann et al. 2018; Parthum, Pindilli, and Hogan 2017; Kochi et al. 2012). See the EPA publication *Guidelines for Preparing Economic Analyses* for more information (U.S. EPA 2010). Kochi et al. (2016) used hospital cost datasets from the California Office of Statewide Health Planning and Development to estimate medical costs of smoke impacts. Other studies relied on per unit cost estimates previously reported in the literature to estimate costs of premature births (Jones and Berrens 2020) and population willingness to pay to avoid smoke health impacts (Jones and Berrens 2017).

There are no data products retroactively tracking dollar value costs of adverse health outcomes attributable to wildland fire smoke exposure in the U.S. or California. There are also no data products tracking the organizational costs incurred by the health sector as a consequence of smoke impacts (see ***Chapter 2: Perspectives on Wildfire Smoke Impacts to Human Health and the Health Sector in California*** for further discussion). There are a few studies that have estimated costs of adverse health outcomes of smoke for select wildfires or time periods (***Table 11***). The studies report costs in the millions to billions of dollars, and it is important to appreciate that even though these estimates are already quite large, they represent only a partial accounting of total smoke health costs. A comprehensive estimate of the costs associated with all mortality, morbidity, and avoidance behaviors that reduce adverse health outcomes for all wildland fire smoke events in California would be much higher than what has already been reported.

4.7 Summary findings, conclusions, and recommendations

4.7.1 Smoke data gaps

Many useful smoke metrics are not being systematically tracked in regularly updated data inventories, limiting our understanding of the human health impacts of wildland fire smoke.

> 35. **Finding:** There are several data inventories that provide ongoing, retrospective tracking of smoke emissions and smoke plumes for the US, but there are no data inventories tracking smoke concentrations, population exposure to smoke, or smoke-related adverse health outcomes.

> 36. **Conclusion:** Ongoing, retrospective tracking of smoke metrics would facilitate more comprehensive assessments of the human health impacts of wildland fire smoke across California.

> 37. **Recommendation:** California and the federal government should consider creating regularly updated data products that retrospectively track air pollution concentrations attributable to wildland fire smoke, population exposure to smoke, and cases of adverse health outcomes attributable to smoke.

4.7.2 Tracing smoke back to fires

Smoke metrics are not being linked back to source fires, limiting our understanding of the human health tradeoffs of forest management strategies.

> 38. **Finding:** Data products that report smoke metrics by individual source fire are available for smoke emissions but are not available for smoke plumes or smoke concentrations.

> 39. **Conclusion:** Data linking smoke impacts back to source wildland fires would facilitate assessments of which landscapes pose the greatest potential risk to human health and thus potential priorities for forest management activities to reduce wildfire risk and improve forest health.

> 40. **Recommendation:** California and the federal government should expand available smoke data products to include estimates of smoke impacts by individual wildland fires. Tracking smoke impacts back to source fires is foundational data for research on the potential human health benefits of alternative forest management strategies.

4.7.3 Standardizing methodology

Lack of standardized methodology for estimating smoke impacts is limiting comparisons across studies.

> 41. **Finding:** There are currently no available methodological guidelines for estimating air pollutant concentrations attributable to wildland fire smoke, population exposure to smoke, or smoke-related adverse health outcomes.

> 42. **Conclusion:** Standardized methodology for estimating wildland fire smoke metrics (smoke air pollutant concentrations and adverse health outcomes attributable to smoke) would facilitate comparison of smoke impact results across studies and could provide useful metrics for management, response, and public education.

> 43. **Recommendation:** California and the federal government should support efforts to create methodological guidelines for estimating smoke air pollutant concentrations and counts of adverse health impacts attributable to wildland fire smoke in order to facilitate future research efforts.

4.7.4 Emissions from human-made fuels

Smoke emissions data don't include burned houses or other human-made materials, limiting our understanding of the human health impacts of wildfires that burn in the WUI.

> 44. **Finding:** Methods for estimating smoke emissions do not account for the emissions from burned houses or other human-made materials for wildland fires that burn into urban areas.

45. **Conclusion:** Data on the contributions of burned homes and other human-made materials to wildland fire smoke would allow for more comprehensive estimates of smoke impacts and facilitate assessments of the relative human health impacts of fires that burn a mix of human-made materials and vegetation in the wildland-urban interface (WUI), compared to fires that burn primarily vegetation in the wildlands.

46. **Recommendation:** California and the federal government should support the development of methodologies to estimate smoke emissions from human-made materials and should expand smoke emissions inventories to additionally include emissions estimates from developed landscapes that are burned by wildland fires.

4.7.5 Smoke risk of different fires

Methods for estimating health outcomes of smoke exposure do not account for differences in how or what fires burn or population vulnerability to smoke, limiting our understanding of the relative health risks of different kinds of fires.

47. **Finding:** Current methods to estimate health impacts from smoke exposure do not account for differences across how or what fires burn (e.g., beneficial wildland fire vs. catastrophic WUI fire), or subpopulation vulnerabilities.

48. **Conclusion:** Research to estimate the differences in health impacts related to how fires burn, what fires burn, and population vulnerability to smoke (i.e., to derive concentration-response functions) would facilitate more accurate estimates of the population-level health impacts from smoke exposure of different kinds of fire and the potential inequities in smoke impacts across population subgroups.

49. **Recommendation:** Research funders should support studies to develop concentration-response functions that can be used to estimate the effect of differences in how fires burn, what fires burn, and population vulnerability on resulting health impacts from smoke exposure.

4.7.6 Chronic, cumulative, and mental health impacts

Most studies estimate acute, physical adverse health outcomes of exposure to a single smoke event and do not account for chronic outcomes, cumulative health impacts from repeated smoke exposure, or mental health impacts, limiting our understanding of the full extent of the health risks of wildland fire smoke.

50. **Finding:** Current data on the of health impacts from smoke exposure focus on acute physical impacts and do not account for chronic, cumulative, or mental health impacts.

51. **Conclusion:** Research to estimate chronic, cumulative, or mental health outcomes would facilitate more comprehensive data on the of the adverse health impacts from smoke.

52. **Recommendation:** Research funders should support studies to better understand the chronic, cumulative, and mental health impacts of smoke exposure and to develop concentration-response functions that can be used to estimate cases of such adverse health outcomes in populations exposed to smoke.

Chapter 5: Evidence that Forest Management can Benefit Human Health

Author: Teresa Feo

A small but growing body of research suggests that management strategies to improve forest health can be tailored to also reduce total smoke impacts and benefit human health.

Non-forested, fire-dependent ecosystems are also a source of smoke, but the potential human health tradeoffs of management in grasslands and chaparral are unknown.

There is growing scientific consensus that a smoke-free future does not exist for California (NASEM 2022b; Petek 2022). California's forests will burn, but healthy, managed forests are expected to burn in very different ways compared to degraded forests (Hunter and Robles 2020; Williamson et al. 2016; Jones et al. 2022; U.S. EPA 2021; Long, Tarnay, and North 2018). Whether or not improving forest health could result in human health benefits is an empirical scientific question requiring careful evaluation (Jones et al. 2022).

Here, we review academic literature, technical reports, and other publicly available resources relevant for understanding the potential human health benefits of improving forest health. First, we present a consensus framework for evaluating the smoke trade-offs of alternative management strategies. Second, we review evidence that forest management, under the right context and conditions, can provide a human health benefit by reducing adverse smoke impact. Our review of the literature focuses on studies that compare the smoke tradeoffs of alternative management scenarios relevant to human health impacts from smoke exposure and excludes studies that focus specifically on smoke impacts (e.g., carbon emissions) relevant to climate change (see ***section 5.5*** for further discussion).

5.1 A framework for evaluating smoke tradeoffs of management

Our framework for evaluating the smoke tradeoffs of alternative management strategies builds upon the work of several previous studies (Hunter and Robles 2020; Williamson et al. 2016; Jones et al. 2022; U.S. EPA 2021; Long, Tarnay, and North 2018). Our framework compares the relative smoke costs[5] of two alternative forest management scenarios: (1) a no-treatment scenario, and (2) a proactive-treatment scenario (***Figure 9***). Here we use "smoke costs" to refer to the costs associated with adverse human health outcomes from population exposure to smoke. The framework could be further extended to also account for human health benefits of improving access to traditional foods by exposing ecosystems to smoke (Long et al. 2016; David, Asarian, and Lake 2018; Long et al. 2017).

In the no-treatment scenario, the landscape does not receive any proactive treatments to restore forest health or to reduce the risk of catastrophic fire—except for fire suppression (***Figure 9a***). This scenario is akin to the 'business-as-usual' scenario or the 'no-action' scenario in National Environmental Policy Act (NEPA) terminology. The no-treatment management scenario never uses beneficial fire or other treatments, and all wildfires that do occur are managed for suppression. The total smoke-related health costs for this no-treatment scenario includes the sum of the costs of all 'no-treatment' wildfires that occur over time.

In the proactive-treatment scenario, forests receive a recurring cadence of treatments across the landscape and over time to maintain a healthy forest and to reduce the risk of catastrophic fire (***Figure 9b***). Management strategies will vary from forest to forest and may or may not include the use of beneficial fire. Treatments that do not employ fire (e.g., mechanical thinning with no subsequent burning of waste piles) will incur zero smoke-related health costs.[6] In contrast, treatments that make use of beneficial fire will generate smoke and are expected to incur some amount of health costs. Unplanned wildfires are still expected to occur with some regularity in this scenario, and these 'proactive-treatment' wildfires will also incur smoke costs. The expected smoke costs of wildfires in proactive treatment scenarios will depend on the

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5 The smoke costs and benefits of individual treatments are almost always separated in time. Treatment costs are paid upfront while benefits are realized at some future date. For simplicity, we discuss comparing alternative scenarios in terms of their costs throughout this report. However, researchers conducting cost-benefit analyses may want to consider applying a discount rate to all estimated costs so that alternative scenarios can be compared in terms of their net-present value (Gray et al. 2019).

6 Although treatment activities such as mechanical thinning generate no smoke, they can still incur other human health costs. The operation of machinery with combustion engines to carry out forest thinning operations can generate air pollution emissions that pose a health risk, particularly to the forest management workforce. Moreover, some thinning treatment projects involve the removal of waste biomass from the forest to an offsite location where it can then be combusted for energy or heat production for a secondary economic benefit. The reutilization of forest waste in this way can also generate air pollutants and pose a risk to human health. A more comprehensive evaluation that considers a broader set of human health tradeoffs beyond just fire smoke should include these additional costs.

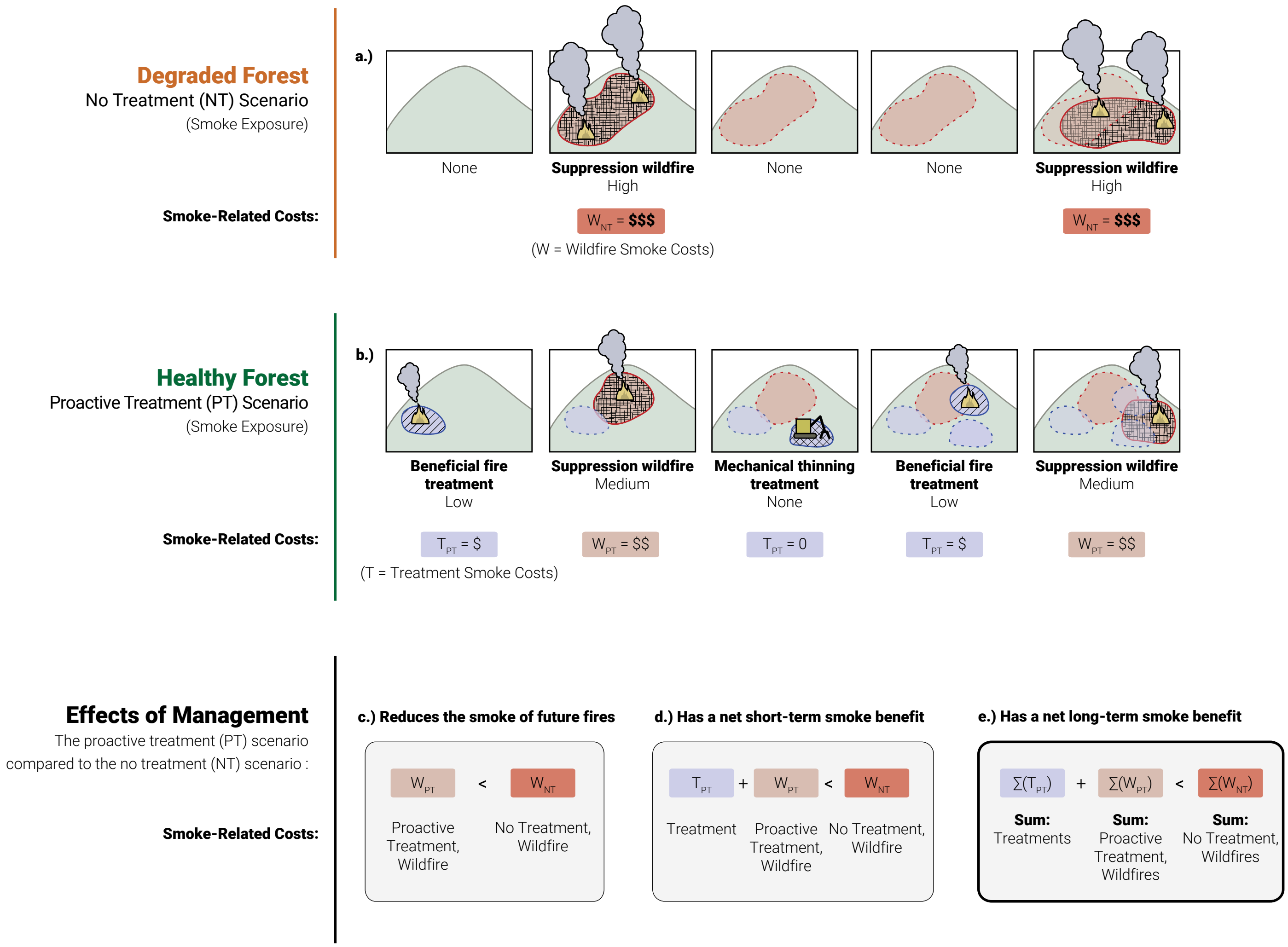

Figure 9. A conceptual framework for evaluating the smoke tradeoffs of forest management. **a:** A no-treatment scenario in which a forested area receives no treatments to improve forest health and all wildfires are managed for suppression. **b:** A proactive-treatment scenario in which a forested area receives a series of treatments spread across the landscape and over time to improve forest health and reduce the catastrophic impacts of wildfires. $\mathbf{W_{NT}}$ = smoke costs of wildfires under a No-Treatment scenario; $\mathbf{W_{PT}}$ = smoke costs of wildfires under a Proactive-Treatment scenario; and $\mathbf{T_{PT}}$ = smoke costs of treatments under a Proactive-Treatment scenario. **c-e:** Forest health has a net human health benefit when expected smoke costs under the proactive-treatment scenario are less than the smoke costs under a no-treatment scenario. Adapted from Figure 1 from Hunter and Robles (2020) and Figure 1 Jones et al. (2022).

effectiveness of prior treatments to modify wildfire behavior and the rate at which treatment effectiveness decreases over time as vegetation regrows (Williamson et al. 2016).The total health-related smoke costs for the proactive-treatment scenario over time includes the sum of the costs associated with all treatments plus the sum of the costs associated with all wildfires.

