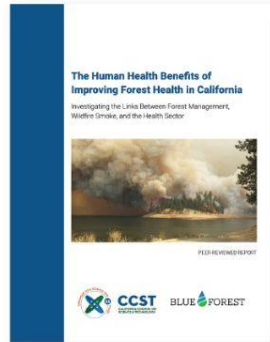# The Human Health Benefits of Improving Forest Health in California

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

Expert Briefing | Peer-Reviewed Report | Released: Sept. 2023 | CCST & Blue Forest

Briefing:
Thu. 9/21
1:00 PM PT
via Zoom

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

CCST   BLUE FOREST

New Report

King Fire | Pacific Southwest Forest Service, USDA

STRONGER WITH SCIENCE FOR 35 YEARS

CCST
CALIFORNIA COUNCIL ON
SCIENCE & TECHNOLOGY

BLUE FOREST

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BlueForest.org | @BlueForestConsv

Report Presentation by

Jennifer Montgomery
Report Steering Committee Chair
Ret. California County and State Government

Teresa Feo, PhD
Lead Project Manager and Author
CCST

Kimberly Quesnel Seipp, PhD
Project Manager and Author
Blue Forest

Signe Stroming
Author
Blue Forest

Kirsten Hodgson
Contributing Author
Blue Forest

Following the briefing, a separate call for credentialed media will be held with the author team.

Organizational Backgrounds

- Nonpartisan, nonprofit organization that **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.

- 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.

- Established via the California State Legislature in 1988.

- Nonprofit organization **using financial innovation for sustainable environmental solutions**.

- Working on research and development to demonstrate 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 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.

About the Study

Study Scope

- Conducted interviews with California health sector organizations and a literature review.

- Explores the connections between forest management, wildfire smoke, and human health

- Identifies potential opportunities for collaboration and motivations for investment in activities that reduce wildfire risk.

Funded By

- Innovative Finance for National Forests grant program
  - U.S. Forest Service
  - U.S. Endowment for Forestry and Communities
- State of California
- J.M. Kaplan Fund
- Alumbra Innovations Foundation

Study Process

Our role is to oversee a very rigorous process, modeled after the **National Academy of Sciences**, to ensure the product is credible and responsive to the study charge.

Balanced Team + Conflict of Interest Evaluation + Peer Review

Credible, Relevant, & Useful Report

Steering Committee and Study Team

Jennifer Montgomery

Retired Placer County Supervisor Director of the Governor's Forest Management Task Force

Ryan Tompkins

Cooperative Extension Forest and Natural Resources Advisor for Plumas, Sierra, and Lassen counties

Adam Kochanski

Assistant professor working at the San José State University as part of the Wildfire Interdisciplinary Research Center

Jun Wu

Professor and Graduate Director of the Department of Environmental and Occupational Health in the Program in Public Health at UC-Irvine

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Heidi Huber-Stearns

Asst. Research Professor at the University of Oregon and Visiting Professor of Practice at the University of Michigan Western Forest and Fire Initiative

CCST study team: Teresa Feo (Lead Author), Garbhita Shah, Audrey Zenner, Brie Lindsey, Sarah Brady, Amber Mace

Blue Forest study team: Kim Seipp (Lead Author), Signe Stroming (Lead Author), Kirsten Hodgson, Clare Loughlin, Phil Saksa

Report Overview

- **Executive Summary**

- **Chapter 1** - Introduction

- **Part I** - Interviews

  - **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

  - **Chapter 4** - Data Resources for Estimating the Health Impacts Smoke

  - **Chapter 5** - Evidence that forest management can reduce smoke and provide a health benefit

- **Findings, Conclusions, and Recommendations**

Executive Summary

Key Takeaways and Recommendations

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

Jennifer Montgomery
Steering Committee Chair
Retired State and Local Government

Executive Summary: Key Takeaways

Christopher Michel | San Francisco under heavy wildfire smoke on Sept 10, 2020
https://www.flickr.com/photos/cmichel67/50327421867

1. Wildfire smoke impacts human health. This includes health sector organizations' workforces, operations, and ability to provide services.

   However, the costs are largely unquantified.
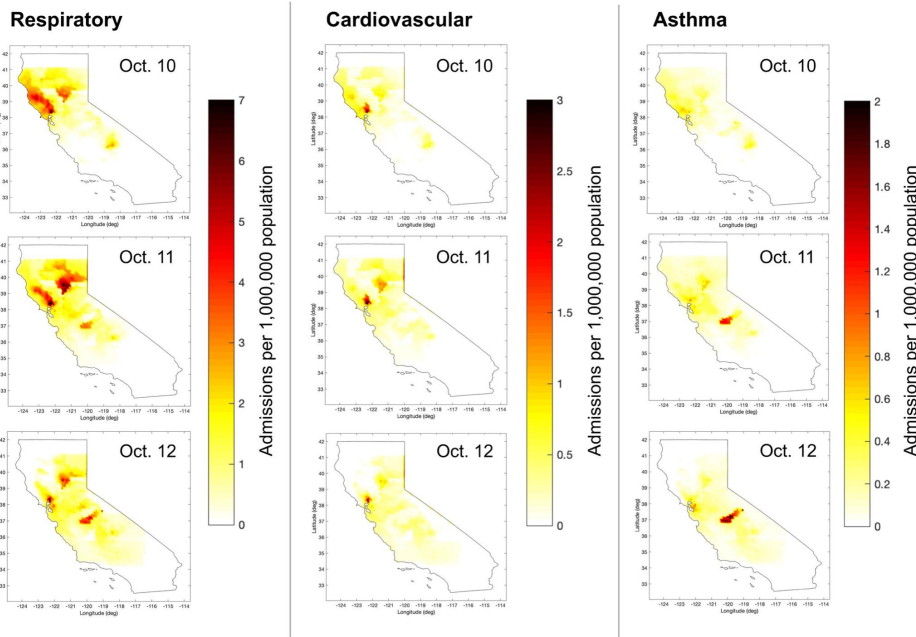
Executive Summary: Key Takeaways

Jennifer Montgomery | Pile burn

2. Many health sector organizations see value in future engagement with forest management to meet shared goals.

   But they require avenues for collaboration and more information on the potential health benefits.

Executive Summary: Key Takeaways

Cleland et. al 2021 | Excess respiratory, cardiovascular, and asthma hospital admissions attributable to wildfire $PM_{2.5}$, expressed as rate per 1,000,000 person-days, during the Wine Country Fires, October 10–12, 2017. https://doi.org/10.1029/2021GH000414

3. Comprehensive statewide or locally specific information on the adverse human health impacts of wildfire smoke could be generated from additional analysis of existing data resources.

Executive Summary: Key Takeaways

Jennifer Montgomery | Preparing for a cultural burn

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

Executive Summary Key Recommendations

California and the federal government should:

1. **prioritize interested health sector organizations' participation** in forest management advisory bodies to strengthen the linkages between public health and forest management planning and practice.

2. **expand existing smoke data products** to create inventories tracking wildland fire smoke $PM_{2.5}$ concentrations, population exposure to smoke, and adverse health outcomes of smoke.

3. **support additional research** to study the smoke-related human health tradeoffs of different possible forest management strategies to improve forest and human health.

