U.S. Department of the Interior
Office of Policy Analysis

Report

Increasing damages from wildfires warrant investment in wildland fire management

Christian Crowley[1], Ann Miller[1], Robert Richardson[1], and Jacob Malcom[1,2]

Wildland fires shape nature and affect people in many parts of the United States. Understanding the benefits and costs of these fires and their management is essential when allocating resources to improve outcomes for people and nature. We conducted a literature review on benefits and economic costs of wildland fire and society's investment in its management. Published research shows wildfires in the United States impose annual costs in the range of tens to hundreds of billions of dollars, health costs in the hundreds of millions of dollars per year, and other market and non-market costs for which we do not have reliable estimates. These total costs (tens to hundreds of billions of dollars per year) are much larger than Federal government expenditures on preparedness and fire suppression (a few billion dollars per year). Additional investments in wildland fire management (preparedness, response, and post-fire stabilization and rehabilitation) could be a cost-effective way to reduce the losses associated with wildfire. More precise estimates of the benefits, costs, and trade-offs of such investments require further data collection, analysis, and methodological development to address gaps in our understanding. We conclude that ongoing additional investment in DOI wildfire-management workforce capacity and capabilities would likely help society avoid some of the large losses associated with catastrophic wildfire.

Publication date: 2023-05-25

Wildland fire is a phenomenon and process with widespread effects on people and nature. Fire is an important part of many natural ecological communities (e.g., ponderosa pine forests, chaparral, and longleaf pine ecosystems) and essential to human activities (e.g., Tribal land management). However, depending on location, timing, and intensity, fire can also be harmful to people and nature (Mason et al., 2006; Pausas & Keeley, 2019; Cullen, 2020). Understanding the interplay among these aspects of wildland fire is essential to making informed decisions about management goals, and allocating resources to achieve them. Science and practice have demonstrated that methods of forest fuel treatments (e.g., thinning stands, prescribed and managed fires) reduce fire intensity and rate of spread (Bartuska & Wibbenmeyer, 2022). However, in the fire-prone chaparral ecosystem (covering much of California), prescribed fire does not necessarily promote biodiversity, and repeated fuels management (especially mastication or mulching) can degrade habitat (Newman et al., 2018). Economic analyses can help inform decision-making by evaluating these and other benefits and costs to facilitate comparison of tradeoffs among alternatives for wildland fire management (WFM). As a complement to the economic context of wildfires, Appendix A provides a brief overview of the natural and management history of wildland fire. More extensive reviews may be found in Thomas et al. (2017) and Simon et al. (2022).

In determining where and when to suppress wildfires—and when to allow managed wildfires to reduce fuel in forests—

[1] Office of Policy Analysis; Policy, Management, and Budget; U.S. Department of the Interior, Washington, DC

[2] Corresponding author: Jacob_Malcom@ios.doi.gov

Table 1. Major categories of costs and losses of wildland fire and its management.

	Expenditures	Loss of Value
Direct	**Suppression**	**Natural Resources**
	Evacuations, sheltering, and donations	**Structures and property**
		Utilities and infrastructure
		Loss of life and injuries
		Health impacts from fire and smoke
		Economic impacts during incidents
Indirect	**Ecology and landscape**	**Ecology and landscape**
	Ecological restoration and cleanup	*Atmospheric carbon emissions, loss of carbon stocks*
	Post-fire monitoring and assessment	*Loss of sequestration potential*
		Post-fire invasive species
		Lost wildlife and biodiversity
	Economics	**Economics**
	Increased insurance premiums or loss of coverage	*Forestry and natural resource industries*
	Mitigation Investments	*Recreation and tourism*
	Pre-planning, risk assessments, zoning efforts	*Other business activity*
	Evacuation routes, safe zones	*Labor markets*
	Defensible space and home hardening	*Lowered property values and tax bases*
	Fuel treatments	*Disrupted interstate and intercity commerce*
	Infrastructure and utility hardening	*Low recruitment/retention to fire agencies*
	Pre-emptive depowering	**Health, safety, and well-being**
	Training and preparedness	*Long-term air quality effects on public health*
		Long-term effects on mental health
		Long-term air quality effects on built assets
		Water supply
		Flooding, slides, and erosion

Source: Troy et al. (2022)

managers are charged with implementing a risk-based approach that must consider fire intensity, the likelihood of fire escape and spread, and potential consequences for resources and infrastructure (Bartuska & Wibbenmeyer, 2022). In assessing risks, managers draw on sophisticated fire-simulation models, which integrate data on topography, vegetation, and a range of potential weather scenarios. Managers then must weigh the potential risks against the potential benefits of allowing fire to play a supporting role—bearing in mind ecosystem health and the reduced risk of future fires.