5.2 Evidence that forest management can reduce the smoke impacts of wildfires

The potential smoke benefits of forest management strategies are realized through their effectiveness in reducing the expected smoke costs of future wildland fires. In our framework, management strategies are effective at reducing the smoke costs of future wildfires whenever the smoke costs of a proactive-treatment wildfire are less than the costs of a no-treatment wildfire (***Figure 9c***). We found several studies that assessed the smoke costs of wildfires that burned under a proactive-treatment scenario compared to a no-treatment scenario (***Table 12***; $W_{PT} < W_{NT}$). However, in cases where the scenario included the use of beneficial fire, the studies did not include the treatment smoke costs in the analysis. All studies reviewed found that forest management can reduce the smoke impacts of post-treatment wildfire compared to a no-treatment wildfire.

Povak et al. (2022) compared four simulated treatment scenarios to investigate potential trade-offs in the Wenatchee River basin, Washington. Proactive treatment scenarios that included prescribed burning and/or mechanical thinning were compared to a no-treatment scenario. For each treatment scenario, researchers estimated $PM_{2.5}$ emissions (kg/ha) of a simulated post-treatment wildfire compared to a no-treatment wildfire. The study found that $PM_{2.5}$ emissions of post-treatment wildfires were lower than the no-treatment wildfires. In particular, scenario RA1 that consisted of a mosaic of treatments across the landscape to maximize both wildfire and climate resilience was expected to result in a 14% reduction in $PM_{2.5}$ emissions compared to the no-treatment scenario.

Long et al. (2018) compared estimated emissions for three simulated wildfire scenarios modeled after the 2013 Rim Fire, which burned in California's Sierra Nevada (Long, Tarnay, and North 2018). The wildfire scenarios were: (1) emissions of the actual 2013 Rim Fire, which occurred following the Grouse and Harden prescribed fire treatments constituting 4% of the Rim Fire area, (2) emissions from the Rim Fire if 100% of the area had received prior treatments, and (3) emissions from the Rim Fire if there had been no prior prescribed fire treatments. The study found that smoke $PM_{2.5}$ emissions of Rim Fire following prescribed fires was lower than the no-treatment wildfire. Compared to the no-treatment scenario 3, scenario 1 had 3.2% lower emissions and scenario 2 had 48% lower emissions.

Table 12: Studies evaluating the human health related smoke tradeoffs of forest management.

Paper	Region	Smoke Metric: Smoke Emissions	Smoke Metric: Smoke Dispersion	Smoke Metric: Population exposure	Smoke Metric: Health Impacts	Tradeoff	Results
Can management **reduce smoke costs of wildfires**? $W_{PT} < W_{NT}$							
Povak et al. 2022	WA	YES	-	-	-	Benefit	Simulated prescribed fire and mechanical thinning treatments reduced smoke $PM_{2.5}$ emissions from post-treatment wildfire by 14% compared to no-treatment wildfire.
Long et al. 2018	CA	YES	-	-	-	Benefit	Prior prescribed fire constituting 4% of the 2013 Rim Fire area reduced $PM_{2.5}$ emissions by 3.2% compared to the no-treatment wildfire. Treating 100% of the Rim Fire area with prescribed fire would have reduced emissions by 48%.
Graw and Anderson 2022	OR	YES	YES	-	-	Benefit	Prior prescribed fire treatments would have reduced $PM_{2.5}$ emissions from the 2015 Stout's Creek Fire by 45% and reduced $PM_{2.5}$ concentrations at the Shady Grove air monitor from 295 μg/m^3 to 175 μg/m^3.
Long et al. 2022	CA	-	YES	-	YES	Benefit	Select individual wildfires simulated as part of alternative 100-year management strategies for the Tahoe Basin had lower measured $PM_{2.5}$ concentrations at downwind urban centers and reduced health costs compared to wildfires under the no-treatment scenario
Ravi et al. 2019	ID, OR, WA	-	-	-	YES*	Benefit	Assuming that a biomass removal treatment was effective at reducing subsequent prescribed fire emissions by 70%, the study then estimates mortality and morbidity attributed to simulated smoke dispersion was expected to be reduced by 25–30% compared to the no-treatment scenario.
Burke et al. 2021	CA	-	-	-	YES*	Benefit	Assuming that prescribed burning is effective at reducing smoke $PM_{2.5}$ concentrations of future wildfires, the study then estimates the smoke reduction in terms of reduced health benefits.
Can management have a **net short-term smoke benefit**? $(W_{PT} + T_{PT}) < W_{NT}$							
Stevens et al. 2016	CA	YES	YES	-	-	Benefit	Simulated mechanical thinning treatments reduced total smoke PM_{10} emissions and the size of the downwind area exposed to high smoke concentrations ($PM_{2.5}$ > 20 μg/m^3) was reduced by 20-56% for post-treatment wildfires compared to no-treatment wildfire.
Hyde and Strand 2019	ID	YES	-	-	-	Neutral	Total smoke emissions ($PM_{2.5}$ kg/hectare) of simulated treatment scenario including prescribed fire was not significantly different from the no-treatment scenario; but the treatment scenario would have spread smoke across two events, each with lower emissions, compared to one event with high emissions in the no-treatment scenario.
US EPA 2021	CA	-	-	-	YES	Benefit	Simulated treatment scenarios with prescribed fire followed by a post-treatment wildfire had lower net adverse health outcomes and up to a 40% reduction in health costs compared to no-treatment scenario.
Can management have a **net long-term smoke benefit**? $(\sum W_{PT} + \sum T_{PT}) < \sum W_{NT}$							
Long et al. 2022	CA	YES	-	-	-	Benefit / Cost	Some simulated forest management scenarios in Tahoe over the next ~100 years had a net cumulative reduction in $PM_{2.5}$ emissions compared to the no-treatment scenario, with the size of the reduction depending on the details of the treatment prescriptions. Other simulated scenarios had a net increase in total $PM_{2.5}$ emission but a fewer number of extreme smoke events.
CARB 2022	CA	YES	-	-	YES	Benefit	Simulated forest management strategies that increase acres of forest treatment above current level for CA over the next ~25 years are expected to result in decreased smoke $PM_{2.5}$ emissions and an annual savings of ~$7 billions in avoided health costs.

Graw and Anderson (2022) evaluated the ability of simulated treatments to reduce the smoke costs of subsequent wildfires in the vicinity of five communities in southwestern Oregon. The study first used meteorological data products from NOAA to model the most common air pathways into each of the community. Wildland fires that burn within a community's frequent air pathway have a greater risk of transporting smoke into the community than fires that occur elsewhere on the landscape. The researchers then selected as a case study the community of Shady Grove on August 2, 2015, when two wildfires (the Stouts Creek Fire and the Cables Crossing Fire) were burning within the frequent air pathways to Shady Grove. Researchers estimated the $PM_{2.5}$ emissions (kg/ha) of a simulated treatment scenario in which 100% of the area burned by the Stout's Creek Fire had undergone fuels reduction with prescribed fire. Estimated smoke $PM_{2.5}$ emissions for a simulated post-treatment wildfire was 45% lower compared to the estimated emissions for the Stout's Creek Fire. Had the simulated treatment been completed just prior to the case study, the observed $PM_{2.5}$ concentration of 295 µg/m^3 at the Shady Grove air monitor on August 2, 2015 (attributable to the two fires) would have been reduced to 175 µg/m^3.

Burke et al. (2021) and Ravi et al. (2019) connected emission impacts to health impacts with an approach that assumes forest treatments are effective at reducing smoke emissions by a stated amount, and then estimating the expected reduction in health impacts. In the Ravi et al. (2019) study, the researchers assume that a treatment to remove waste biomass from the landscape (to be used offsite) would be effective at reducing smoke emissions during a follow-on prescribed fire by 70% (compared to a prescribed fire without pre-treatment). The study then simulated smoke dispersion to estimate expected health impacts. A 70% reduction in emissions was expected to reduce mortality and morbidity attributed to smoke by 25% to 30% compared to the no-treatment scenario.

5.3 Evidence that forest management can result in a net short-term smoke benefit

When management strategies include the use of beneficial fire, the smoke impacts of those treatments must be weighed against the benefit of reducing the costs of future fires. Studies conducted during the interval between a single treatment project and the next wildland fire event provide insight on the potential short-term smoke tradeoffs. In our framework, forest management strategies have a net short-term smoke benefit whenever the total costs of a treatment project plus the next post-treatment wildfire is less than the expected costs of a no-treatment wildfire (***Figure 9d***).

We found several studies that evaluate the net short-term smoke impacts of forest management strategies (***Table 12***; $T_{PT} + W_{PT} < W_{NT}$). When the treatments included the use of beneficial fire, the costs of the treatment fires were also estimated and included in the analysis. Two studies found net short-term smoke benefit for proactive-treatment scenarios, whereas one study found a net neutral effect compared to the no-treatment scenario.

Stevens et al. (2016) simulated five mechanical fuel treatment scenarios to study trade-offs among various objectives to reduce the destructiveness of wildfires and improve forest health. Treatments and wildfires were simulated in the Lake Tahoe Basin, California. For each of the five scenarios, researchers simulated a post-treatment wildfire and compared estimated smoke PM_{10} emissions, smoke plume dispersion, and smoke $PM_{2.5}$ concentrations against estimates from a no-treatment scenario wildfire. Because the scenarios only used mechanical thinning and no beneficial fire, the smoke costs of the treatments were all zero. All five scenarios demonstrated a net reduction in total smoke PM_{10} emissions, and the size of the downwind area exposed to smoke $PM_{2.5}$ concentrations greater than 20 $\mu g/m^3$ was reduced by 20% to 56% depending on the scenario.

Hyde and Strand (2019) simulated a treatment scenario of mechanical thinning followed by prescribed fire in the Boise National Forest, Idaho. The simulated treatment was modeled after the proposed Becker project, which was planned but not implemented due to the 2016 Pioneer Fire. Researchers estimated smoke emissions (PM_{10}, $PM_{2.5}$ and other air pollutants) of the prescribed fire, a post-treatment wildfire, and a no-treatment wildfire. The simulated wildfire was modeled based on the 2016 Pioneer Fire that occurred in the Boise National Forest. Researchers found no significant difference in total net smoke emissions between the no-treatment scenario and the treatment scenario. However, they note that the treatment scenario would have split the total smoke emissions across two separate lower emissions events compared to one high emissions event of the no-treatment scenario.

The U.S. EPA (2021) study simulated prescribed fire treatments scenarios for the area in Oregon burned by the 2018 Timber Crater 6 wildfire and the area in California burned by the 2015 Rough wildfire. The study estimated the number of adverse health outcomes (respiratory and cardiovascular emergency department visits, hospital admissions, and mortality) and the dollar value costs of the health outcomes for the simulated prescribed fires, post-treatment wildfires, and no-treatment wildfires. The study found that the net smoke-related health costs of treatment projects followed by a post-treatment wildfire were 40% lower than a no-treatment wildfire. These findings suggest that treatments could contribute to positive health and economic outcomes.

5.4 Evidence that forest management can have a net long-term smoke benefit

Stewarding a healthy forest in perpetuity will likely necessitate a regular cadence of treatments spread across the landscape and over time. As a patchwork of treatments builds in a forest, feedback between treatments and wildfires could begin to generate emergent benefits. Long-term studies, conducted over a time period longer than the fire return interval, provide an opportunity to account for any beneficial cumulative feedback that builds over time between recurring treatments and fires. Additionally, long-term studies provide an opportunity to account for the costs of any long-term chronic health impacts that present long after a fire event has occurred or cumulative health impacts that develop in response to recurring smoke exposure. In our framework, forest management strategies have a net cumulative long-term human health benefit whenever the sum of all smoke costs expected for the proactive-treatment scenario is less than the sum of all smoke costs expected from the no-treatment scenario (***Figure 9e***). We found two studies, both recently published, that evaluate the net long-term smoke impacts of forest management strategies (***Table 12***; $\sum T_{PT} + \sum W_{PT} < \sum W_{NT}$).