Chapter 1

Introduction

Kim Seipp, PhD
Project Manager &
Lead Author
Blue Forest

Teresa Feo, PhD
Study Manager &
Lead Author
*California Council on
Science and
Technology*

California's forests are burning at increasing size & severity, leading to intense, widespread wildfire smoke events
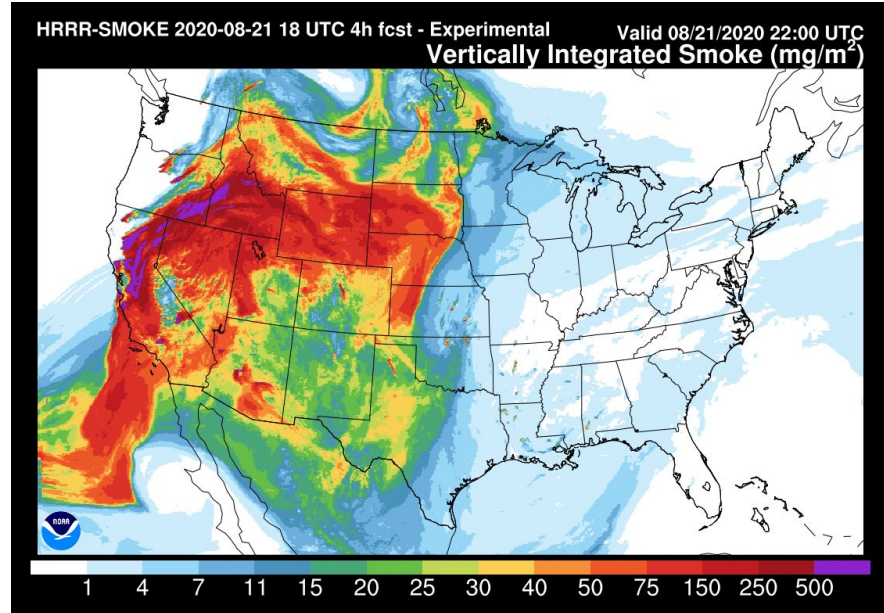

August Complex Fire, 2020

Figure 1. NOAA HRRR-Smoke Forecast for August 21st, 2020 showing harmful levels of smoke PM2.5 air pollution across California and other western states.

Wildfire smoke leads to adverse health outcomes

Health impacts from wildfire smoke may be the largest economic impact from wildfires with the short- and long-term impacts of smoke exposure estimated at nearly $100 billion annually, though researchers note health impacts may still be under-quantified

Forest management is a tool to improve forest resilience

Degraded Forest

Forest Management

- **Forest Restoration:** mechanical thinning, beneficial fire, invasive species removal, and meadow restoration

- **Fuels Reduction:** reducing the density of small diameter trees and surface fuels

Healthy Forest

Forest management alternatives lead to smoke trade-offs

Population smoke exposure, health, and health sector tradeoffs

Degraded Forest
No Treatment Scenario

↑ **Smoke emissions**, dispersion, and population exposure.

↑ **Adverse health impacts** and health sector organizational impacts from wildfire smoke exposure.

↑ **Financial costs** to the public, vulnerable populations, and health sector.

Healthy Forest
Future Proactive Treatment Scenario

↓ **Reduced** smoke emissions, dispersion, and population exposure.

↓ **Reduced** adverse health impacts and health sector organizational impacts from wildfire smoke exposure.

↓ **Reduced** financial costs to the public, vulnerable populations, and health sector.

Given that a smoke-free future does not exist for California...

> *Opportunities for cross-sector collaboration to meet shared goals may exist if accelerated and proactive forest management can meet ecological, human health, and economic triple-bottom lines for the health and forest management sectors (Exec. Sum. pg. 3).*

Potential avenues of engagement:

Community engagement	Cost-sharing
Advocacy	Other ideas

Linking forest resilience, wildfire smoke, and human health

These emerging connections suggest the potential for collaboration in the pursuit of resilient forests, but certain knowledge gaps exist:

- **Part I:** How is wildfire smoke impacting the health sector, and how does the health sector perceive potential opportunities to engage with forest management?

- **Part II:** Is there evidence that improving forest resilience delivers human health benefits related to wildfire smoke?

Research Questions

- **Chapter 2:** How is wildfire smoke impacting California's health sector organizations, and to what extent are the costs of impacts being financially tracked?

- **Chapter 3:** Are these health organizations interested in engaging with land managers around forest management, and what motivations, barriers, and opportunities currently exist?
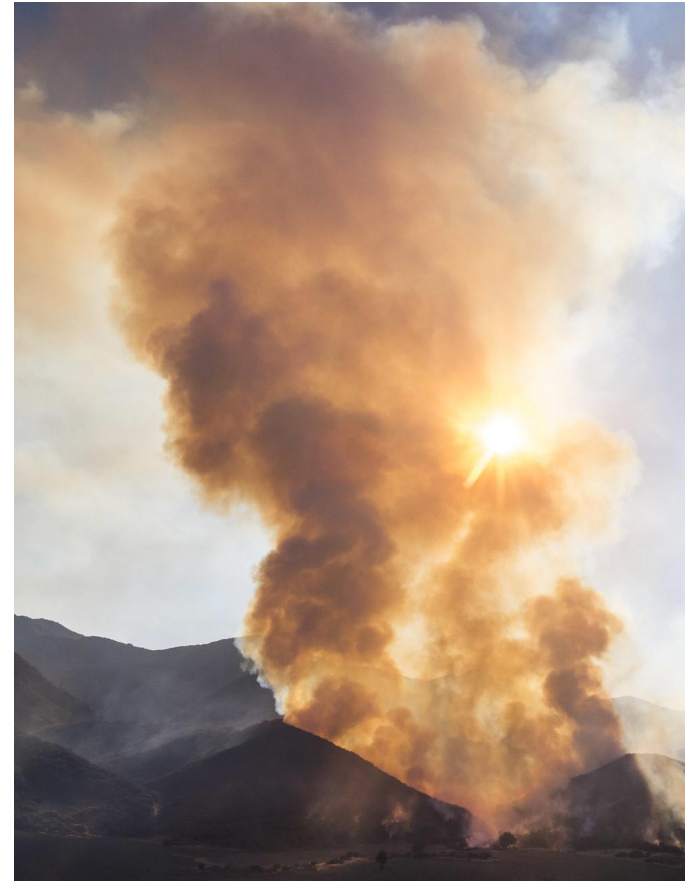
Methods

- **Population of interest:** public health, health systems, and health insurers in California

- **Recruitment:** email outreach to ~350 individuals representing ~200 organizations

- **Data Collection:** semi-structured interviews with 60 individuals representing 48 organizations in 2022

- **Analysis:** interview transcription, iterative coding of our qualitative data, patterns and themes identified and described to develop findings in the report
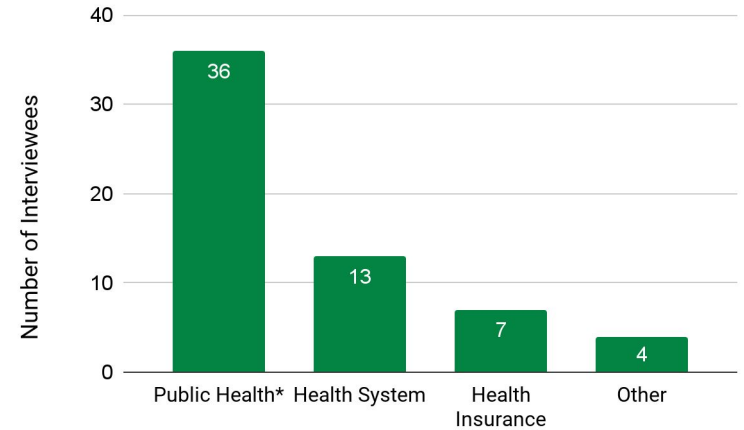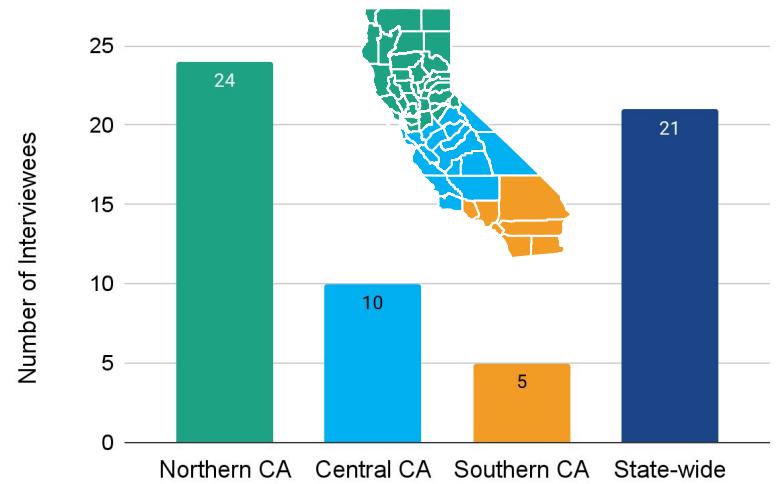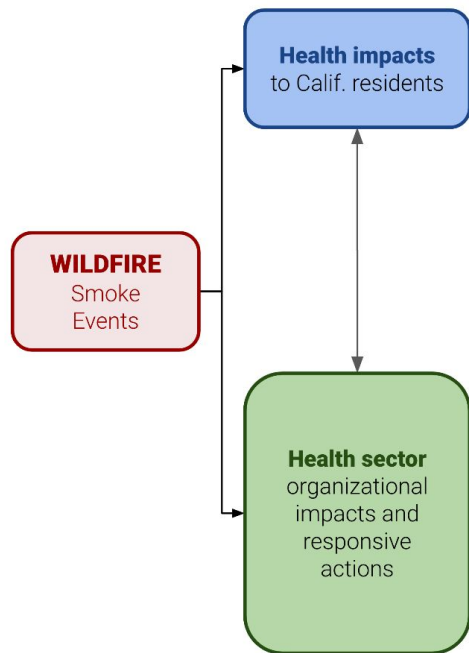