Information on the costs of wildfires is commonly reduced to the sum of suppression costs and structure losses. Headwaters Economics (2018) reports that suppression costs account for about nine percent of total wildfire costs. The remaining costs include short- and long-term costs in the months and years following a wildfire. Troy et al. (2022) describe the full range of costs associated with wildfire in the Western United States (U.S.), and the policy implications of efforts to improve wildfire response and mitigation. Other costs relate to human health, water supply, transportation, cultural resources, recreation, aesthetics and non-use values (e.g., for habitat), and lost economic opportunity in local economies. These additional costs borne by society may be “massive in aggregate,” and Troy et al. (2022) present a comprehensive typology of the costs and losses of wildfire and its management (see Table 1). The typology includes three high-level categories: (I) Direct Costs, incurred directly during an incident; (ii) Indirect Costs — Losses, incurred after an incident but attributable to it; and (iii) Indirect Costs — Mitigation Investments, expenditures that would reduce the incidence of and damage from future catastrophic fire. These mitigation costs may be overlooked because they are more difficult to quantify and their linkage to a wildfire event may be indirect.

Headwaters Economics (2018) reviewed the literature on community costs of wildfire and concluded that nearly half of the community costs of wildfire are paid for at the local level by homeowners, businesses, and government agencies. They find that many of these costs relate to long-term damages to community and environmental services, landscape rehabilitation, lost business and tax revenues, and property and infrastructure repairs.

The Federal government is responsible for wildfires that begin on Federal lands (CRS, 2022). The Department of the Interior (DOI) manages wildfire response for more than 400 million acres of national parks, wildlife refuges and preserves, other public lands, and Indian reservations. The U.S. Forest Service (USFS), within the U.S. Department of Agriculture (USDA), manages wildfire response across the 193 million acres of the National Forest System. Wildland fire and its management inherently involve economic costs, while also being ecologically and economically beneficial. For example, Zybach et al. (2009) report that USFS suppression costs account for only two to ten percent of total wildlfire-related costs and losses. USFS spent $3.7 billion on suppression in 2021 (NIFC, 2022), which, following Zybach et al. (2009), implies non-suppression related costs in the range of $37 billion to $185 billion for 2021. This comparison highlights the enormity of fire-related losses of valuable property and resources relative to management costs.

States are responsible for suppressing wildfires on non-Federal (State, local, and private) lands, although the response may be managed jointly for comingled Federal and non-Federal lands. Many States have partnerships with Federal agencies to provide wildfire suppression services through cooperative fire-protection agreements. States also may request assistance from the Federal Emergency Management Agency (FEMA) for wildfires that begin on State or private lands (CRS, 2022).

Public-land managers use various strategies and actions for managing landscape conditions that can affect wildfire. Broadly speaking, this includes fuels treatments (and other pre-fire risk mitigation), fire suppression, and post-fire landscape rehabilitation. With any of these strategies there is considerable uncertainty in the outcomes that managers can obtain, and thus in the societal costs and benefits associated with the specific management actions (Simon et al., 2022). Nevertheless, investing in risk management in the near term has the potential to mitigate future wildfire disasters (Calkin et al., 2014).

To better understand the economics of wildfire and its relationship to DOI, we examined the estimated annual spending on and economic burden of wildfire in the United States. Economists use analytical techniques to inform WFM, including determining the resources to allocate to WFM in general, and how to allocate these resources among specific WFM activities (Gorte & Gorte, 1979).

Table 1 provides a comprehensive view of the costs of wildfire (Troy et al., 2022). In this report we take a more targeted approach to synthesizing economic categories, while recognizing the broad range of potential impacts. Drawing on academic literature, research reports, and other publications that have examined the costs and benefits of WFM and wildfire containment, we address four guiding questions:

1. What are the **monetary costs** of wildfire on various asset categories, such as loss of property, loss of life, healthcare costs, costs of evacuation, etc.? We discuss categories of costs that can be valued based on expenditures, replacement costs, value of a disability-adjusted life year, etc.
2. What are the **non-market impacts** of wildfire, including to human well-being and ecosystem services? Effects to ecosystem services may be positive (e.g., maintaining fire-dependent ecosystems), neutral, or negative (e.g., introducing invasive species or habitat loss).
3. What have been the **investments and expenditures** in WFM over time?
4. What are the **costs specific to the Department of the Interior**?