Long et al. (2022) estimated net cumulative smoke emissions for five simulated treatment scenarios in Lake Tahoe basin over the next century of modeled climate conditions (2010-2110). The five scenarios were: (1) no treatment other than suppression; (2) treatments emulating the recent history of thinning in WUI areas; (3) treatments with more intensive and extensive thinning throughout the forest; (4) treatments with prescribed burning at modest levels along with thinning at a rate like that in scenario 2; and (5) treatments with high levels of prescribed burning along with thinning at a rate like that in scenario 2. Smoke emissions were estimated for wildfires, prescribed fires (broadcast burns), and pile burns of mechanical thinning waste. The study found that scenarios 2 and 3 over the next ~100 years are expected to have a net cumulative reduction in $PM_{2.5}$ emissions compared to the no-treatment scenario 1 with the amount of the smoke reduction depending on the details of the treatment prescription. Forest management strategies that resulted in a net increase in total emissions (scenarios 4 and 5), nevertheless had fewer extreme smoke events (e.g., more total emissions but spread out into many more smoke events each with smaller emissions) compared to the no-treatment scenario. The study also estimated smoke dispersion and health impacts for several individual wildfires and prescribed fires from each scenario from a single model year (2039) as a case study. The study found that select individual wildfires from treatment scenarios had lower health costs than wildfires from the no-treatment scenario, suggesting that forest management strategies can have a net short-term human health benefit.

The CARB 2022 Scoping Plan includes an analysis comparing expected $PM_{2.5}$ emissions and associated health costs for several climate mitigation scenarios proposed for statewide implementation between 2025 to 2045 (CARB 2022). Forest management strategies for the modeled scenarios are as follows:

- **Business-As-Usual:** Current rate of forest treatment activities; ~ 250,000 acres treated per year.
- **Scenario 1:** No forest treatment activities; 0 acres treated per year.
- **Scenario 2:** ~ 1 million acres treated per year.
- **Scenario 3:** ~ 2-2.5 million acres treated per year.
- **Scenario 4:** ~ 5-5.5 million acres treated per year.

The dollar value of health costs was estimated for several adverse respiratory and cardiovascular health outcomes and all-cause mortality. Scenario 1, treating fewer acres than the current strategies, resulted in a net $500 million in additional human health costs. Scenarios 2-4, treating more acres than the current strategy, resulted in a net human health benefit. Scenario 4, the largest proposed increase in treated acres, resulted in the biggest human health benefit, with $7 billion in reduced health costs compared to a business-as-usual base case scenario.

5.5 The health tradeoffs of forest management compared to climate tradeoffs

Wildland fire smoke is composed of a complex mix of chemical compounds, some of which are known to be toxic to humans. Wildfire smoke also includes the greenhouse gases carbon dioxide (CO_2) and methane (CH_4), which contribute to global climate change (Andreae 2019). Our literature review is focused on the smoke-related human health tradeoffs of forest management, but there is a complementary body of literature focused on the smoke-related climate change tradeoffs of forest management (Hunter and Robles 2020). Studies evaluating the carbon tradeoffs of forest management find mixed results: the increased use of prescribed fire can result in a net benefit, a net cost, or no significant change depending on the context (Hunter and Robles 2020).

However, the results from studies on the smoke-related carbon tradeoffs of management strategies should not be used to draw conclusions on the potential smoke-related human health tradeoffs (or vice versa). Only the first factor of the Long et al. (2018) framework, the amount of carbon emissions to the atmosphere, needs to be taken into consideration when evaluating the potential climate impacts of wildland fire. Where those carbon emissions disperse to, or the populations that might also be exposed to those carbon emissions, are irrelevant to their potential climate impact. A wildland fire with a large climate-related cost could have very low human health costs if most of the smoke blows away from any populated areas. It is conceivable that forest management strategies with a net climate benefit could nevertheless have a net human health cost (or vice versa). Consequently, the known tradeoffs of one type of smoke impact should not be used as a proxy to infer the tradeoffs of other types of smoke impacts without careful consideration to ensure the underlying analysis is still valid.

5.6 The smoke tradeoffs of management in non-forested ecosystems

Many of California's non-forested ecosystems, such as grasslands and chaparral shrublands, experience frequent wildfires and are a significant source of smoke in the state (Stephens, Martin, and Clinton 2007; Calhoun et al. 2022). During the past 20 years, close to half of the total area burned in California was shrublands and grasslands (Calhoun et al. 2022). Between 1984 to 2020, 19% of total $PM_{2.5}$ emissions from large fires (greater than 1,000 acres) in California were from grasslands and shrublands (Xu, Westerling, and Baldwin 2022).

Many of these non-forested ecosystems are also fire-adapted, and altered fire regimes (e.g., too little or too much fire) can threaten the resilience of these plant communities. In California's coastal annual grasslands, evidence indicates that frequent fire return intervals (i.e., less than 5 years) helped maintain native coastal grasslands by keeping shrub or forest encroachment at bay, and the exclusion of fire from these plant communities has reduced their prevalence (Rutherford, Evett, and Hopkinson 2020). However, frequent fire in these systems can also lead to invasion of alien plant species which can further degrade the health of native grasslands (Keeley 2000).

In other vegetation types, increasing fire frequency can reduce resilience. For example, chaparral in Southern California is adapted to infrequent high-severity fire, and increasing frequency of high severity fire fueled by invasive annual grass species can adversely impact shrub regeneration (Keeley and Brennan 2012). Southern California chaparral ecosystems have experienced more frequent wildfires than historically (unlike the fire deficit experienced by many of the forested ecosystems) and are under threat of an ecosystem type change as a result (Syphard, Brennan, and Keeley 2019).

Management options to effectively reduce the risk of catastrophic wildfire and protect communities in non-forest ecosystems can include mechanical vegetation reduction, mastication, prescribed fire, prescribed grazing treatments, or fuel breaks, but these may or may not be well aligned with ecological health of these systems (Keeley and Syphard 2019). In these cases, the opportunities to manage for both ecological and public health goals are less clear. Although our study was focused on forested ecosystems, we did not restrict our literature search to only studies of forests. Nevertheless, we found no studies for non-forested ecosystems that evaluated smoke tradeoffs of management strategies.

5.7 Tools for evaluating the smoke impacts of alternative management strategies

The California Wildfire and Forest Resilience Task Force is in the process of publishing Regional Resource Kits to help regional planners prioritize landscape treatments to mitigate fire risk, maximize ecological benefits, and help California's landscapes adapt to climate change (California Wildfire and Forest Resilience Task Force 2023). The Resource Kits assess the potential benefits of forest management for various metrics including potential air quality improvements. For each region, the kit includes datasets estimating potential smoke emissions (short tons of $PM_{2.5}$) at 30-meter resolution for high-severity fire expected for uncontrolled wildfire (e.g., no-treatment landscape) and moderate-severity fire expected for prescribed fire (e.g., proactive-treatment landscape). Tradeoffs between wildfire and prescribed fire smoke production can be assessed by comparing the difference between high-severity and moderate-severity estimates over a specified area (Young-Hart et al. 2022). Additionally, the California Natural Resources Agency, in collaboration with the U.S. Department of Agriculture Forest Service, Google, the University of California, and others, is developing a new wildfire resilience decision support planning tool named Planscape that is based on the Resource Kit data layers (Planscape 2023). There are also commercial products for evaluating forest management treatments, but review of these products is beyond the scope of this study.

5.8 Summary findings, conclusions, and recommendations

5.8.1 Smoke benefits of forest management

A small but growing body of research suggests that management strategies to improve forest health can be tailored to also reduce total smoke impacts and benefit human health.

53. **Finding:** There is evidence that forest management strategies (even those that increase the use of beneficial fire) can reduce smoke-related health impacts compared to a no-treatment scenario.

54. **Conclusion:** Scientific evidence for the human health benefits of improving forest health are limited, but preliminary results are supportive.

55. **Recommendation:** California, the federal government, and other research funders should support additional research to study the smoke-related human health tradeoffs of different possible forest management strategies in order to improve forest and human health.

5.8.2 Health tradeoffs compared to climate tradeoffs

The health tradeoffs of forest management are distinct from the climate tradeoffs

56. **Finding:** Evaluating the human health impacts of smoke emitted from a wildland fire requires context about smoke dispersion and population exposure, which is not necessary when evaluating the climate impacts of carbon emitted by the same fire.

57. **Conclusion:** Although evaluating the climate-related carbon tradeoffs of wildland fire smoke is valuable for understanding the relative costs or benefits of alternative forest management strategies, carbon tradeoffs results should not be used as a proxy for inferring the human health tradeoffs of a management strategy.

58. **Recommendation:** Evaluations of the cost/benefits tradeoffs of alternative forest management strategies should include separate analyses for the potential human health tradeoffs and for the potential climate tradeoffs of wildland fire smoke.

5.8.3 Smoke tradeoffs in non-forested ecosystems

The smoke tradeoffs of management in non-forested ecosystems are unknown

> 59. **Finding:** There appear to be no studies that have investigated the effectiveness of management activities to reduce wildland fire smoke impacts in non-forested ecosystems (i.e., chaparral, grasslands, etc.).

> 60. **Conclusion:** The potential human health benefits of management in non-forested, fire-dependent ecosystems, such as chaparral shrublands or grasslands, is currently unknown.

> 61. **Recommendation:** California, the federal government, and other research funders should support additional research to evaluate the human health tradeoffs of management strategies to improve the health of non-forested, fire-dependent ecosystems including chaparral shrublands and grasslands.

List of FCRs

Chapter 1: Introduction

Chapter 2: Perspectives on Wildfire Smoke Impacts to Human Health and the Health Sector in California

Chapter 3: Perspectives on the Connections Between Forest Health and Human Health

Chapter 4: Data Resources for Estimating the Health Impacts of Smoke

Chapter 5: Evidence that Forest Management can Benefit Human Health

Appendix A: Supplemental Quote Tables

Table A1: Quotes from health sector interviewees on the interaction of COVID and wildfire smoke.

Theme	Illustrative Quote
COVID negatively impacted healthcare workforce capacity, which has implications for responding to wildfire smoke events.	**QA1.** "Coming out of a pandemic for public health, it's a really hard time because a lot of people are leaving because they're so exhausted and burned out. And so I think we're trying to rebuild and figure out what that rebuilding looks like, that's both an opportunity but also a challenge. You know, we have an opportunity to focus on things that we haven't done before, and we are doing that with a tired and smaller workforce." – Public Health Interviewee [id716]
COVID and wildfire smoke both negatively impact communities, potentially exacerbating existing vulnerabilities and creating a double burden on health systems.	**QA2.** "We're already getting dozens of patients showing up to the hospital with severe respiratory complaints from COVID. So you know, if [a wildfire] was to occur during a COVID surge, it would just exacerbate that problem." – Public Health Interviewee [id952]
Actions taken to respond to and prepare for COVID may also help the health sector prepare for wildfire smoke events.	**QA3.** "There's been this interesting kind of overlap or intersection between some of the COVID work, in terms of upgrading filtration systems in schools and other built environments like housing… Addressing COVID could actually lead to perhaps some increased protections or resilience for wildfires, smoke and other air pollutants as well." – Public Health Interviewee [id581] **QA4.** "Our experience having to go through the COVID pandemic actually has helped us in preparing for these smoke events. Keeping people indoors, making sure that we have good working air filters, the availability of masks at the time." – Public Health Interviewee [id860]
Public health guidance on protective behaviors for COVID and wildfire smoke are sometimes in contradiction.	**QA5.** "We were both experiencing a COVID surge, as well as we had a local wildfire. And as far as COVID goes, it was like 'stay outside, don't go inside with people, because you might get exposed to COVID.' And then we had the fire and things like 'don't go outside, stay inside because of the air quality.' And it was like there was nowhere you could go, literally ashes were raining down the sky, the sky was full of smoke. And we had COVID situation, so we couldn't physically distance people because of the outdoor air quality. This was an example of, you know, an infectious disease pandemic that was complicated by an environmental catastrophe that was making it hard for people to breathe inside or outside." – Health System Interviewee [id561]

Table A2: Quotes from health sector interviewees on who bears the cost of wildfire smoke.

Theme	Illustrative Quote
While everyone bears the costs of wildfire smoke, vulnerable populations are especially burdened.	**QA6.** "All of us. It's anybody. It's anybody who's breathing the air in the air basin… That being said, some of us work in nice, air-conditioned facilities that may have good air filtration or we can afford to put HEPA filters in our homes and every room… Individuals who are in job situations where they have to be outside or the homeless, those people are going to have a much higher exposure to wildfire smoke." – Health System Interviewee [id996] **QA7.** "So I think everybody there, all the residents of California bear some of the cost, but it's definitely disproportionately on the shoulders of those who are most vulnerable and are least likely to be able to afford it." – Public Health Interviewee [id817] **QA8.** "We have a lot of patients who have just gone through [transplants], who have no immune system. They can't handle any exposure to indoor air quality changes. So our populations in the hospital are extremely vulnerable. And so the cost to the health of our community [from wildfire smoke] is just, I mean, I don't even know how you would put dollars on that." – Health System Interviewee [id596]
While health systems and insurance may bear intermediate costs, those costs are usually passed on to the public.	**QA9.** "When these health impacts [from wildfire smoke] happen, that cost gets passed on to the insurers who, you know, basically turn around and charge the government or private individuals who pay for their health care. Those costs just kind of get passed on." – Health Insurance Interviewee [id575] **QA10.** "At the end of the day, the only people that end up paying are the patients. You know, when [health systems'] costs go up, it just makes it more expensive to get care. And the insurance companies, more and more, shift the burden to the patient." – Health System Interviewee [id096]

Table A3: Quotes from health sector interviewees on tracking the costs of smoke events and associated data challenges.