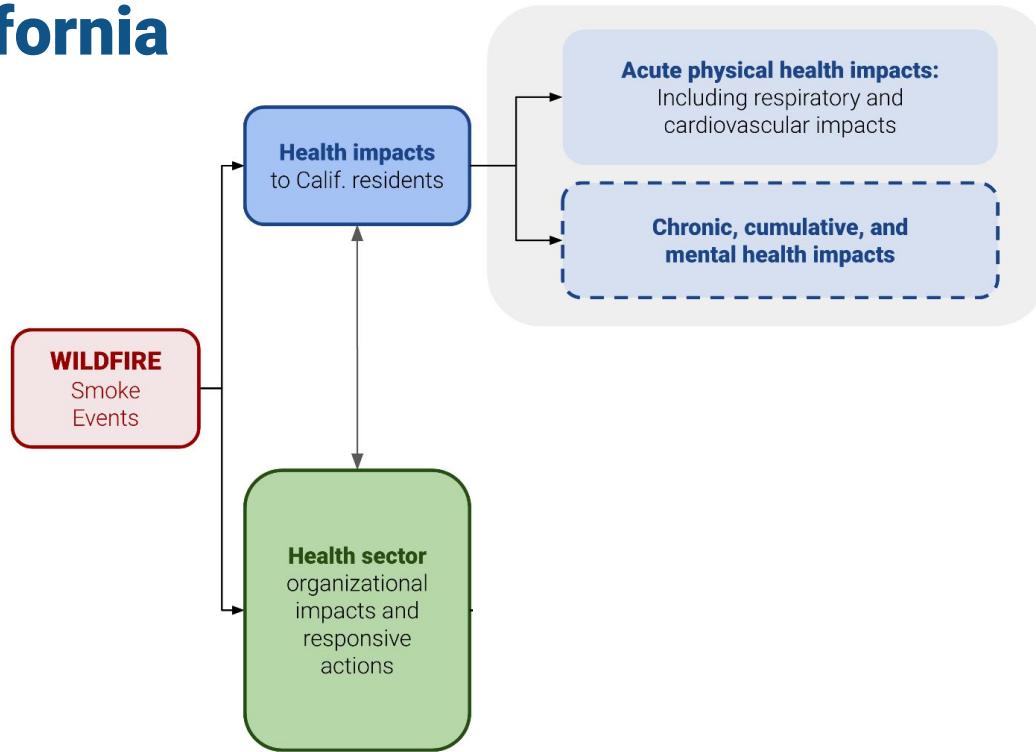*Includes interviewees serving Tribal governments or communities

Chapter 2

Perspectives on wildfire smoke impacts to human health and the health sector in California

> **Wildfire smoke impacts human health and health sector organizations' workforces, operations, and ability to provide services, yet the costs are largely unquantified.**
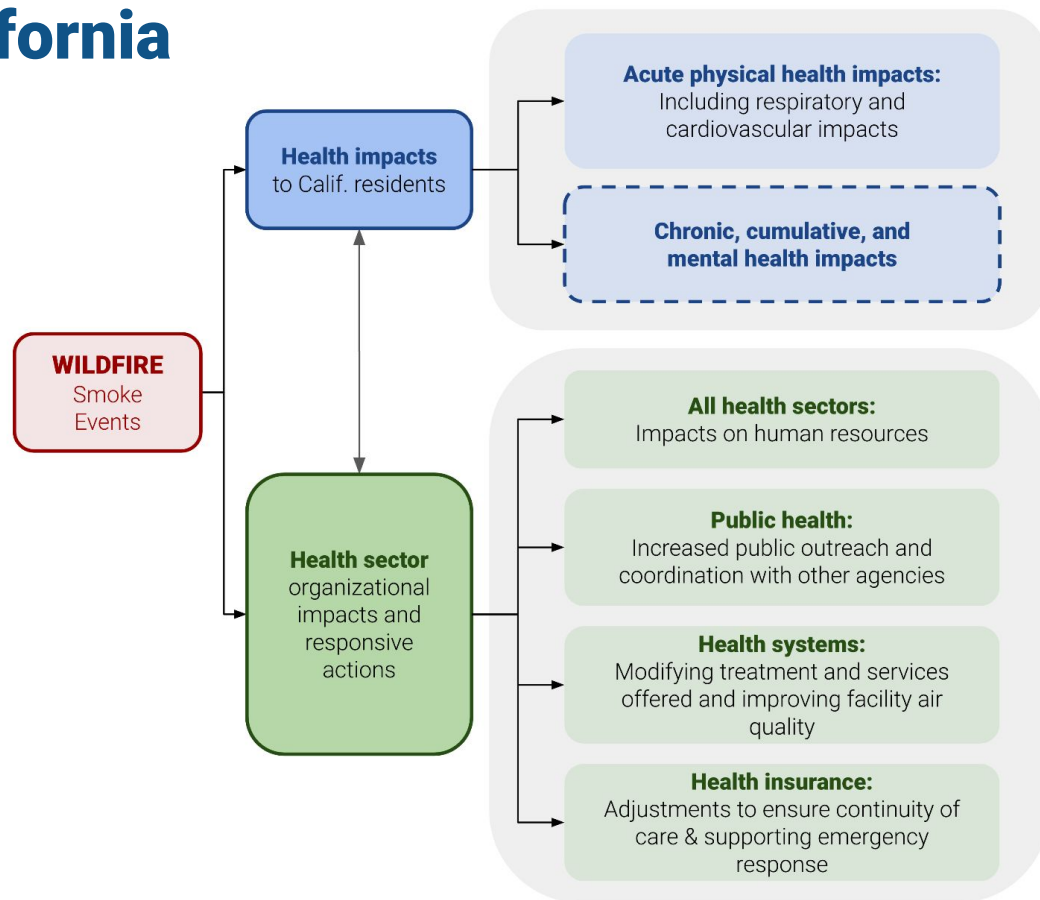
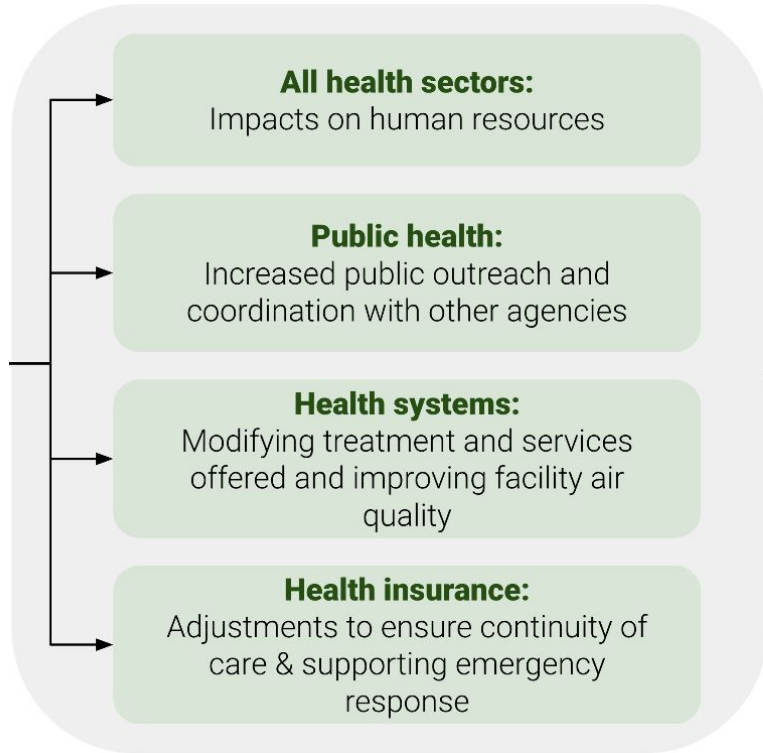# Wildfire smoke has real and growing impacts on health in California