Monetary costs

First, we summarize costs from property losses and damages to human health. The National Institute of Standards and Technology carried out a comprehensive estimate of the economic burden of wildfires on the U.S. economy (Thomas et al., 2017). The economic burden includes wildfire-induced damages and losses as well as the management costs to suppress and mitigate ignitions and fire spread. The annualized burden was estimated to be between $71 billion and $348 billion in 2016 dollars ($87 billion to $424 billion in 2022 dollars).[3] These estimates can be used for C+NVC (cost plus net value change) modeling and can also be used to produce an estimate of the "economic burden" of wildfire for the United States (Donovan and Rideout 2003). The economic burden represents the impact wildfire has on the U.S. economy and could be used to assess return on investment of wildfire interventions.

The economic burden is decomposed into (i) intervention costs; (ii) prevention, preparedness, mitigation, and suppression costs; and (iii) direct and indirect wildfire-related (net) losses. Other studies have used information on insurance losses to show broader National-level trends. For example, the Allianz Group and World Wildlife Fund (2006) reported $6.5 billion in insured losses related to catastrophic wildfire in the United States from 1970 to 2004.

Wildfire has resulted in significant loss of property and lives in the United States, and California leads the States in terms of fire costs. The Insurance Information Institute (2021) reports that ten of the costliest wildfires in U.S. history have occurred in California. This is due in part to the large human populations in California's Wildland-Urban Interface (WUI), combined with the State's fire-prone climate and vegetation conditions. In 2008, the California Department of Forestry and Fire Protection recorded property worth over $105 billion in high-risk wildfire areas. From 1997 through 2007, wildfire-related insurance losses in California averaged approximately $490 million annually (Grossi, 2008).

WUI residents can improve the probability of structures and people surviving a wildfire by undertaking suitable preparation (Penman et al., 2016). A relatively small proportion of WUI residents adequately prepare for wildfire, citing monetary and time costs as significant impediments. Nevertheless, relatively few studies have quantified the monetary and time costs for residents to prepare.

Along with the property costs, human health and well-being is impacted by wildfire. In evaluating the benefits and costs associated with health effects, the U.S. Environmental Protection Agency (EPA) has used a value of $7.4 million (in 2006 dollars, equivalent to $9.0 billion in 2022 dollars) for the value of a "statistical life" (U.S. EPA, 2010).[4] Mason et al. (2006) report an average of 4.8 deaths per million acres of wildfires over the 1990s. They estimate that if fuel removals could avoid the high-intensity fires that caused these deaths, the value of avoided fatalities would range from $5 to $10 per acre over a 30- to 60-year period, depending on each area's risk of burning (Mason et al., 2006). This is equivalent to $7 to $15 per acre in 2022 dollars. Given changes in fire regimes since that publication, new studies (e.g., from EPA) could provide updated estimates.

A major impact of wildfires on human health is exposure to smoke. Cullen (2020) studied California fires from 2012 to 2018 and found that an additional day of wildfire smoke led to over twelve hospital admissions for respiratory or circulatory issues, with associated medical costs of about $189,000 (2020 dollars, equivalent to about $213,000 in 2022 dollars). The average annual cost of wild-fire smoke exposure in California was $192 million (2020 dollars, $217 million in 2022 dollars), making up 0.07 percent of California's annual health-care spending. The total cost over the 2012-2018 study period was $1.3 billion for California alone (2020 dollars, $1.5 billion in 2022 dollars).

[3] The ranges of economic costs and losses represent estimates of a five-year low economic burden to a five-year high economic burden. Estimates vary by frequency, intensity, and severity.