Theme	Illustrative quote
Are health sector organizations tracking the health or organizational costs of smoke events?	
Almost all organizations are not tracking these costs, but health insurance interviewees noted that they had the data to do so.	**QA11.** "We are not. I think that would be an important thing to do. We are not doing that on a routine basis." – Public Health Interviewee [id716] **QA12.** "When you're kind of dealing with the tyranny of the urgent in a small hospital during a wildfire event, then you're just not necessarily calculating, doing anything more than you have to do." – Health System Interviewee [id423] **QA13.** "I'm unaware that we've assigned dollar figures to any particular disaster. But I'm sure that's something that could be done. I would think that the claims data in particular would tell you geographically, by our members, if something happened, what was the impact from a cost perspective or utilization perspective." – Health Insurance Interviewee [id845]
Very few health sector organizations are calculating costs of wildfire smoke events.	**QA14.** "When something bad happens that causes you to invest a lot of money, you can keep track of it, and you can file a claim against your insurance… I don't know what the criteria are for us to file an insurance claim about a wildfire or a smoke event. But somebody up there decides we should start tracking how much we're spending on this response… we'll just start tracking all of our labor and meetings, all of our equipment rentals, all of our response times, all of our overtime, if we need new filters, if we're calling in vendors to help us change air filters. All of the costs associated with the smoke that would [be recorded]." – Health System Interviewee [id596]

Continues on next page.

Table A3 (Continued): Quotes from health sector interviewees on tracking of the costs of smoke events and associated data challenges.

Theme	Illustrative quote
Data Challenges	
Capacity constraints limit opportunities to track impacts.	**QA15.** "We don't have a way, with our epidemiologists, of measuring [health impacts of wildfire smoke] for residents in [this community] per se. We have a very rough ability to understand acute respiratory issues that happen in the same timeframe as we're seeing smoke events and wildfire events. But again, those are very blunt, broad ways of assessing what's going on." – Public Health Interviewee [id716]
Health sector organizations lack access to high-quality, relevant data.	**QA16.** "We are finding that it's a little difficult to really put your finger on saying that this event was triggered by that cause though. So I think what we're really looking to do is to think about this from a data perspective and try to see if we can, over time, tie surges in certain health conditions that necessitate healthcare encounter events–whether that's ER or trip to your family physician, whatever–to an actual climate event. So I think over time, we'll have some sophistication to do that." – Public Health Interviewee [id789] **QA17.** "Because it's so infrequent, we don't really have the infrastructure set up to measure [health impacts from wildfire smoke] directly. And then the kinds of health effects from wildfire smoke, they overlap with sort of natural disease as well. So, in order to sort of calculate a cost, you'd have to understand what your current rate is over a background rate. And so it gets pretty complicated. To do that requires really good data, it requires a big enough N to be able to see a signal rather than just noise. And it requires, you know, a duration of event that could be clearly attributed to wildfire smoke to understand the kind of health effects and the cost of treating that." – Public Health Interviewee [id795]
Tracking wildfire smoke impacts is methodologically complex.	**QA18.** "You have so many confounders. You know, imagine somebody evacuating from their home. And they're exposed to smoke, but they're also exposed to the stress of the evacuation. They're probably doing physical exertion, and they're not used to doing it. They're now living in a parking lot eating fast food. So you can imagine all these confounders that would make it difficult to know to what extent the wildfire smoke would affect that." – Public Health Interviewee [id795]

Table A4: Quotes from health sector interviewees on information availability and delivery gaps important to facilitating engagement with forest management.

Information Gap	Description or Examples	Illustrative quotes
Information about the impacts of wildfire smoke on health and organizational outcomes.	Information about the impacts of wildfire on human health and organizational resources, including: • Acute impacts • Chronic impacts • Cumulative impacts • Tangible tracking of health outcomes • Financial resources • Staffing and capacity	**QA19.** "We haven't as a society... done a great job of quantifying health impacts based on smoke events, or other sorts of environmental issues. So I think, key for the healthcare system writ large, is really connecting those dots. I think it's evident to people that these things happen, but not tangible." – Health Insurance Interviewee [id845] **QA20.** "One of the big questions is what are the longitudinal impacts of wildland fire smoke?… As that smoke settles into our ag worker population, and you've got ag workers in the fields… what's the impact of them seeing that same level of particulate matter day after day, week after week, recognizing that it's more impactful over time? We just don't have that data." – Public Health Interviewee [id850] **QA21.** "Making it tangible for these organizations that investing on the front end on public health has a near-term financial return on investment matters a great deal." – Health Insurance Interviewee [id845]
Information about forest management and evidence that it will lead to improved health and organizational outcomes.	Information about forest management techniques and goals, including: • What responsible forest management entails • Whether and how forest management decreases wildfire smoke exposure • Whether forest management benefits human health • How population exposure during wildfire smoke events can be mitigated • Evidence that health sector engagement in forest management will help in realizing these outcomes	**QA22.** "If the science is clear that there's mitigation strategies that reduce the amount of smoke that's emitted, or the amount of wildfire risks, I think public health could stand behind those strategies for the public health benefit that it represents." – Public Health Interviewee [id877] **QA23.** "We would be very interested in [data on] what interventions others have found to be successful or promising or best practices." – Public Health Interviewee [id024]
Local information.	Information in the above categories that is granular, locally specific, and contextualized to a community. Also may include information about: • Local risk of wildfire smoke • Potential impacts of a future local fire • Local air quality	**QA24.** "Using things like CalEnviroScreen that tracks ED visits and so forth is useful, but sometimes making that localized… to show direct correlation to people can help facilitate interest in this." – Health System Interviewee [id996] **QA25.** "Something that would be helpful for a county like ours would be to understand a little bit more granularly what our risk is, and that is so hard because it's community by community." – Public Health Interviewee [id024]

Appendix B: Qualitative Interview Methods

B.1 Motivations and research considerations

Given Blue Forest's experience with bringing additional interested and relevant parties into forest management through conservation finance, largely through the shared interest of water resources benefits (Madeira and Gartner 2018), we wanted to explore opportunities for collaboration between the health sector and land managers based on potential human health benefits. The link between forest management, wildfire smoke, and human health is a growing area of interest for many parties as wildfires, smoke, and related health impacts are anticipated to worsen. As such, we conducted exploratory interviews with health sector interviewees across California to better understand if and how wildfire smoke is affecting their organizations and the populations they serve, and whether there are opportunities for greater health sector engagement in forest management in the pursuit of shared goals. Because the topic of forest management is new to the health sector, we chose interviews over other research methodologies (e.g., surveys) to encourage richer insights and dialogue. We captured perspectives from health sector groups, based on their experiences within their own organizations and niche within the health sector.

As we detail in this Appendix, our interviews capture perspectives from individuals who responded to email outreach from July to November 2022, when there were varying levels of air quality issues from wildfire smoke across the state of California, which may have led to interviewee responses based on recent lived experiences.

Figure B1 summarizes our research process and timeline.

B.2 Sampling

Our population of interest for this research study was individuals working for public health entities, health systems, health insurers, and/or other entities in California's health sector. Wherever possible, we aimed to interview individuals in decision-making roles within their organization.

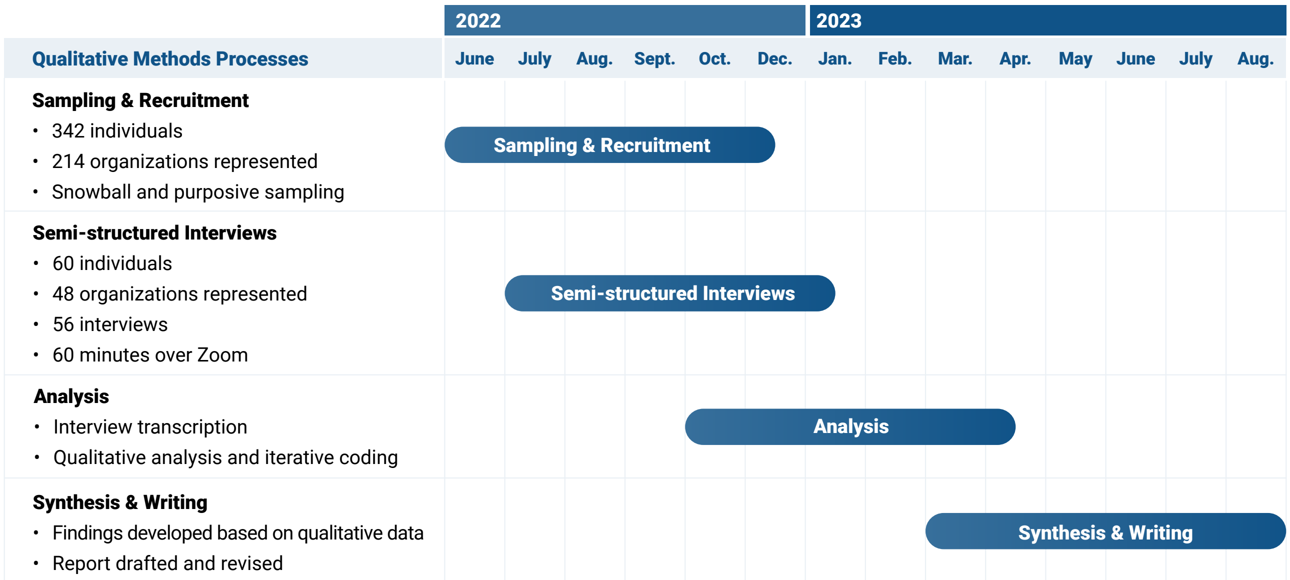

Figure B1. Qualitative methods summary and timeline for interviews with health sector organizations.

B.2.1 Interviewee locations

This research focused on wildfire smoke impacts within the state of California. While wildfire smoke travels both beyond California into neighboring states and into California from fires located elsewhere, our scope was limited to individuals working for health sector organizations serving California populations. To get a geographic diversity of opinions, we directed outreach to recruit individuals across the state (covering Northern, Central, and Southern California) and those whose organizations serve urban and rural communities. We based our classification of counties into Northern, Central, and Southern California regions on the delineations used by California Department of Parks and Recreation CEQA Notifications (CDPR 2023). Our final set of completed interviews included more interviewees from Northern California than other regions, which we suspect is due in part to our use of snowball sampling as part of our recruitment strategy and likely greater interest and experience with wildfire smoke in Northern California. Though we did not review the literature on wildfire smoke exposure by California regions for Part I, evidence suggests that Southern California communities are generally less impacted by wildfire smoke (Petek 2022).

In an effort to incorporate perspectives from Tribal communities in California, we conducted targeted outreach to federally recognized and non-federally recognized Tribes. However, we received few responses. We recognize that Tribes are often significantly under-resourced and have limited staff capacity, which may have limited the response rates to our recruitment efforts. We further recognize that our use of email as our only mode of contact was a limitation, since some individuals prefer phone-based or in-person outreach. The study team's positionality as non-Indigenous individuals working for non-Tribally affiliated organizations was also likely a limiting factor. Our future work in this area with Tribal communities may benefit from different outreach strategies, investing more resources in outreach in general, relationship building, and the inclusion of Indigenous leadership within the study team.

B.2.2 Interviewee organizations

Our population of interest within the health sector included three main subgroups that we sought to include because they represent a cross-section of the health sector:

- **Public health:** State, county, and Tribal governments and non-governmental organizations working on public health. This included the California Department of Public Health (CDPH) and other state-level organizations, county-level public health offices, Tribal members and employees of Tribal governments, and some research/auxiliary organizations providing public health guidance.
- **Health systems:** Public and private hospital systems, health networks, and clinics across the state of California.
- **Health insurers:** Health insurers in California, including both private insurers and those serving only Medicare or Medicaid communities.

As our interviews progressed, we occasionally were referred to people whose work experience was aligned with our research goals but who did not work for an organization that fit within one of the above categories. Our "Other" group thus includes a school district, a grantmaking organization, and a consulting firm. Across all organization types interviewed, we aimed to find individuals in a decision-making role. ***Table B1*** describes our selection criteria for interviewees.

B.2.3 Outreach and recruitment

We recruited participants using two main non-probability sampling strategies: purposive sampling and snowball sampling. Non-probability sampling selects participants from a population, rather than striving to achieve a random sample that is representative of the population (Battaglia 2008). Our report represents perspectives from particular segments of the health sector (public health, health systems, and health insurers) who responded to our email-based outreach efforts, and may under-represent perspectives of certain groups, particularly Tribal governments.

Purposive sampling is a type of non-probability sampling which relies on the researchers' judgment to identify and include cases that provide the best information to achieve the study's objectives (Battaglia 2008). We compiled a list of organizations working in the health sector

Table B1: Interviewee selection criteria

Selection criteria category	Criteria
Relevance of organization Current role working in a public health, health system, or health insurance organization in California	• Had a relevant professional affiliation with a health sector organization serving populations within California, in either public health, health systems, or health insurance. • Could speak to wildfire smoke effects on communities served in California.
Relevance of individual's position or experience Capacity to speak on behalf of their organization about wildfire smoke impacts	Individuals who: • Were in leadership positions, such as the head of their department, or were knowledgeable about organizational priorities and allocation of financial resources. • Held specializations in wildfire smoke, or adjacent topics of interest (including environmental health, air quality, community health, environmental stewardship, or sustainability).
Practicality Feasibility of successfully completing interviews	• Available contact information via public information online, snowball sampling, or the research team's network. • Willingness and availability to participate within data collection time period.

space in California in our defined categories of public health, healthcare, and health insurance. We then searched websites, online databases, and company directories to find contact information for potential participants and sent emails requesting interviews. To increase our pool of contact information for potential participants, we also sent out an interviewee nomination form to the Steering Committee, Blue Forest staff and contacts, and CCST staff and contacts. Many individuals further forwarded the nomination form to other groups in their networks.

Snowball sampling is a type of non-probability sampling commonly used to survey members of a particular population, in which the researchers identify one or more members of the population and ask them to identify additional members (Chromy 2008). At the close of an interview, we asked participants if they could connect us with anyone in their network (within their organization and beyond their organization) who would be an appropriate interviewee.