Wildfire smoke has real and growing impacts on health in California

WILDFIRE Smoke Events
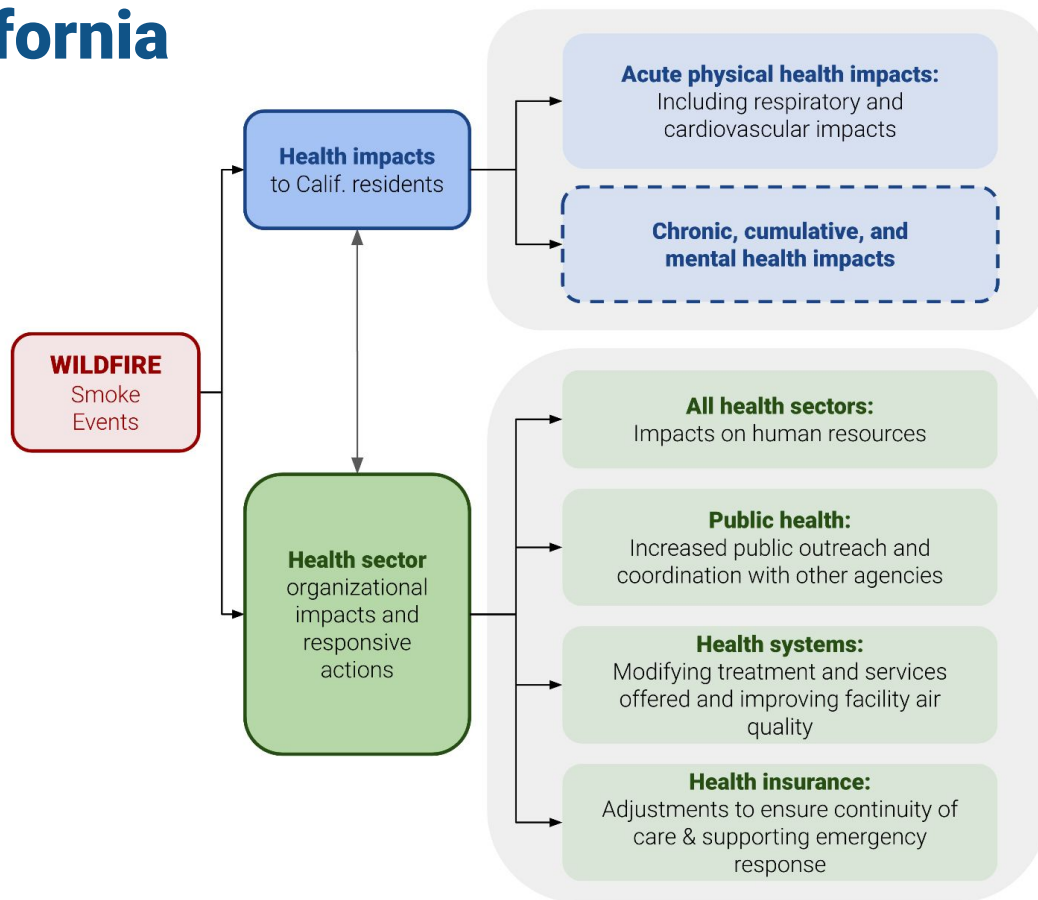
Health impacts to Calif. residents

Acute physical health impacts: Including respiratory and cardiovascular impacts

Chronic, cumulative, and mental health impacts

Health sector organizational impacts and responsive actions

Wildfire smoke has real and growing impacts on health in California

WILDFIRE Smoke Events

Health impacts to Calif. residents

Acute physical health impacts: Including respiratory and cardiovascular impacts

Chronic, cumulative, and mental health impacts

Health sector organizational impacts and responsive actions

All health sectors: Impacts on human resources

Public health: Increased public outreach and coordination with other agencies

Health systems: Modifying treatment and services offered and improving facility air quality

Health insurance: Adjustments to ensure continuity of care & supporting emergency response

All health sectors:
Impacts on human resources

Public health:
Increased public outreach and
coordination with other agencies

Health systems:
Modifying treatment and services
offered and improving facility air
quality

Health insurance:
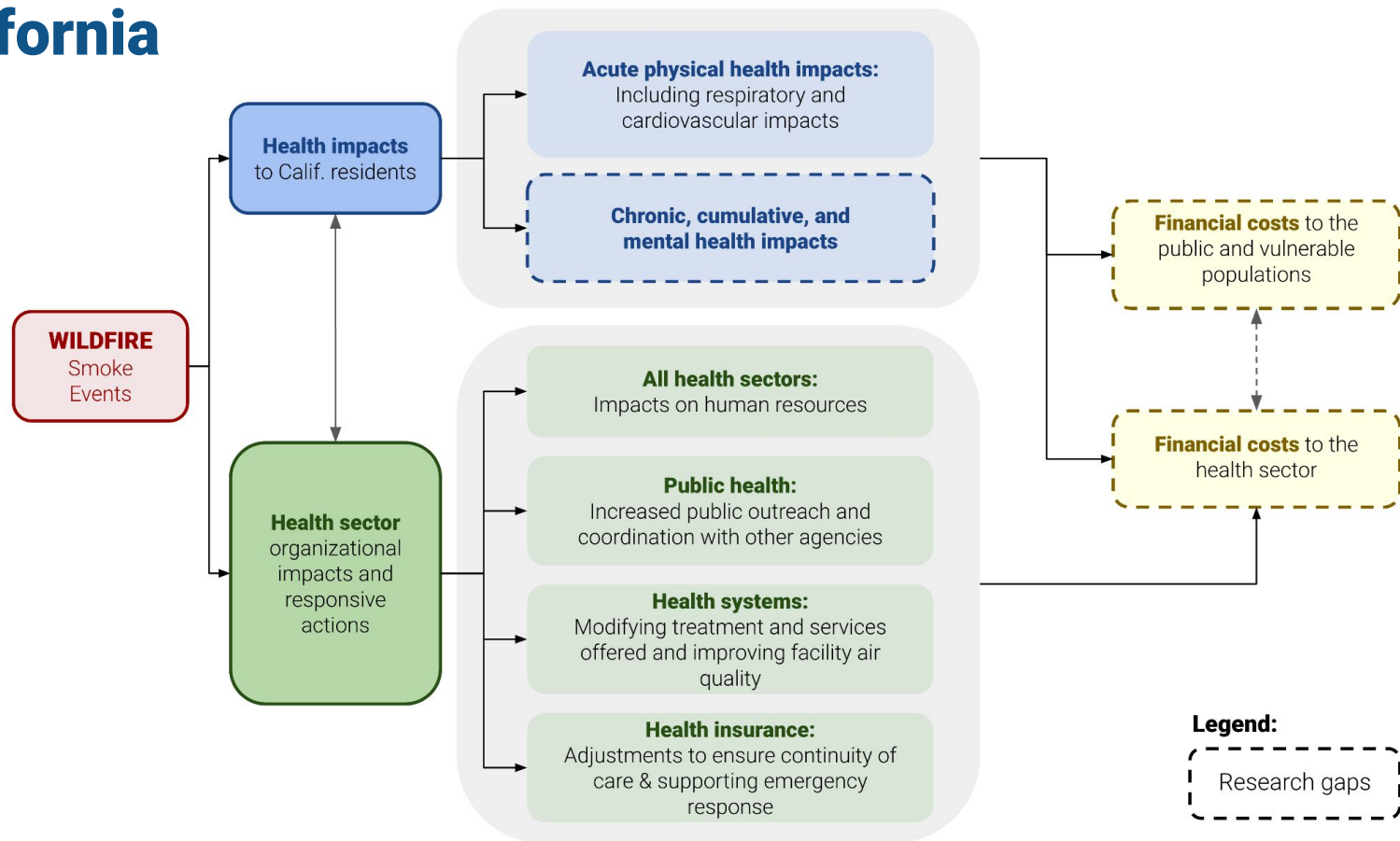Adjustments to ensure continuity of
care & supporting emergency
response

Wildfire smoke is requiring increasing time, capacity, and resources to prepare for and respond to, and its impacts are not equally distributed.