We contacted interviewees via email and followed up 1 to 3 times, a week apart in case of non-response. We did not contact interviewees via phone or in-person outreach, as we did not have phone numbers for all potential interviewees and lacked staff time to conduct 2+ phone calls for each interviewee (initial contact and follow-ups in case of non-response). Future work in this area may benefit from the use of phone and in-person outreach, as some individuals prefer or are only reachable by these methods.

Upon expressing interest in an interview, we provided additional documentation about the study and consent forms for research participation. These materials are available in ***Appendix C: Informed Consent Materials***.

Interview timeline

In mid-October 2022, after completing 19 interviews, we reviewed our progress and observed:

1. Interviewees: We were missing perspectives from health insurers, public health or healthcare providers serving Tribal communities, and from all types of health sector organizations in Southern California, and
2. Interview content and saturation: We were not yet hearing the same information repeated consistently by multiple interviewees.

We then concentrated our efforts to identify new potential contacts, leverage our networks, and snowball from previous interviews. We extended our deadline for interviews to the end of October to accommodate interviewees' schedules and extended the deadline again to December 2022 for interviewees representing Tribes or health insurance companies. Through this process, we completed an additional 37 interviews.

In total, we reached out to 342 individuals representing 214 unique organizations to request interviews. We completed interviews with 60 individuals representing 48 unique organizations. ***Table B2*** details outreach and recruitment outcomes by organization type.

B.2.4 Interviews

We conducted 56 semi-structured interviews from July to November 2022. Two members of the research team were present at each interview. Four interviews were conducted with two interviewees present, for a total of 60 interviewees. Interviews were conducted over Zoom and lasted no more than 60 minutes.

Table B2: Individual interviewee recruitment outcomes by organization type.

	Total	Health System	Health Insurance	Public Health		Other*
				Non-Tribal	Tribal	
Interview Requests	**342**	**39** (11%)	**63** (18%)	**86** (25%)	**132** (39%)	**22** (6%)
Outreach Outcomes						
1. Non-response	**231** (68%)	15 (38%)	49 (78%)	43 (50%)	114 (86%)**	10 (45%)
2. Declined	**31** (9%)	2 (5%)	6 (10%)	13 (15%)	4 (3%)	6 (27%)
3. Interested, but no interview	**20** (6%)	6 (15%)	1 (2%)	3 (3%)	9 (7%)	1 (5%)
4. Completed interview	**60** (18%)	16 (41%)	7 (11%)	27 (31%)	5 (4%)	5 (23%)

* As our interviews progressed, we occasionally were referred to people whose work experience was aligned with our research goals but who did not work in public health, healthcare, or health insurance. This sometimes included non-profits, school districts, researchers, grantmaking organizations, or consultant groups, among others.

**Many emails (n=29) for potential Tribal interviewees bounced, indicating we had incorrect or out-of-date contact information.

B.2.5 Informed consent

Prior to beginning the interview, we reviewed informed consent materials with the interviewee(s) and asked for verbal consent to participate. We also asked for consent to:

- Record the interview;
- Use non-attributed quotes from the interviewee(s) in our report; and
- List the interviewees' organization in the Appendix.

Although the authors' organizations do not have human subjects research policies or processes (refer to ***Appendix G: Memo to Steering Committee on IRB Requirements***) our study process nonetheless followed informed consent principles and best practices. Our informed consent materials are included in ***Appendix C***.

Of 56 interviews, 55 gave consent to record. When consent to record was not given (n = 1 interview), detailed written notes were taken instead. 51 interviews gave consent to include non-attributed quotes and 46 consented to listing their organization in the appendix (***Appendix D: List of Organizations Interviewed***).

B.2.6 Interview questions

All interviews were semi-structured, following a predetermined list of questions, but were allowed to flow like a conversation and explore other topics as they came up. In all sections of the interview, the interviewee was asked to speak to the perspective of their organization rather than their personal perspective, to the extent possible.

We designed our interview guide to address the interviewee's organizational experience with wildfire smoke and concerns about impacts of wildfire smoke, as well as awareness of forest management and perspectives on opportunities to collaborate on forest management projects. In the first section of the interview, we learned more about the population served by the organization and local communities. The second section addressed impacts of wildfire smoke on the organization and related actions the organization has taken in response to wildfire smoke events, and the third section explored connections between the health sector and forest management.

Due to the semi-structured nature of the interviews, and as we gained experience with the process, the interview guide evolved over time. We also reframed the last section of the interview guide for our interviewees representing Tribal groups, to account for the role many Tribal governments already play in managing the land. Our interview guides for Tribal and non-Tribal interviewees are included in ***Appendix E***.

B.3 Data analysis

B.3.1 Data processing & systems

Audio recordings of interviews were transcribed using the online software Otter.ai. All personally identifiable information, including transcripts, interview logs, and written notes, were stored in a confidential folder accessible only to the research team. High-level written notes were compiled into a single document and personally identifiable information was removed, apart from some organizational information when the interviewee had provided consent to list the organization. Interview transcripts and the detailed notes from unrecorded interviews were all uploaded to Dedoose, a qualitative analysis software. Audio recordings, interview transcriptions, and other non-anonymized research materials will be stored on an encrypted hard drive stored by CCST for three years after the publication of the study and then deleted.

B.3.2 Qualitative coding and analysis

The goal of our qualitative data analysis was to describe the presence or absence of patterns as they related to our research questions, so we used a combination of both deductive and inductive coding approaches. This dual approach means that prior to beginning data analysis, we developed an initial codebook, or list of topics and ideas with definitions, that we expected to see represented in our interviews based on our research questions (deductive coding). As we analyzed our interviews, patterns emerged in additional topics and ideas not captured in our codebook, so we created new codes for these themes as appropriate (inductive coding) (Saldaña 2013). The final version of our codebook is included in ***Appendix F***. To ensure consistency between coders, we revisited and discussed code definitions frequently, and conducted inter-coder reliability checks on several interview transcripts at the outset of data analysis and whenever the codebook was revised. We also ensured that each transcript was processed by two members of the research team: one to code and the other to review. Team members' roles switched for half the completed interviews. Once the interviews were coded, we analyzed each code to find patterns and themes, which led to the narrative in ***Chapter 2*** and ***Chapter 3*** that include our Findings, Conclusions, and Recommendations. Where possible, we provide examples of relevant patterns and themes in interviewee's own words in quote tables found in ***Chapter 2***, ***Chapter 3***, and ***Appendix A***.

Appendix C: Informed Consent Materials

BLUE FOREST CONSERVATION

CCST CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

SEEKING HEALTH PERSPECTIVES

Consent for Interview Participation

Blue Forest & CCST Wildfire Smoke Study

You are being asked to participate in a research study. The box below highlights key information about this research for you to consider when making a decision whether or not to participate. Carefully consider this information and the "Informed Consent FAQ" listed on the following page. Please ask questions about any of the information you do not understand before you decide whether to participate.

Key Information for You to Consider
• **Voluntary Consent**. You are being asked to volunteer for a research study. It is up to you whether you choose to participate or not.
• **Purpose**. The purpose of this research is to understand if and how wildfire smoke events affect public health groups, health insurance companies, and healthcare providers, and the level of concern and preparedness of these groups for future wildfire smoke events.
• **Duration.** We will keep the interview under 60 minutes.
• **Procedures and Activities.** You will be asked to participate in one interview, with no pre-work or follow-up work required. We will send the interview topics ahead of time (in the "About the Study" document), but will also go over them during the interview, so it is not necessary to pre-read any documents.
• **Confidentiality.** Your participation and responses during the interview are confidential and will not be shared beyond the research team. We will ensure any reference to your responses in our final report is anonymized and we will not identify you by name or title. We will ask specific permission to include the name of your organization in our report appendix, which we believe will provide valuable context to the final report.
• **Risks.** Although we will do our best to ensure that your participation is confidential and your responses are anonymous, there is always a chance that a reader of the report may identify you, especially if you agree to have your organization name listed. In some cases, this may be a reputational or professional risk.
• **Benefits**. There is no direct benefit to you for participating. The research results may help to inform future research on the links between forest management activities and public health and engagement of health stakeholders in forest management solutions.

Key contacts for the interviews with health stakeholders:

Kim Seipp, PhD, Blue Forest Conservation (Lead Author)
Email: kim@blueforest.org or Phone: 530-913-7363

Phil Saksa, PhD, Blue Forest Conservation (Project Director)
Email: phil@blueforest.org or Phone: 209-756-3668

Informed Consent FAQ

What happens to the information collected for this research?

Findings based on the information collected for this research are intended to guide future research and inform policy decisions on forest management, wildfire smoke, and public health and strategies for engagement of health stakeholders in wildfire smoke risk reduction activities like forest management.

The Study Team will aggregate your responses with responses from other interviewees from the same type of entity (i.e. public health, healthcare provider, or health insurance) and analyze the responses for emerging patterns or themes. We will compile our findings into a report chapter on perspectives from health stakeholders.

How will my privacy and data confidentiality be protected?

We will not identify you by name or title in the final report, and we will ensure that no personally identifiable information is included in any quotes or referenced interview responses. Instead we will identify respondents by the type of organization they work for (e.g. “public health”).

At the beginning of the interview, we will ask for your consent to include non-attributed quotes from your interview in our final report. If you consent, we may include quotes from your interview, but we will not attribute the quotes to you by name, title, or organization.

At the beginning of the interview, we will also ask your permission to include the name of your organization in our report. If you agree, we will include your organization in a list of all affiliations interviewed as an Appendix to our report. Otherwise, we will not identify your affiliation anywhere in the report. We believe that including a list of affiliations provides evidence of the depth and breadth of interviewee organizations, thus adding valuable context to the findings of this report.

Only the core research team will have access to information about who participates in this research study and personally identifiable interview materials, including notes, audio recording, and transcripts (if you consent to be recorded). All Study Team members have signed Non-Disclosure Agreements (NDAs) agreeing to not share any details of participants or interviews externally. These materials will be stored on a secure server for a minimum of 3 years after the completion of the research before being deleted.

Despite taking steps to protect your privacy, we can never fully guarantee your privacy will be protected.

What are the risks if I participate in this research?

While we will do our best to ensure that you are not personally identifiable from your interview responses, there is always a small chance that someone may identify you or your responses, given the small network of professionals working for public health entities, healthcare providers, or health insurance companies in California.

If you agree to the inclusion of your affiliation in a list of responding organizations, the likelihood that someone may identify you is higher. In some cases, this may be a reputational or professional risk.

What if I want to stop participating in this research?

Taking part in this research study is your decision. You can stop the interview at any time. Your decision whether or not to participate will not affect your relationship with the researchers or Blue Forest Conservation or the California Council on Science & Technology.

Will it cost me money to take part in this research?

No.

Will I receive a payment or incentive of any kind for participating in this research?

No.

Who can answer my questions about this research?

If you have questions or a research-related concern, contact the research team at wildfiresmokestudy@blueforest.org. You can reach Lead Author Kim Quesnel Seipp at kim@blueforest.org or Project Director Phil Saksa at phil@blueforest.org.

Appendix D: List of Organizations Interviewed

Disclaimer: These organizations have not reviewed the report or endorsed the content in this report.

Anonymous (3)

Bay Area Air Quality Management District

Blue Shield

Blumberg West Consulting

California Primary Care Association

California Department of Public Health (CDPH)

California Office of Environmental Health Hazard Assessment (OEHHA)

Care Flight Ground

Chalon Indian Nation

Contra Costa Health Services

Del Norte County, Public Health Branch

El Dorado County, Health and Human Services Agency

Fresno County, Department of Public Health

Frontline Medical

Health Alliance of Northern California

Karuk Tribe

KCS Health

Los Angeles Unified School District

Marin County, Health and Human Services

Mariposa County, Health and Human Services

Mendocino County, Department of Public Health

Merced County, Department of Public Health

Napa County, Health and Human Services Agency

Nor-Cal EMS

Orange County, Health Care Agency

Partnership HealthPlan of California

Placer County, Health and Human Services

Plumas District Hospital

Providence

Public Health Alliance of Southern California

Public Health Institute

Sacramento County, Department of Health Services

San Francisco City and County, Department of Public Health

Santa Cruz County, Health Services Agency

Shasta Community Health Center

Siskiyou County, Department of Public Health

Solano County, Department of Public Health

Sonoma County, Department of Health Services

Stanford Health Care

Stanislaus County, Health Services Agency

Tejon Indian Tribe of California

The California Endowment

Tule River Tribe of California

Tuolumne County, Office of Emergency Services

UCI Health

Western States Pediatric Environmental Health Specialty Unit

Appendix E: Interview Guide

Part 0. Consent

- Consent to participate
- Consent to record audio
- Consent to include non-attributed quotes in final report
- Consent to include org's name in a list of responding entities in the Appendix

Part 1. Context

- Individual: Name, organization, title or department
- Organization: type and size
- Population served: geography, demography, size

Part 2. Organizational experience and concern around wildfire smoke

- General concern
  - Is your organization generally concerned about wildfire smoke? Why or why not?
  - In what ways is wildfire smoke affecting the population that your org serves?
- Health outcomes
  - Which, if any, health outcomes is your organization most concerned about affecting the population you serve?
- Operations
  - How does wildfire smoke impact your organization's operations in preparation for, during, and after wildfire smoke events?
  - What actions does your organization take?
  - Are there any new initiatives or programs related to wildfire smoke?
- Costs
  - Is your org tracking any costs associated with wildfire smoke events and the impact to your bottom line?
  - Who bears the costs of severe wildfire smoke events?
- Planning
  - Does your organization have an existing plan to deal with wildfire smoke?

    - What does the plan involve?

Part 3. Connections between health, wildfire smoke, and forest management

All Interviewees except Tribes:

- Forest management
    - Some research suggests that certain forest management activities, such as prescribed fire and selective tree removal, have the potential to reduce the risk of severe wildfires, which could then reduce risk of people being exposed to harmful wildfire smoke. Are you aware of this? Is this common knowledge at your organization?
- Opportunities for cross-sector partnership between health and land/forest managers?
    - Partnerships that involve advocacy work?
    - Partnerships that involve community engagement or education?
    - Partnerships that involve cost-sharing or contributing funds?
- Motivations and barriers to cross-sector collaboration to advance forest management to improve health outcomes
    - Potential motivations for your organization or the health sector at large?
    - Potential barriers for your organization or the health sector at large?

Tribes:

- Perspectives on connections between land/forest management, smoke, and health?
    - Level of familiarity with connections between forest management and human health?
- Perspective on role of health sector involvement in land management practices
    - Advocacy?
    - Community education / engagement?
    - Funding or cost-sharing?
    - Potential motivations or barriers to health sector partnership with land managers
    - Suggestions on data needs information gaps to be addressed by future research

Part 4. Wrap-up

- Anything else to share?
- Any questions for us?
- Anyone to recommend for an interview?

Appendix F: Codebook

- **Geography:** Info on where organization is located and/or where the populations they serve are located
- **About the Org:** Includes general info about the org, as well as any information around staffing issues/concerns/context outside of wildfire smoke study effects
- **Population Served:** Any information about the people the organization serves
    - **Vulnerable Populations:** Any mention of a specific group the interviewee is worried about (e.g. children, homeless, elderly, outdoor workers)
- **Past Wildfire Examples:** Any direct mention of a wildfire by name or year, or description of the impacts of a particular wildfire/wildfire smoke event
    - **2017 fires:** Any mention of the Tubbs fire or 2017 fires in general
    - **2018 fires:** Any mention of the Camp Fire, Paradise, or the 2018 fire season
    - **2020 fires:** Any mention of the 2020 fire season, the "orange day" in the Bay Area
    - **2021 fires:** Any mention of the 2021 fire season, including Dixie or Caldor
    - **Other years:** Direct mentions of major fires in other years, e.g. Rim or King (2014)
    - **Multiple fires:** Cumulative effect of multiple fires, without singling out a fire or fire year
- **Concerns:** Self-described level of concern; do they describe their organization as concerned or not
    - **Yes:** Response of "yes"
    - **No:** Response of "no" or "it's very low on our list of concerns"
- **Timeline:** How long they have been thinking about this, in response to our question about the timeline of concern.
- **Impacts:** Any and all impacts of wildfire smoke or wildfires mentioned by the interviewee
    - **Health Impacts:** Effects on health outcomes of the population served
        - **Mental Health:** Specific mention of impacts on mental health and wellbeing
    - **Operational Impacts:** Effects on the interviewee's org or other health sector orgs of interest
        - **Employees:** Effects on staff / personnel at a health sector org

        - **Infrastructure & Services:** Effects on facilities or property at a health sector org (closing hospitals, buildings burned), or effects on the org's ability to provide services (e.g. closures, evacuation, service disruption)
    - **Other Impacts:** Other effects beyond the health sector (e.g. tourism, public safety or homes burning, schools)
        - **Displacement or Rebuilding:** Discussion of impacts from burning down of businesses or homes (not the interviewee's org) and changes to desire or ability to remain in the community, including difficulty getting insurance
        - **Local Economies:** Impacts to major economic sectors like tourism or agriculture from smoke or fire
        - **Schools:** Mention of impacts or uncertainty around wildfire smoke impacts on schools or school-age children
        - **Miscellaneous:** Other impacts not captured above (examples: cost of air filters for homes, Impacts to firefighters, Canceling sporting events, downstream environmental impacts, e.g. water quality and erosion, landslides)
- **Actions Taken:** Examples of actions they take related to wildfire smoke events. This also includes mention of future actions or partnerships that they are working towards, but have not yet implemented.
    - **Emergency Response:** Description of actions taken in relation to wildfires or wildfire smoke in relation to "official" emergency response or preparedness guidance
    - **Treatment/ Service Changes:** Changes in treatment or services offered by health sector organizations in response to smoke events
    - **Air quality interventions:** Actions taken to limit exposure to "bad air," including distribution of masks, setting up clean air spaces (public or DIY at home), Improving facility air (HVACs, air filters, air scrubbers, HEPA filters)
    - **Info Sharing / Communication:** Communication, education, messaging, or collaboration about wildfire smoke, wildfires, or air quality
    - **Info Gathering:** Gathering information via monitoring, tracking, collaboration
- **Calculating Costs:** Answer to "do you know of/are you calculating the costs of these impacts?", inclusive of reasoning or description of how.
    - **Yes:** Yes, at least in part
    - **No / DK:** No or Don't Know

- **Who bears costs?:** Response to the question of "Who bears Costs?" / Naming or mentioning specific groups that bear the costs or suffer the impacts of wildfire smoke events.
    - **Everybody:** Mention that "everybody" bears costs
    - **Specific Vulnerable Populations:** Mention of specific vulnerable populations bearing it more than others (examples: outdoor workers, unhoused, firefighters, those w/ COPD or respiratory conditions)
    - **Financial Costs:** Discussion of groups that bear costs that are monetary/financial, e.g. people (paying for meds, buying air filters), local economies, insurers, the health system
    - **Non-financial Costs:** Discussion of other groups or ways in which costs are born (e.g. general human health, quality of life changes, outdoors access, etc).
- **Planning:** Mention of existing plans or intention/desires to create a plan to guide response to wildfire smoke events
    - **Emergency Planning:** Description of a plan for general emergency response or preparedness, of which wildfires may be a part
    - **Climate Planning:** Description of a plan for climate adaptation, mitigation, or resilience, of which wildfires may be a part
    - **Wildfire Smoke Specific Plan:** Description of specific plan to respond to or plan for wildfire smoke events in the future
    - No Plan / Don't Know
- **Information:** Mentions of data, guidance, or other sources of information on wildfire smoke, health effects, costs, or forest management that is used or could be used to inform health sector actions
    - **Info Gaps:** Mentions of where information gaps exist, where additional information is desired or could be useful to inform actions related to wildfire smoke or forest management
        - **Health Info:** Desire for information about health impacts of forest management or wildfire smoke, including over time/distance/concentration scales.
        - **Resource Info:** Desire for information about resource impacts of forest management or wildfire smoke, including financial benefits or impacts on staff availability

        - **Methods of Mitigation:** Desire for information about how we can decrease the negative impacts of wildfire smoke, etc., including uncertainty of what responsible forest management is, indoor vs. outdoor air quality, mask effectiveness, etc.
        - **Localized Info:** Explicit desire for locally specific information.
        - **Miscellaneous:** Anything that does not fit above.
    - **Content:** Mentions of information the org has on wildfire smoke or air quality (example: research study or product)
- **Forest Management:** Mentions of actions taken to alter landscapes, including both forested and non-forested landscapes (e.g. prescribed fire, tree thinning, other landscape restoration activities)
    - **Prescribed Burns:** Mentions of prescribed burning or the use of fire for land management purposes, including Indigenous use of fire or cultural burning
    - **Awareness:** Typically the response to "How aware are you and your team of the concepts of forest management"
    - **Connection to Health:** Explicit recognition of the connection between forest mgmt and health or value of the connection between forest mgmt and health; does not imply participation, Can also include explicit recognition of environmental determinants on health in general
    - **Misc**
- **Participation:** Discussion of if and how health sector groups could support, partner, or participate in forest management activities or in other activities that improve upstream health determinants
    - **Willingness to participate :**Direct response to "Are there opportunities for the health sector to participate in…"
        - **Funding:** Specifically responses to questions about willingness to participate in funding or cost-sharing of forest management
    - **Ideas for Participation:** Speculations on what kind of programs could be made or what partnership could look like (also other people that might be able to pay)
    - **Motivations:** Discussion of the reasons or motivations that would drive a health sector group to support, partner, engage or participate in activities that improve upstream health determinants (including forest management)
        - **Health benefits:** The organization would be motivated to participate based on expected or observed decreases in smoke-related or fire-related illnesses and deaths

    - **Financial return:** The organization would be motivated to participate based on a financial or other physical resource benefit, e.g. less money or personnel would be needed if forest management decreased fire/smoke threat
    - **Climate urgency:** A sense that climate change is worsening, linked to health, and we are responsible to our environment and therefore health sector should be involved in forest/land management
    - **Fit with mission:** The organization would be motivated to participate based on an alignment between forest management or decreased fire/smoke threat and the organization's mission or values, including benefits for vulnerable populations and appreciation for the environment
    - **Other:** Other specific motivations that do not fit into other child codes.
- **Barriers:** Discussion of the reasons or motivations that would prevent a health sector group from supporting, partnering, engaging, or participating in activities that improve upstream health determinants (including forest management)
    - **"Not our job":** Any reference to forest management being outside of the organization's role, e.g. "we don't have forests, so we can't/won't/shouldn't", health sector aren't experts and should stay out of it, Including suggestions of other groups that they think should participate instead
    - **Capacity:** Unwillingness or hesitance to participate based on too little available staff or time, including mentions to burnout or mental health
    - **Financial Constraints:** Any reference to there not being enough money or not a strong enough financial case to participate
    - **Politics/Social License:** Inability to participate because of political or social factors outside of the organization, e.g. conservative communities that do not trust public health involvement
    - **Rules:** Restrictions on participation coming from inside the organization or the organization's funding sources, e.g. grant or government restriction or inability to get permission from governing board
    - **Competing Priorities:** Inability to participate based on relatively low priority of wildfire smoke relative to other local or organizational concerns, e.g. COVID, other climate change impacts, health disparities, or other common health concerns
    - **Other:** Other specific barriers that do not fit into other child codes.

  - **Decision-making:** Description of the process within a health sector org for starting new programs or initiatives to participate/partner/support in activities to improve upstream health determinants
  - **Existing Programs:** Examples of ways in which health sector orgs already support or participate in activities that improve upstream health determinants, including land or forest management

- **Interacting Events:** Mentions of how another health or environmental disaster interacts with efforts to work on wildfires or wildfire smoke (e.g. COVID, extreme heat, etc). This includes both complications/confounding factors, but also how lessons learned from one event may be applied to another. (Note: Climate change may be double-coded here sometimes)
  - **COVID:** Mention of COVID or the pandemic, and how it has affected wildfire smoke response
  - **Extreme Heat:** Mention of extreme heat events and how it interacts with wildfire smoke events
  - **Other:** Mention of other interacting events, including but not limited to the economy, mental health, power shut-offs/blackouts, drought, smog/air quality
- **Climate Change:** Explicit mentions of climate change, global warming, or unstable climate
- **Data Challenges:** Any mention of the challenges of collecting, tracking, or analyzing data on smoke or health. This includes challenges of attribution, parsing out details, or getting quality data. Can be an explanation of why some desired information hasn't been gathered.

Appendix G: Memo to Steering Committee on IRB Requirements

BLUE FOREST CONSERVATION
Financial Innovation for Sustainable Solutions

To: IFNF Wildfire Smoke Study Steering Committee

From: Kim Quesnel Seipp, PhD, Blue Forest
Signe Stroming, Blue Forest

Date: April 13, 2022

Subject: Investigation into requirements and best practices for conducting interviews for the IFNF-funded Wildfire Smoke Study.

The California Council of Science and Technology (CCST) and Blue Forest Conservation are collaborating on a research project to better understand the links between forest health, wildfire smoke, and public health in California. Blue Forest is leading Task 3 of the project which involves qualitative interviews with individuals involved in the healthcare system in California, including public health agencies, insurance companies, hospital associations and interest groups.

As this research involves interviews, we aimed to determine:

- Does our project count as "human subjects research"?
- If so, what are the associated legal requirements?
    - Are we required to go through an approval process with an Institutional Review Board (IRB) or Ethics review committee? If there is a formal approval process, are there ways that we could formulate our study process to qualify for an exemption?
- What are best practices for ethical qualitative research?

Through desk research, we determined that this project does count as human subjects research (e.g. What is Human Subjects Research? | US EPA), which prompted us to further investigate requirements and best practices. We first reached out to both CCST and Blue Forest leadership about organizational requirements. We determined that neither organization has (1) existing precedent or (2) an IRB or Ethics review committee that we would be required to consult for approval. We also contacted a representative from our funding body, the Innovative Finance for National Forests (IFNF) grant program, and they informed us that they also do not have a requirement or precedent of seeking IRB approval. Thus, we are not required to go through any formal approval processes.

To glean best practices in interviewing, we consulted with several academic researchers familiar with qualitative research methods in addition to doing our own desk research. After these discussions and reading online documents, we compiled the following list of best practices for ethical qualitative research that we plan to follow during this study, including:

- Participants will give both written and verbal informed consent before proceeding with interviews

- The study team will clearly communicate to interview participants about how their responses will be used and confidentiality of their responses, including whether or not they and/or their organization will be named or anonymous in the final report.
- The study team will clearly communicate to participants about the interview format, time commitment, recording, recording storage, and other logistics in the interview protocol
- Participants will be asked about the views of their organization, not their personal views
- At least one study team member will complete the CITI Program Human Subjects Research training to learn more ethical research practices and consent procedures

We hope this memo can serve as a reference for other researchers from CCST or Blue Forest undertaking human subjects research and considering whether or not they require IRB approval and looking for best practices to follow for similar projects in the future.

Addendum (July 22, 2022)
Research team members who (i) have multiple research or academic affiliations and (ii) can access non-anonymized human subjects research data inquired about IRB requirements from their affiliations.