Wildfire smoke has real and growing impacts on health in California

WILDFIRE
Smoke Events

Health impacts
to Calif. residents

Acute physical health impacts:
Including respiratory and cardiovascular impacts

Chronic, cumulative, and mental health impacts

Health sector
organizational impacts and responsive actions

All health sectors:
Impacts on human resources

Public health:
Increased public outreach and coordination with other agencies

Health systems:
Modifying treatment and services offered and improving facility air quality

Health insurance:
Adjustments to ensure continuity of care & supporting emergency response

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WILDFIRE Smoke Events

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Health insurance: Adjustments to ensure continuity of care & supporting emergency response

Financial costs to the public and vulnerable populations

Financial costs to the health sector

Legend:

Research gaps

Impacts exist, but are rarely quantified as financial costs

- Most organizations are interested in understanding dollar-value of impacts

- Yet, most organizations are not tracking these costs themselves
  - Some have data to do so
  - Many lack capacity or expertise

"*"When you're dealing with the tyranny of the urgent in a small hospital during a wildfire event, you're just not necessarily calculating costs or doing anything more than you have to do."*

Chapter 3

Perspectives on the connections between forest health and human health

> **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.**

Connecting the health sector to forest management

Photo credit: Pacific Southwest Forest Service, USDA

The health sector is aware of forest management but most are not connecting it to their work

- Some recognition of **relationship** between forest management and human health

- Not considering forest management as a **relevant tool** for their work

- **Prescribed burning** commonly recognized as an important element of forest management

"As members of the general public 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."

There is general openness to different avenues of engagement

Interviewees saw value in engagement between the health sector and forest management, but lacked clarity around how to begin.

Potential avenues of engagement:

 Community engagement

 Advocacy

 Cost-sharing

 Other ideas

Key motivations and barriers for health sector engagement

Motivations

1. Demonstrated **health benefits**

2. Interest in **climate initiatives**

3. Demonstrated **financial return**

4. Fit with **organization's mission**

Barriers

1. **Financial constraints**

2. **Capacity** and bandwidth

3. **Political** aspects

4. **Competing priorities**

5. Outside of **organization's scope**

Information and institutional structures needed to enable collaboration

Enabling conditions for greater cross-sector engagement:

- **Information...**
  - On smoke impacts on health and the health sector
  - On health benefits of forest management and value of health sector engagement
  - That is available at various spatial scales and accessible to diverse audiences
- **Institutional structures...**
  - which model potential pathways for collaboration

"

"We've had these forays in talking with forest science and public health, but that needs to be more deliberate...Who drives this conversation and brings in the policymakers? Because you can have the science, you can have the public health, but if you don't have policy driving it, then we'll end up raking forests."

Part II

Literature Review

Smoke Data and Management Tradeoffs

Teresa Feo, PhD
Study Manager and Author
California Council on Science and Technology

Overview of Literature Review

Research Questions

- **Chapter 4**: What data resources are available for estimating the adverse health impacts of wildland fire smoke?

- **Chapter 5:** Can forest management benefit human health benefit by reducing wildland fire smoke?

Methods

We conducted a review of:
- peer-reviewed academic literature
- technical reports
- publicly available data resources
- and modeling tools

Chapter 4

Data Resources for Estimating the Adverse Health Impacts of Smoke

> **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.**
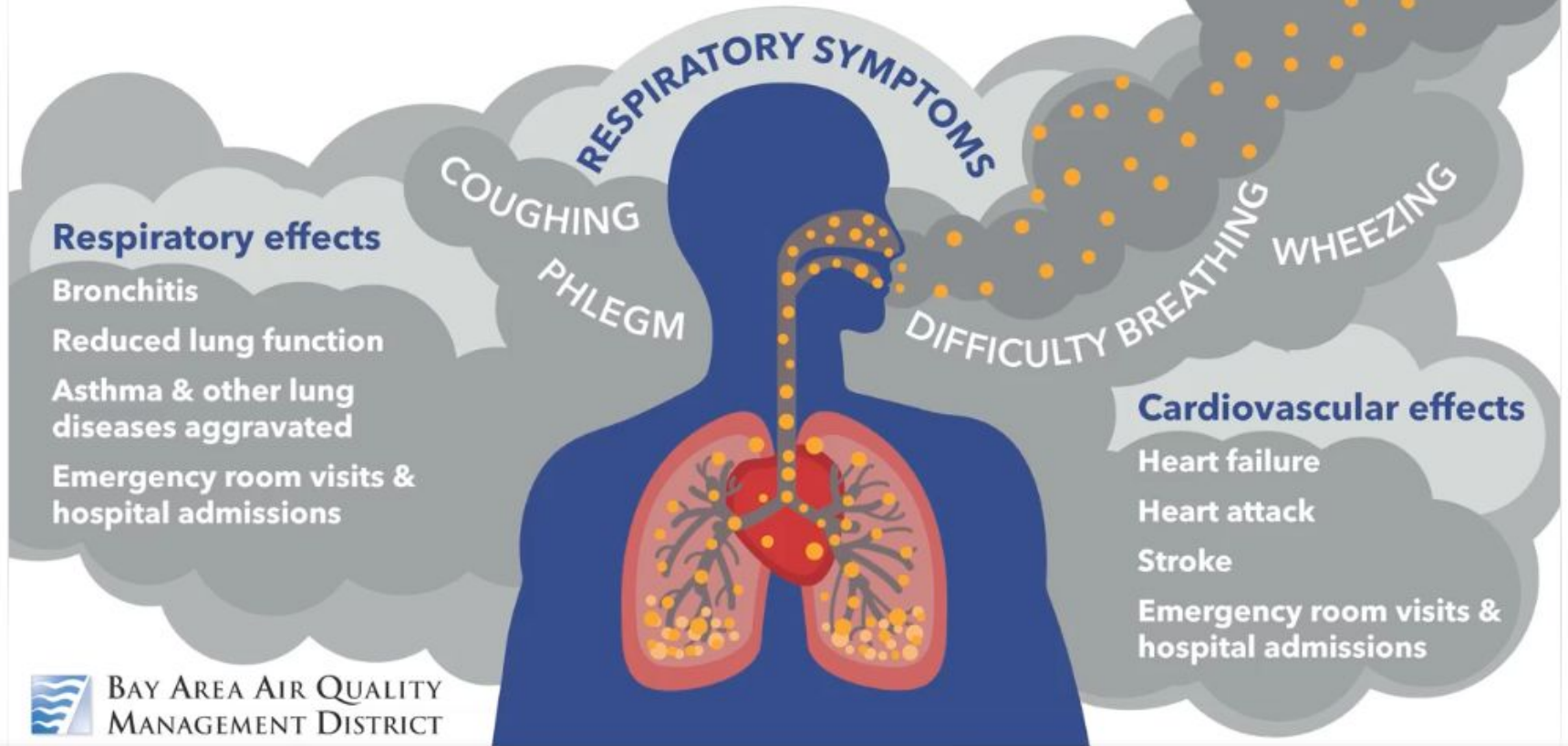
Estimating health impacts relies on 3 types of smoke data