- **Teresa Feo**, PhD, (CCST) holds a research affiliation with the Smithsonian Institution. She inquired about IRB requirements and was determined exempt.
- **Heidi Huber-Stearns, PhD**, holds a research affiliation with University of Michigan. She inquired about IRB requirements, and was determined to be exempt because "research at organizations is not considered human subjects at Michigan."
- **Clare Loughlin** (Blue Forest) is an incoming MPH student at Yale University. She inquired about IRB requirements, and Yale determined that she did not need to pursue IRB approval because she is "not using the data as part of your studies here, Yale University is not engaged in the conduct of that research protocol, no funds associated with a that protocol are being disbursed here, and no data is being brought to Yale for analysis or for storage (either physical files or electronic files)."

Appendix H: Steering Committee Members

The Steering Committee (SC) oversees the report authors, reaches conclusions based on the findings of the authors, drafts recommendations and writes an executive summary.

Full curricula vitae for the SC members are available upon request. Please contact CCST (916) 492-0996.

Steering Committee Members

- **Jennifer Montgomery**, (Chair), Retired Placer County and Calif. State Government
- **Joshua Graff Zivin**, PhD, University of California, San Diego
- **Heidi Huber-Stearns**, PhD, University of Michigan and University of Oregon
- **Adam Kochanski**, PhD, San José State University
- **Ryan Tompkins**, University of California, Cooperative Extension
- **Jun Wu**, PhD, University of California, Irvine

Jennifer Montgomery

Chair, Steering Committee
Former Placer County Supervisor
Former Director, CA Governor's Forest Management Task Force

Jennifer Montgomery is retired from private enterprise as well as from County and State Government. She owned her own business, has experience in sales, government operations, as an elected official and as an appointee focusing on forest health and wildfire risk reduction management. She served as the appointed Director of the California Governor's Forest Management Task Force from April 2019 - October 2020. Prior to that she served as a Placer County Supervisor for more than 10 years. Jennifer is a graduate of the American Leadership Forum Class XXII (Mountain Valley Chapter), has degrees in Ornamental Horticulture (A.A. Sierra College, Rocklin, CA) and Film and Video Production (B. A. Mills College, Oakland, CA), she was also awarded membership in Phi Beta Kappa in 1983. Her lifelong love of science was spurred by her father, an amateur lepidopterist and by working with Dr. Paul R Ehrlich at Stanford University and the Rocky Mountain Biological Laboratory in Gothic, CO.

Joshua Graff Zivin

Professor of Economics
School of Global Policy and Strategy and Department of Economics,
University of California, San Diego

Joshua Graff Zivin is an economist whose broad research interests include the environment, health, development, and innovation economics. He has published numerous articles on a wide range of topics in top economic, policy and science journals. Much of his current work is focused on three distinct areas of research: the relationship between the environment, health and human capital, the economics of innovation and productivity, and the design of health interventions and their economic impacts.

Professor Graff Zivin received both his Ph.D. and M.S. from UC Berkeley and a B.A. from Rutgers University. Prior to joining UC San Diego in 2008, he spent 11 years on the faculty at Columbia University, where he served as professor of economics in the Mailman School of Public Health and the School of International and Public Affairs and directed the Ph.D. Program in Sustainable Development. From 2004-05, Graff Zivin served as Senior Economist for Health and the Environment on the White House Council of Economic Advisers.

Heidi Huber-Stearns

Visiting Professor of Practice, University of Michigan School for Environment and Sustainability
Director, Institute for Sustainable Environment, University of Oregon
Director, Ecosystem Workforce Program, University of Oregon

Ph. D., Colorado State University, Forest Sciences (Natural Resource Policy) (2015)

M.S., Colorado State University, Human Dimensions of Natural Resources (2012)

B.S., Southern Oregon University, Environmental Studies Social Science and Policy (2007)

Heidi Huber-Stearns is a Visiting Associate Professor of Practice at the University of Michigan in the School for Environment and Sustainability, focused on engaged research for the Western Forest and Fire Initiative. Heidi is an interdisciplinary social scientist, with expertise in environmental governance and linking science to action through strategic and diverse partnerships. Her work focuses on organizations and boundary spanning to address wildfire risks and watershed vulnerabilities in at-risk communities, particularly in the western United States. She is also an Associate Research Professor and Director of the Ecosystem Workforce Program, in the Institute for Resilient Organizations, Communities, and environment at the University of Oregon.

Adam Kochanski

Associate Professor
Department of Meteorology & Climate Science
San José State University

Dr. Adam Kochanski is an associate professor at the San José State University leading the fire modeling group in the Wildfire Interdisciplinary Research Center. He received his M.Eng in Chemical Engineering and MBA from Technical University of Lodz (Poland) and Ph.D. in Atmospheric Sciences from the University of Nevada, Reno. His main research interests include fire-atmosphere interactions including air quality impacts of wildland fires. He is a modeler with extensive experience in running numerical simulations of fire, smoke, and regional climate on high-performance computing platforms. He is a co-developer of the coupled fire-atmosphere model WRF-SFIRE, the integrated fire and air quality system WRF-SFIRE-CHEM, as well as the fire forecasting system WRFX. He is one the modeling leads for the Fire and Smoke Model Evaluation Experiment (FASMEE), a member of the Rocky

Mountain Center for Fire-Weather Intelligence (RMC) steering committee and an author of over 30 scientific publications.

Ryan Tompkins

Forest & Natural Resources Advisor
UC Cooperative Extension

Ryan Tompkins is the UC Cooperative Extension Forest & Natural Resources Advisor for Plumas, Sierra, and Lassen Counties. He is a California Registered Professional Forester and was a certified silviculturist during his 17-year tenure with the USDA Forest Service. For over two decades, he's worked on a myriad of landscape level forest and fire restoration efforts in the northern Sierra Nevada. His research interests include silviculture for ecological restoration, post-fire reforestation to promote ecosystem resilience, community wildfire preparedness, and forest management practice and policy. He received his B.S. and his Masters in Forestry from UC Berkeley.

Jun Wu

Professor and Graduate Director
Department of Environmental and Occupational Health
University of California, Irvine

Dr. Jun Wu is Professor and Graduate Director of the Department of Environmental and Occupational Health in the Program in Public Health at UC-Irvine. She received her Bachelor of Engineering degree in Environmental Engineering from Tsinghua University, China in 1997, M.S. degree in Environmental Engineering from Penn State University in 2000, and Ph.D. degree in Environmental Health from University of California, Los Angeles in 2004.

Dr. Wu's interests focus on population-based research of environmental exposure assessment, environmental epidemiology, and environmental health disparity. She has extensive experience and knowledge in examining the influences of various environmental exposures (e.g. air pollution, climate, and built environment) on reproductive outcomes (e.g. maternal and fetal health), children's health, and other health endpoints. She also has strong interest in research on environmental justice and environmental health disparity, particularly working in partner with communities.

Appendix I: Report Author Biosketches

Report Authors

- **Teresa J. Feo**, PhD, California Council on Science and Technology
  Lead Project Manager and Author

- **Kimberly Quesnel Seipp**, PhD, Blue Forest
  Project Manager and Author

- **Signe Stroming**, Blue Forest
  Author

Contributing Authors

- **Kirsten Hodgson**, Blue Forest

- **Clare Loughlin**, Blue Forest

- **Phil Saksa**, PhD, Blue Forest

Teresa J. Feo, Ph.D.
California Council on Science and Technology
1017 L St, #438
Sacramento, CA 95814
teresa.feo@ccst.us

EDUCATION

2015 **Ph.D., Ecology and Evolutionary Biology**
Yale University, CT

2007 **B.A., Integrative Biology**
University of California, Berkeley, CA

CURRENT AND PAST POSITIONS

Since 2018 **Senior Science Officer**
California Council on Science and Technology (CCST), Sacramento, CA

Since 2017 **Research Associate**
Smithsonian Natural History Museum, Vertebrate Zoology, Birds, Washington, D.C.

2017-2018 **CCST Science & Technology Policy Fellow**
California State Senate, Office of Research, Sacramento, CA

2015-2017 **National Science Foundation Postdoctoral Research Fellow**
Smithsonian Natural History Museum, Vertebrate Zoology, Birds, Washington, D.C.

2008 **Field Technician**
Museum of Vertebrate Zoology, University of California, Berkeley, Berkeley, CA

2007-2008 **Biological Technician**
Museum of Vertebrate Zoology, University of California, Berkeley, Berkely, CA

HONORS AND AWARDS

2015 George Gaylord Simpson Prize, Yale Peabody Museum; $3,000

Kimberly Quesnel Seipp Ph.D
Blue Forest
5960 S Land Park Dr, Suite 1264
Sacramento, CA 95822
kim@blueforest.org

EDUCATION

2019	**Ph.D Civil and Environmental Engineering** Stanford University, CA
2015	**MS Civil and Environmental Engineering** Stanford University, CA
2010	**BS Civil Engineering** Cal Poly, San Luis Obispo, CA

CURRENT AND PAST POSITIONS

Since 2020 **Senior Project Scientist (2020-2021); Research and Program Director (2021-present)**
Blue Forest

2019-2020	**Postdoctoral Research Scholar**, Woods Institute for the Environment & Bill Lane Center for the American West, Stanford
2014-2019	**Graduate Research Assistant**, ReNUWIt and Water in the West, Stanford
2014	**Graduate Student Researcher & Student Mentor,** Juneau Icefield Research Program
2011-2014	**Associate Civil Engineer, Remediation Practice**, TRC Environmental Corporation

HONORS AND AWARDS

2020	Outstanding Reviewer, Journal of Sustainable Water in the Built Environment
2016-2019	Awardee, U.S. EPA Science to Achieve Results (STAR) Fellowship ($132,000)
2018-2019	Awardee, Water Innovation Policy Fellowship, ImagineH2O ($10,000)
2018	Selected Participant, Rising Environmental Leaders Program, Stanford University
2017	Best Student Presentation, AWRA Annual Conference
2015	Winner, Vail Global Energy Forum Video Competition, Precourt Institute for Energy
2014	Awardee, Joan W. Miller Scholarship, Juneau Icefield Research Program ($1,450)
2013-2014	Awardee, Femineer's Scholarship Fund, Stanford University ($5,000)

Signe Stroming
Blue Forest
signe@blueforest.org

EDUCATION

2019	**Bachelor of Science in Science, Technology and International Affairs** Walsh School of Foreign Service, Georgetown University, Washington DC

CURRENT AND PAST POSITIONS

Since 2022	**Senior Project Associate (2023-present), Project Associate (2022-2023), Project Analyst (2022),** Blue Forest, Salt Lake City, UT
2021	**Research Consultant,** Giving Green, Washington, DC
2019-2021	**Associate,** IDinsight, Delhi, India
2016-2019	**Mortara Undergraduate Research Fellow,** Mortara Center for International Studies, Georgetown University, Washington, DC
2018	**Research Intern,** Resources for the Future, Washington, DC
2017-2018	**Sustainability Associate,** Office of Sustainability, Georgetown University, Washington, DC
2017	**Field Research Intern,** International Water Management Institute, Gujarat, India

HONORS AND AWARDS

2019	*Awardee*, The Carol J. Lancaster Award, Georgetown University
2016	*Recipient*, Improving the Human Condition Grant, Georgetown University

Kirsten Hodgson

Blue Forest
kirsten@blueforest.org

EDUCATION

2022 **Master of Environmental Science and Management**
Bren School of Environmental Science & Management
University of California, Santa Barbara (UCSB)

2018 **Bachelor of Science in Biological Sciences**
University of California, Davis (UC Davis)

CURRENT AND PAST POSITIONS

Since 2022 **Project Associate**
Blue Forest

2021 – 2022 **Graduate Student Associate**
Blue Forest

2018 – 2020 **Water and Energy Education Technician**
Sonoma Water, Santa Rosa, CA

2018 – 2019 **Water and Energy Education Intern**
Sonoma Water, Santa Rosa, CA

2016-2018 **Undergraduate Research Assistant**
Ramírez Lab, Department of Evolution and Ecology,
University of California, Davis, Davis, CA

2017 **Undergraduate Research Assistant**
Putah Creek Nestbox Highway, Department of Wildlife, Fish, and Conservation Biology, University of California, Davis, Davis, CA

HONORS AND AWARDS

2018 Citation Award for Outstanding Performance in Biological Sciences, College of Biological Sciences, University of California, Davis

Clare Loughlin
Blue Forest
clare@blueforest.org

EDUCATION

2024 **Master of Public Health** (In progress)
Environmental Health Sciences
Yale University, Yale School of Public Health, New Haven, CT

2018 **Bachelor of Arts in Environmental Studies**
Connecticut College, New London, CT

CURRENT AND PAST POSITIONS

Since 2022 *Science Communications Analyst*
Blue Forest, Remote

2023 *Stolwijk Fellow*
Yale School of Public Health, New Haven, CT

2021 – 2022 *Co-Managing Content Editor*
Climate Boot Camp (Climate Reality Project & Harvard Alumni for Climate and the Environment), Remote

2020 – 2021 *Analyst*
Blue Access LLC, Remote

2019 *English Teaching Assistant*
The Fulbright Program, Pahang, Malaysia

2018 Research Assistant
Connecticut College Hydraulic Research Lab New London, CT & Cherryfield, ME

HONORS AND AWARDS

2023 Yale Stolwijk Fellow
2023 Yale Horstmann Scholar
2023 Yale Center on Climate Change and Public Health Student Scholar
2018 Connecticut College Barbara Shattuck Kohn '72 Environmental Studies Award
2018 Connecticut College Goodwin-Niering Center for the Environment Student Scholar

Phil Saksa, Ph.D
Blue Forest
phil@blueforest.org

EDUCATION

2015	**Ph.D Environmental Systems** University of California, Merced
2007	**M.S Forestry** Louisiana State University
2003	**B.S. Natural Resources** Ohio State University

CURRENT AND PAST POSITIONS

Since 2019	**Chief Scientist** Blue Forest Conservation, Sacramento CA
2017 – 2018	**Senior Research Advisor** Blue Forest Conservation, Sacramento CA
2016	Postdoctoral Scholar Sierra Nevada Research Institute, University of California, Merced
2010 – 2015	Graduate Researcher Sierra Nevada Research Institute, University of California, Merced
2008 - 2009	Field Hydrologist Sierra Nevada Research Institute, University of California, Merced
2004 – 2005	Applications Scientist Earth Satellite Corporation, Rockville MD

Appendix J: Scope of Work

This project in partnership with **Blue Forest**, was made possible by an Innovative Finance for National Forests (IFNF) grant.

Details

The report will include a literature review of existing tools for tracking and forecasting the connections between the restoration of forests and other fire-influenced ecosystems (e.g., chaparral, oak woodlands), smoke produced by wildfires (including uncontrolled, prescribed, managed, and cultural wildland fires), and the public health impacts due to population exposure to wildfire smoke.

Additionally, the report will engage public and private healthcare stakeholders to identify key information needed to motivate their inclusion of wildfire smoke-related health impacts in their fiscal forecasts, and potentially prompt their financial participation in forest restoration as a means of mitigating the healthcare costs of wildfire smoke. The report will identify gaps between current knowledge and the needs of healthcare stakeholders and make recommendations for new research, tools, and resources to address these knowledge gaps.

Questions likely to be addressed in this study include, but are not limited to:

1. What are the existing methods, metrics, and tools for tracking the health impacts of population exposure to wildfire smoke?
2. What are the existing methods, metrics, and tools for tracking or forecasting wildfire smoke based on the condition of forests and other fire-influenced ecosystems?
3. What are the motivations and information needed for healthcare stakeholders to incorporate smoke-related health impacts in their planning and fiscal forecasts?
4. What are the gaps in existing tools, resources, and knowledge to be able to connect investments in forest health with savings in healthcare costs?

As the project nears completion, CCST seeks nominations of individuals (including self-nominations) with expertise relevant to the following topics to serve as peer reviewers for the report:

- Management practices for restoring the health of forests other fire-influenced ecosystems
- Linkages between forest restoration, including fuel reduction treatments, and changes in wildfire behavior
- Linkages between wildfire behavior and wildfire smoke
- Wildfire smoke transport, tracking, and forecasting methods, models, and data
- Methods and tools for tracking population exposure to wildfire smoke
- Public health interventions, including community outreach and education, to reduce exposure to wildfire smoke
- Health impacts of exposure to wildfire smoke, including to vulnerable populations
- Costs of wildfire smoke health impacts
- Frameworks for systematic monitoring of public health impacts
- The healthcare industry and risk modeling
- Air quality management
- California policy relevant to forest management, wildfires, air quality, public health, and/or healthcare.
- Social science/qualitative research expertise for natural resource management

Appendix K: Review of Information Sources

This study was conducted as a review of existing publicly available data including the results of many currently ongoing or recently-completed relevant studies, protocols, and proposed regulations. The quality of the assessment depended on the quality of the information and time available for the study. Our scientists cited a given reference in the report if it met all three of the following criteria:

1. Fit into one of the eight categories of admissible literature (described in a-h below).
    a. Published, peer-reviewed scientific papers.
    b. Government data and reports.
    c. Academic studies that are reviewed through a university process, textbooks, and papers from technical conferences.
    d. Studies generated by non-government organizations that are based on data, and draw traceable conclusions clearly supported by the data.
    e. Other relevant publications including reports and theses. We state the qualifications of the information used in the report.
    f. Additional authoritative sources including the expert opinion of the committee and scientific community.
    g. News articles (only when the discussion centered on anecdotal information being the only publicly-available information).
2. Was relevant to the scope of the report.
3. Added substantive information to the report. For this report, the authors reviewed many sources of public information, including some that are not easily accessible to all citizens, such as fee-based scientific journals. If a member of the public wishes to view a document referenced in the report, they may contact CCST directly.

Appendix L: CCST Study Process

For 30 years, the California Council on Science and Technology (CCST) has been advising California on issues of science and technology by leveraging exceptional talent and expertise. CCST studies are viewed as valuable and credible because of the organization's reputation for providing independent, objective, and nonpartisan advice with high standards of scientific and technical quality. Checks and balances are applied at every step in the study process to protect the integrity of the studies and to maintain public confidence in them.

CCST Entities Involved in the Study Process

The study process, including accepting and defining projects and building the teams to carry them out, involves a number of entities that are a part of CCST.

1. **CCST Leadership** – Consisting of the CCST CEO and the CCST Deputy Director, these positions are generally involved in interfacing with the sponsor and working through the initial ideation of the project and securing the contract. They work with the Board on all steps after ideation.
2. **CCST Board of Directors ("Board")** – Consisting of directors from CCST's academic and research partner institutions as well as independent directors often from industry, philanthropy or with a policy background. The Board gives final approval to take on a peer-reviewed report.
3. **Program Committee** – A subcommittee of the CCST Board, the Program Committee oversees and advises the programs by which CCST fulfills its mission to provide science advice to inform decision-making in the State of California. The Program Committee provides oversight throughout the study process.

Study Process Overview: Ensuring Independent, Objective Advice

CCST enlists the state's foremost scientists, engineers, health professionals, and other experts to address the scientific and technical aspects of society's most pressing problems.
CCST studies are funded by state agencies, foundations, and other private sponsors. CCST provides independent advice; external sponsors have no control over the conduct of a study once the statement of task and budget are finalized. Authors and the Steering Committee gather information from many sources in public and private meetings, but they carry out their deliberations in private in order to avoid political, special interest, and sponsor influence. After the report has been drafted, it undergoes a rigorous peer review process, overseen by

an independent Report Monitor who ensures all Peer Reviewer comments are sufficiently considered..

Stage 1: Defining the Study

Before the author(s) and Steering Committee selection process begins, CCST staff, and other CCST experts as needed and informed by the CCST Program Committee work with the study sponsors to determine the specific set of questions to be addressed by the study in a formal “statement of task,” as well as the duration and cost of the study. In line with CCST’s dedication to supporting diversity, equity, and inclusion (DEI) through its work, CCST intentionally integrates the social sciences and questions of equity. The statement of task defines and bounds the scope of the study, and it serves as the basis for determining the expertise and the balance of perspectives needed for the study authors, Steering Committee members, and peer reviewers.

The statement of task, work plan, and budget must be approved by CCST leadership in consultation with CCST’s Project Director. This review sometimes results in changes to the proposed task and work plan. On occasion, it results in turning down studies that CCST believes are inappropriately framed or not within its purview.

Stage 2: Study Authors and Steering Committee (SC) Selection and Approval

Selection of appropriate authors and SC members, individually and collectively, is essential for the success of a study. CCST intentionally recruits a diverse team of experts. All authors and SC members serve as individual experts, not as representatives of organizations or interest groups. Each expert is expected to contribute to the project on the basis of his or her own expertise and good judgment.

To build the SC and Author teams, CCST staff solicit an extensive number of suggestions for potential SC members and authors from a wide range of sources, then recommend a slate of nominees, and send invitations to each provisional SC member and author to complete a non-disclosure agreement (NDA), a conflict of interest (COI) form and submit their current Curriculum Vitaes (CVs). The NDA is essential for ensuring an environment which supports frank and open discussion among study participants, both in establishing the team and as the study is ongoing. CCST staff send the COIs and current CVs to outside counsel for a thorough COI review and then organize all results and recommendations from the outside counsel. CCST organizes an in-person meeting for the provisional SC and lead authors to discuss the balance of the committee and evaluate each person for any potential COIs based on the outside counsel feedback. Any issues raised in this discussion are investigated and addressed. CCST sends the proposed study participant list and associated COI information, including any recommendations or concerns noted at the in-person meeting, to the Program Committee of the

CCST Board for final approval. In some cases, the Program Committee is asked to review potential COIs ahead of the in-person SC meeting at the discretion of CCST Leadership. While the lead authors attend the in-person meeting for the discussion of their own potential COIs, they do not contribute to the discussion of the provisional SC Members' COIs. Members of a SC and the lead author(s) are anonymous until this process is completed.

Careful steps are taken to convene SCs that meet the following criteria:

An appropriate range of expertise for the task. The SC must include experts with the specific expertise and experience needed to address the study's statement of task. A major strength of CCST is the ability to bring together recognized experts from diverse disciplines and backgrounds who might not otherwise collaborate. These diverse groups are encouraged to conceive new ways of thinking about a problem.

A balance of perspectives. Having content expertise is not sufficient for success. It is also essential to evaluate the overall composition of the SC in terms of different experiences and perspectives. The goal is to ensure that the relevant points of view are, in CCST's and the Program Committee's judgment, reasonably balanced so that the SC can carry out its charge objectively and credibly.

Screened for conflicts of interest. All provisional SC members are screened in writing and in a confidential group discussion about possible conflicts of interest. For this purpose, a "conflict of interest" means any financial or other interest which conflicts with the individual's service because it could significantly impair the individual's objectivity or could create an unfair competitive advantage for any person or organization. The term "conflict of interest" is beyond individual bias. There must be an interest, ordinarily financial, that could influence the work of the SC or that could be directly affected by the work of the SC, for an individual to be disqualified from serving. Except for a rare situation in which CCST and the Program Committee determine that a conflict of interest is unavoidable and promptly and publicly disclose the conflict of interest, no individual will be appointed to serve (or continue to serve) on a SC used in the development of studies while having a conflict of interest relevant to the required functions.

SC members and authors continue to be screened for conflict of interest at regular intervals throughout the life of the committee. (In addition to the SC and Authors, co-authors, peer reviewers and CCST staff working on each project are also screened for COI.)

Point of View is different from Conflict of Interest. A point of view or bias is not necessarily a conflict of interest. SC members are expected to have points of view, and CCST attempts to balance these points of view in a way deemed appropriate for the task. SC members are asked to consider respectfully the viewpoints of other members, to reflect their own views rather than be a representative of any organization, and to base their scientific findings and conclusions on the evidence. Each SC member has the right to issue a dissenting opinion to the study if he or she disagrees with the consensus of the other members. COIs are updated throughout the study process to capture any new or updated information and to ensure a continued lack of conflicts.

Diversity. CCST members are often asked to serve on an SC, though membership in CCST is not a requirement SC selection. CCST seeks a diverse SC in all dimensions, including women, minorities, and professionals in varying career stages where available.

Stage 3: Author and Steering Committee Meetings, Information Gathering, Deliberations, and Drafting the Study

Authors and the Steering Committee typically gather information through:

1. meetings;
2. submission of information by outside parties;
3. reviews of the scientific literature; and
4. investigations by the study authors and/or SC members and CCST staff.

In all cases, efforts are made to solicit input from individuals who have been directly involved in, or who have special knowledge of, the problem under consideration.

The lead author(s) maintain continued communication with the SC as the study progresses through frequent updates and background meetings.

For larger reports, lead authors may request additional authors to ensure the appropriate expertise is included. Every author must be approved by the SC Chair(s) and CCST staff. Some of the additional authors may become section leads. The lead author reviews and approves the work of all other chapter authors, including section leads.

During the course of a report, authors' duties may shift which may change the lead author or section lead designations. Any such changes must be made in conjunction with CCST staff and the SC Chair(s). If the reorganization of author responsibilities or the addition of a new author raises conflict of interest concerns, they are presented to and resolved by the Program Committee.

The authors shall draft the study and the SC shall draft the Executive Summary which includes findings, conclusions, and recommendations (FCRs). The SC deliberates in meetings closed to the public in order to develop FCRs free from outside influences. All interim analyses and drafts of the study remain confidential.

Stage 4: Report Review

As a final check on the quality and objectivity of the study, all CCST full commissioned reports must undergo a rigorous, independent external peer review by experts whose comments are provided anonymously to the authors and SC members. CCST recruits independent experts with a range of views and perspectives to review and comment on the draft report prepared by the authors and the SC. The proposed list of peer reviewers is approved by the Program Committee to ensure all report sections are adequately reviewed.
The review process is structured to ensure that each report addresses its approved study charge, that the findings are supported by the scientific evidence and arguments presented, that the exposition and organization are effective, and that the report is impartial and objective. Peer Reviewers will be made aware of any COIs that have been disclosed on the website by CCST.

The authors and the SC must respond to, but need not agree with, reviewer comments in a detailed "response to review" that is examined by one or more independent "report monitor(s)" responsible for ensuring that the report review criteria have been satisfied. After all SC members and appropriate CCST officials have signed off on the final report, it is transmitted to the sponsor of the study and the sponsor or CCST can release it to the public. Sponsors are not given an opportunity to suggest changes to the content of the reports though may ask clarifying questions about findings, conclusions, and recommendations. All reviewer comments and SC deliberations remain confidential. The names and affiliations of the report reviewers are made public when the report is released.

Appendix M: Expert Oversight and Review

Oversight Subcommittee of the Program Committee of CCST's Board of Directors

- **Andy McIlroy, PhD**, Sandia National Laboratories
- **Elizabeth Hadly, PhD**, Stanford University
- **Pramod Khargonekar, PhD**, University of California, Irvine

Report Monitor

- **Alistair Hayden, PhD**, Cornell University

Expert Reviewers

- **Garen Corbett**, University of California, Berkeley
- **Deniss Martinez, PhD**, University of California, Davis
- **Brad Simmons**, University of California, Davis
- **Tracy Katelman**, ForEverGreen Forestry
- **Savannah D'Evelyn, PhD**, University of Washington
- **Rupa Basu, PhD**, CA Office of Environmental Health Hazard Assessment (OEHHA)
- **Rosana Aguilera-Becker, PhD**, University of California, San Diego
- **Minghui Diao, PhD**, San José State University

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The Human Health Benefits of Improving Forest Health in California:
Investigating the Links Between Forest Management, Wildfire Smoke, and the Health Sector

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