Smoke
Emissions

$+$

Smoke
Dispersion

$+$

Population
Exposure

$=$
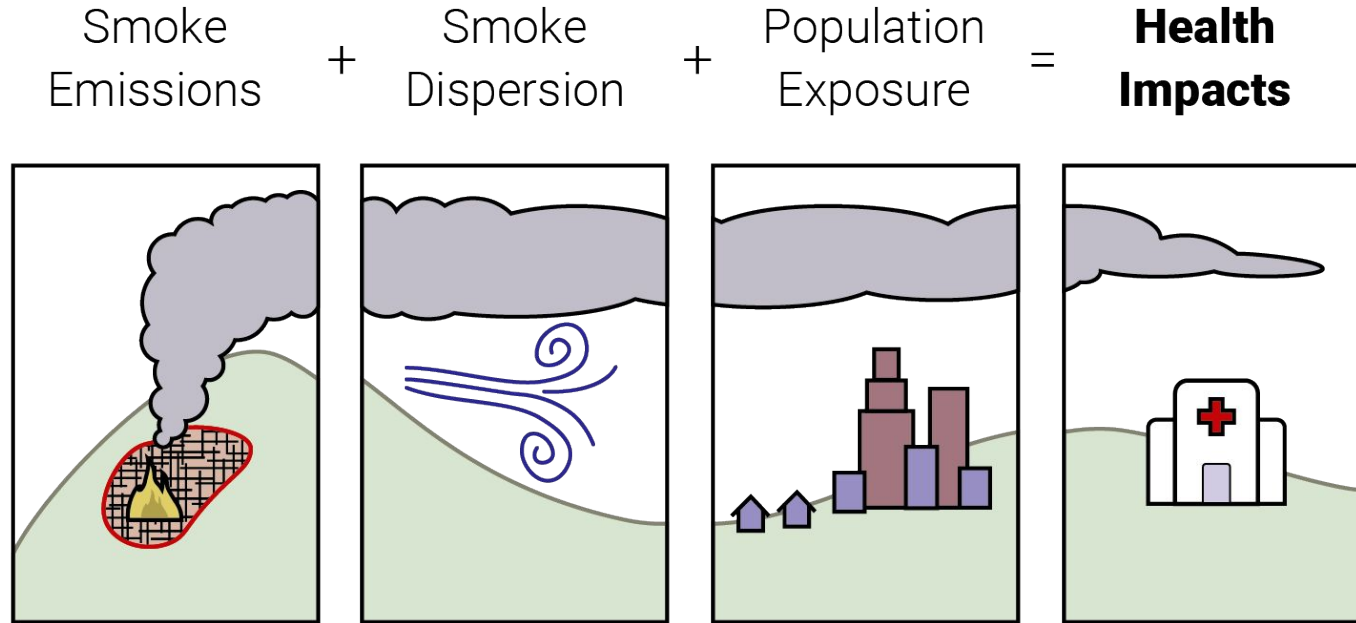
**Health
Impacts**

Figure 9: Framework for estimating the health impacts of wildland fire smoke.

Availability of smoke data resources

Table 5 (Summary): Publicly available data products that report smoke impacts for localities across California

		Study	Dataset	Data Inventory	By Source Fire
Smoke Emissions					
Smoke Dispersion	Smoke Plumes				
	Smoke $PM_{2.5}$ conc.				
Population Exposure					
Health Impacts					

Smoke Emissions: EPA inventory is tracking how much smoke fires produce.
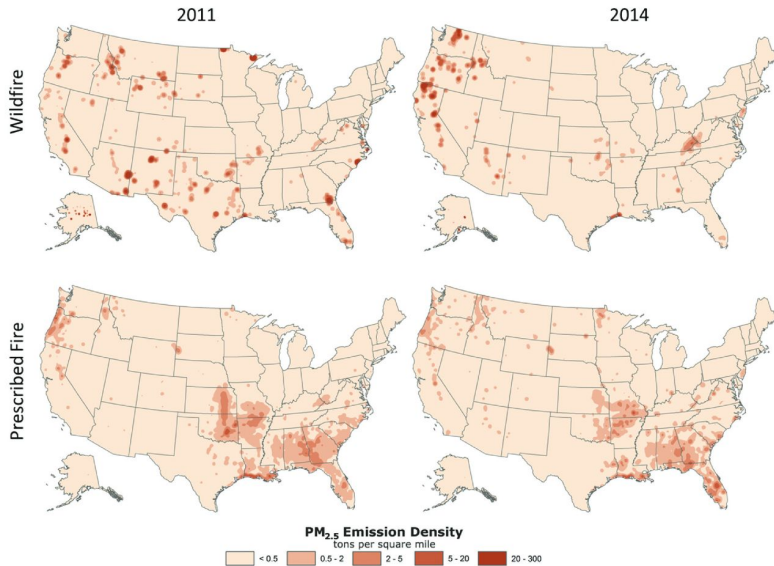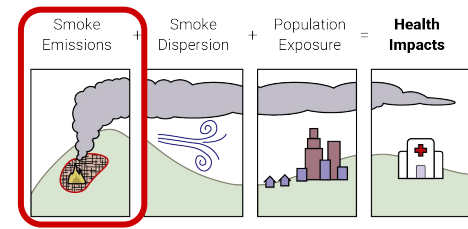
Figure 5. Annual wildland fire PM$_{2.5}$ emission totals shown as tons emitted per square mile for each location. Both the 2011 and 2014 CFIRE inventory are shown and are separated into wildfire and prescribed burn annual totals.

Larkin et al. (2020); https://doi.org/10.1080/10962247.2020.1802365

- The U.S. EPA National Emissions Inventory tracks emissions of various air pollutants, including PM$_{2.5}$ for individual wildland fires (wild and prescribed).

- Known limitation: Emissions estimates are for burned vegetation only and don't include emissions from burned human-made materials (e.g. houses, cars, etc.).

Smoke Dispersion: NOAA inventory is tracking smoke plumes
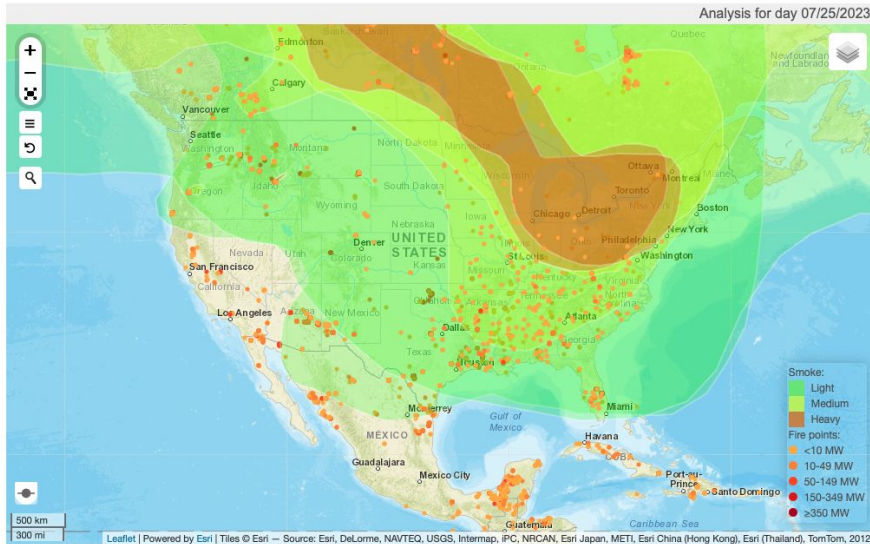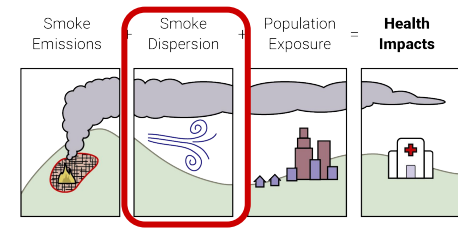
HMS Fire and Smoke map for 07/25/2023;
https://www.ospo.noaa.gov/Products/land/hms.html#maps

- The NOAA Hazard Mapping System Fire and Smoke Product tracks the spatial footprint and optical density (light, medium, heavy) of wildland fire smoke plumes daily across the US.

- The U.S. EPA Air Now Fire and Smoke Map shows current conditions of smoke plumes, fire locations, and ground-level air quality readings.

Smoke Dispersion: Datasets report the concentration of smoke PM$_{2.5}$
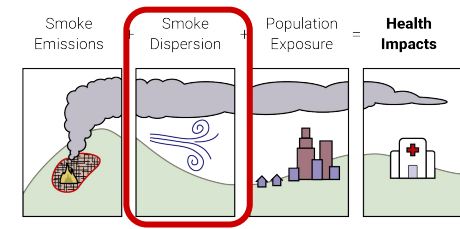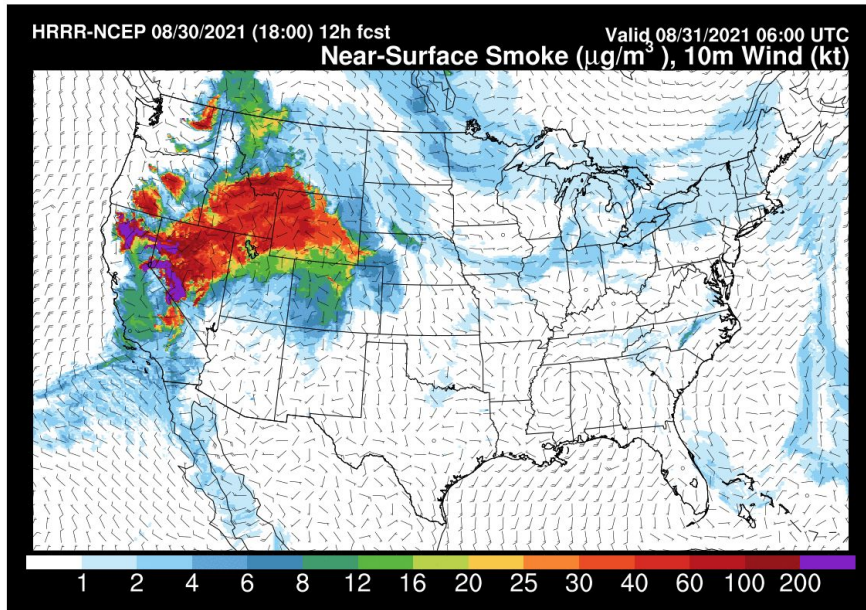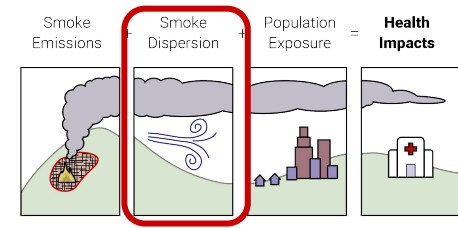

Maximum Wildfire PM$_{2.5}$ (μg m^{-3})
(2006-2020)
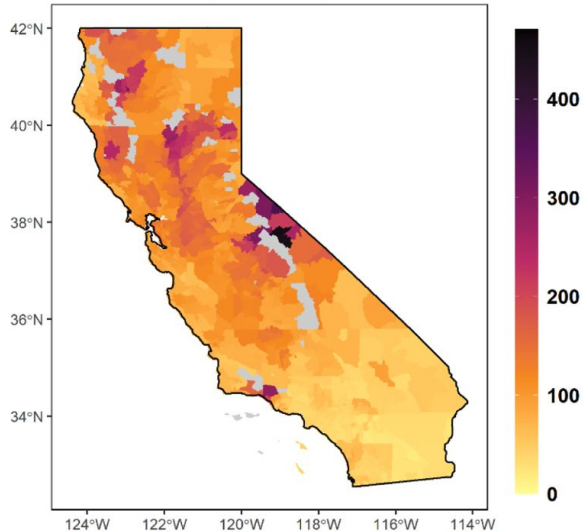
Fig. 6. Mean (top) and maximum (bottom) wildfire-specific PM$_{2.5}$ concentrations at ZIP codes within the 2006–2020 study period.

Aguilera et al (2023); https://doi.org/10.1016/j.envint.2022.107719

- Two recent studies have published datasets of daily smoke PM$_{2.5}$ concentrations for years 2006−2020.

  - Childs et al (2022): contiguous U.S. by 10km grid

  - Aguilera et al (2023): California by ZIP code

Smoke Dispersion: NOAA inventory tracks forecasts of smoke PM$_{2.5}$

HRRR-NCEP 08/30/2021 (18:00) 12h fcst   Valid 08/31/2021 06:00 UTC
Near-Surface Smoke (μg/m^3), 10m Wind (kt)

HRRR Smoke Forecast 08/30/2021; https://rapidrefresh.noaa.gov

- The NOAA High-Resolution Rapid Refresh (HRRR) Smoke Product provides hourly forecasts with 18- or 48-hour lead time of PM$_{2.5}$ concentrations from satellite detected wildland fires in the U.S. by a 3 km grid.

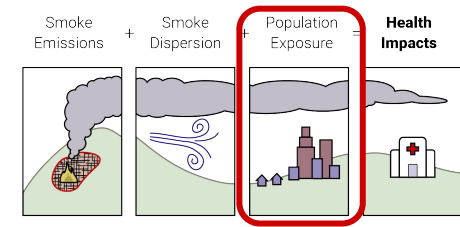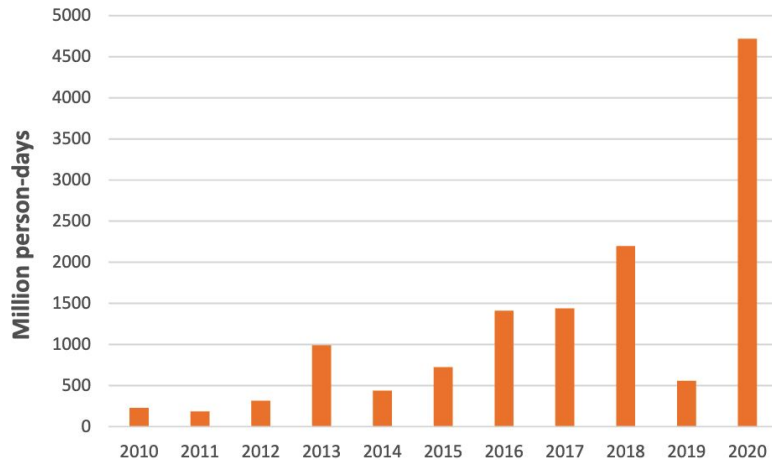# Population Exposure: Dataset reports person-days of smoke exposure

Figure 1. Potential population exposures* to wildfire smoke, 2010-2020

Source: NOAA, 2021; US Census Bureau, 2010 (analysis based on Vargo, 2020)

* Graph presents the estimated number of people living in areas where smoke plumes were present multiplied by the number of days when the plumes were present in those areas.

- [Vargo (2020)](#) provides a historical dataset of US population exposure to wildfire smoke plumes between years 2010-2019.
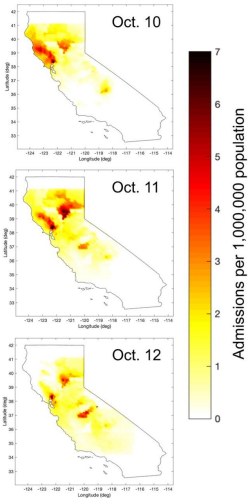
OEHHA (2022) "Indicators of Climate Change in California, Fourth Edition."
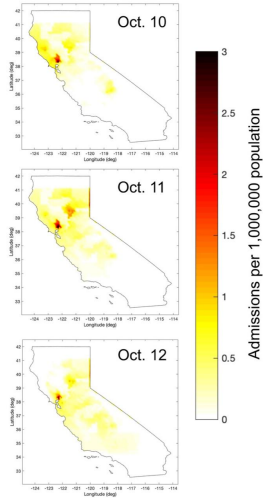https://oehha.ca.gov/climate-change/report/2022-report-indicators-climate-change-california

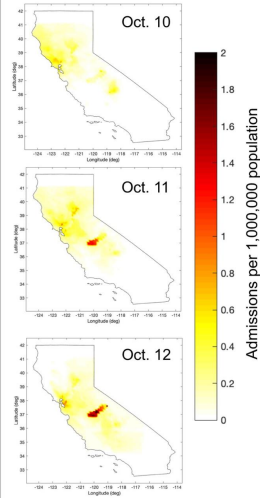# **Health Impacts:** Studies report adverse health outcome for specific cases.
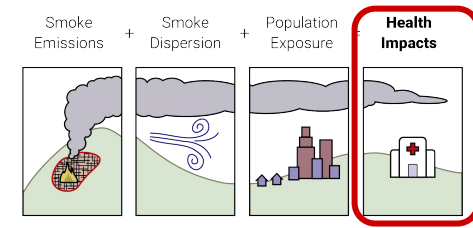
Respiratory | **Cardiovascular** | **Asthma**

Oct. 10, Oct. 11, Oct. 12

Admissions per 1,000,000 population

Cleland et. al 2021 | Excess respiratory, cardiovascular, and asthma hospital admissions attributable to wildfire $PM_{2.5}$, expressed as rate per 1,000,000 person-days, during the Wine Country Fires, October 10–12, 2017. https://doi.org/10.1029/2021GH000414

- There are no datasets of inventories tracking smoke health impacts across California.

- But there are studies that estimate the cases and/or costs of adverse health outcomes attributable to smoke in California for specific cases.
(see Table 6 for list of studies)

Data inventories are tracking smoke, but not smoke health impacts

Table 5 (Summary): Publicly available data products that report smoke impacts for localities across California

		Study	Dataset	Data Inventory	By Source Fire
Smoke Emissions		✔	✔	✔	✔
Smoke Dispersion	Smoke Plumes	✔	✔	✔	✘
	Smoke $PM_{2.5}$ conc.	✔	✔	✘	✘
Population Exposure		✔	✔	✘	✘
Health Impacts		✔	✘	✘	✘

Recommendation: Expand smoke inventories to better understand the health impacts of wildland fire smoke

Table 5 (Summary): Publicly available data products that report smoke impacts for localities across California

		Study	Dataset	Data Inventory	By Source Fire
Smoke Emissions		✔	✔	✔	✔
Smoke Dispersion	Smoke Plumes	✔	✔	✔	✘
	Smoke $PM_{2.5}$ conc.	✔	✔	✘	✘
Population Exposure		✔	✔	✘	✘
Health Impacts		✔	✘	✘	✘

Chapter 5

Evidence that forest management can provide a human health benefit

> **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.**

Forest management success stories

'The fire moved around it': success story in Oregon fuels calls for prescribed burns

The Guardian

Oregon's Bootleg fire has offered new evidence that Indigenous techniques can change how megafires behave

Copyright 2021 John F Marshall

These maps show where prescribed burns helped curb the Caldor Fire's rapid growth

San Francisco Chronicle

Wildfires threaten the world's oldest trees—but prescribed burns are protecting them
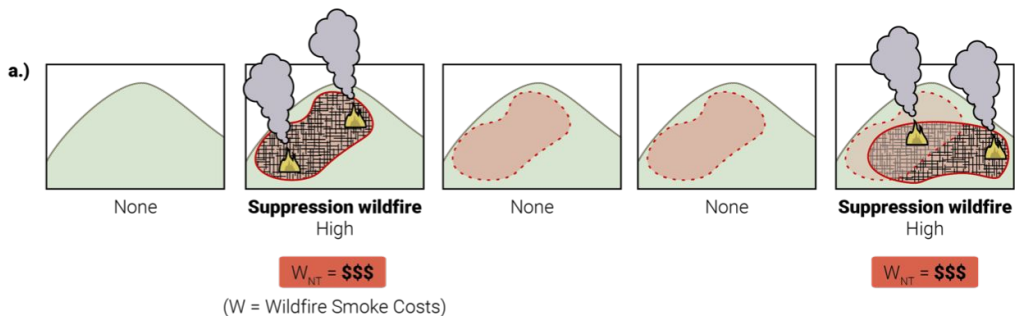
Famous sequoias like the General Sherman are protected by a long history of intentionally set fires, but other giant sequoias are in big trouble.

NATIONAL GEOGRAPHIC

Comparing the smoke tradeoffs of forest management strategies to understand which has fewer health impacts
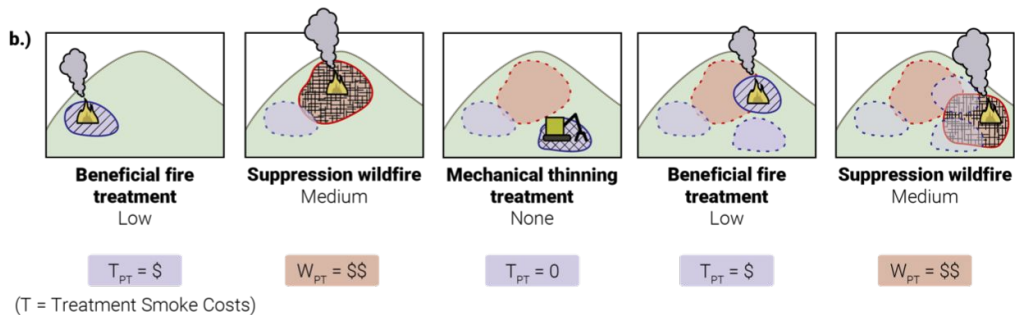

Figure 10: A conceptual framework for evaluating the smoke tradeoffs of alternative treatment scenarios.

Forest management can benefit human health, but it depends on local context and conditions

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

Scenario Comparison	Paper	Region	Rx fire	Smoke Metric				Effect
				Smoke Emissions	Smoke Dispersion	Population exposure	Health Impacts	
REDUCE SMOKE COSTS OF WILDFIRES? $W_{PT} < W_{NT}$	Povak et al. 2022	WA	YES	YES	-	-	-	Benefit
	Long et al. 2018	CA	YES	YES	-	-	-	Benefit
	Graw and Anderson 2022	OR	YES	YES	YES	-	-	Benefit
	Long et al. 2022	CA	YES	-	-	-	YES	Benefit
	Ravi et al. 2019	ID, OR, WA	YES	-	-	-	YES*	Benefit
	Burke et al. 2021	CA	YES	-	-	-	YES*	Benefit
NET SHORT-TERM SMOKE BENEFIT? $(T_{PT} + W_{PT}) < W_{NT}$	Hyde and Strand 2019	ID	YES	YES	-	-	-	Neutral
	Stevens et al. 2016	CA	NO	YES	YES	-	-	Benefit
	US EPA 2021	CA	YES	-	-	-	YES	Benefit
NET LONG-TERM SMOKE BENEFIT? $(\sum T_{PT} + \sum W_{PT}) < \sum W_{NT}$	Long et al. 2022	CA	YES	YES	-	-	-	Cost / Benefit
	CARB 2022	CA	YES	YES	-	-	YES	Benefit

Health-related smoke tradeoffs is a new area of research and the tradeoffs in non-forested ecosystems are still unknown

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

Scenario Comparison	Paper	Region	Rx fire	Smoke Emissions	Smoke Dispersion	Population exposure	Health Impacts	Effect
REDUCE SMOKE COSTS OF WILDFIRES? $W_{PT} < W_{NT}$	Povak et al. 2022	WA	YES	YES	-	-	-	Benefit
	Long et al. 2018	CA	YES	YES	-	-	-	Benefit
	Graw and Anderson 2022	OR	YES	YES	YES	-	-	Benefit
	Long et al. 2022	CA	YES	-	-	-	YES	Benefit
	Ravi et al. 2019	ID, OR, WA	YES	-	-	-	YES*	Benefit
	Burke et al. 2021	CA	YES	-	-	-	YES*	Benefit
NET SHORT-TERM SMOKE BENEFIT? $(T_{PT} + W_{PT}) < W_{NT}$	Hyde and Strand 2019	ID	YES	YES	-	-	-	Neutral
	Stevens et al. 2016	CA	NO	YES	YES	-	-	Benefit
	US EPA 2021	CA	YES	-	-	-	YES	Benefit
NET LONG-TERM SMOKE BENEFIT? $(\sum T_{PT} + \sum W_{PT}) < \sum W_{NT}$	Long et al. 2022	CA	YES	YES	-	-	-	Cost / Benefit
	CARB 2022	CA	YES	YES	-	-	YES	Benefit

Executive Summary: Key Takeaways

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

2. 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.

3. 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.

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.

Executive Summary Key Recommendations

1. California and the federal government should further prioritize interested health sector organizations' participation in forest management advisory bodies to strengthen the linkages between public health and forest management planning and practice.

2. California and the federal government should expand upon existing smoke data products to create inventories tracking wildland fire smoke $PM_{2.5}$ concentrations, population exposure to smoke, and adverse health outcomes of smoke.

3. The state and federal government should support additional research to study the smoke-related human health tradeoffs of different possible forest management strategies to improve forest and human health.