[4] As of March 14, 2023, this amount remains EPA's default guidance for valuing mortality risk changes. https://www.epa.gov/environmental-economics/mortality-risk-valuation#whatisvsl

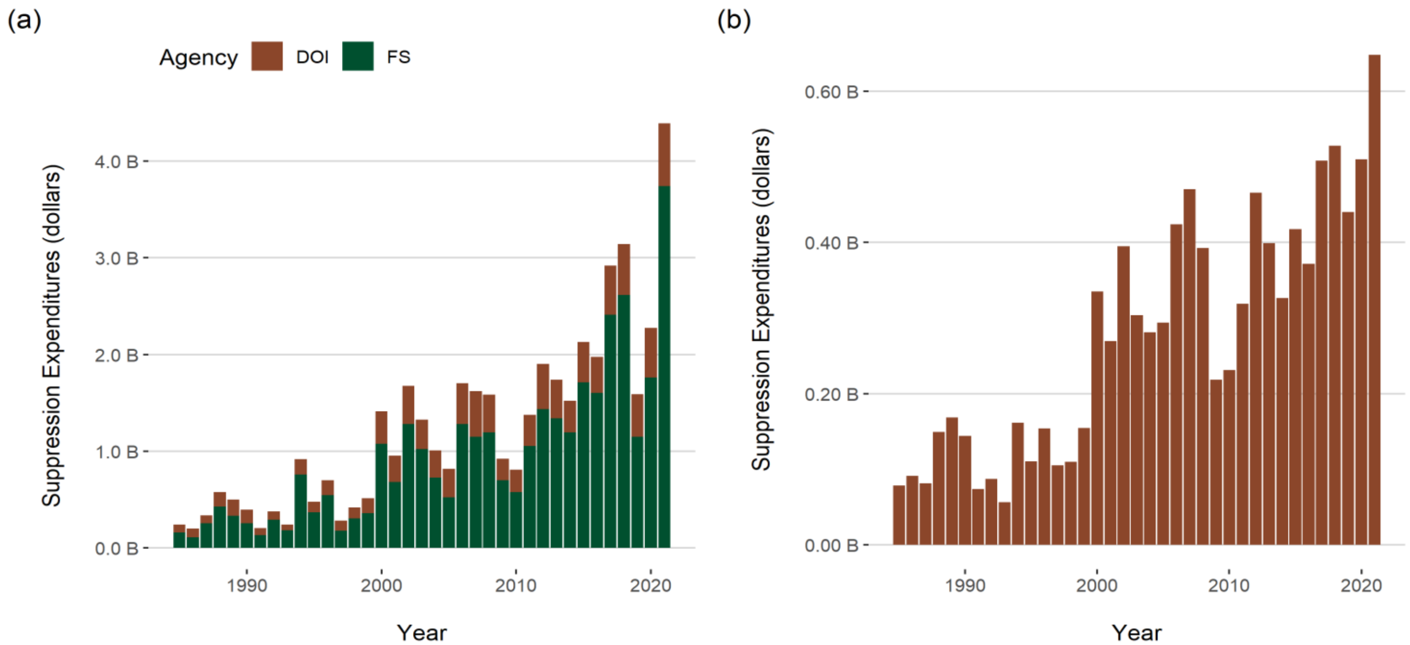

Figure 1. Federal expenditures on wildland fire suppression—(a) USFS plus DOI and (b) DOI alone—have increased steadily over the past three decades. Spending by the U.S. Forest Service (Department of Agriculture, green) accounts for most ($\bar{x}$ = 74%) Federal fire suppression expenditures, followed by the Department of the Interior (brown). Source: National Interagency Fire Center data, https://www.nifc.gov/fire-information/statistics/suppression-costs.

Richardson et al. (2012) studied the economic cost of health effects of exposure to smoke from the largest wildfire in the modern history of Los Angeles County, California, estimating an average cost of nearly $10 per exposed person per day ($12 in 2022 dollars). These costs likely underestimate the welfare effects of illness. They estimated willingness to pay to avoid one smoke-induced symptom-day at over $84 per person ($110 in 2022 dollars), about nine times higher than the per-day cost of illness. Kochi et al. (2016) studied the economic costs of morbidity from wildfires in southern California in 2007, finding excess admissions to hospitals and emergency rooms related to respiratory and cardiovascular issues with associated medical costs exceeding $3.4 million (about $4.2 million in 2022 dollars). Wildfires that occur in locations far from large population centers typically have smaller air-quality and health impacts than larger fires near population centers (U.S. EPA, 2021). Updated data may allow us to improve these estimates, and clarify the effects on various subgroups (e.g., lower-income populations).

Exposure to smoke during pregnancy has been found to be associated with higher rates of pre-term birth (Heft-Neal et al., 2022). An estimated 6,974 excess preterm births were attributable to wildfire smoke exposure in 2007-2012 in California, accounting for 3.7 percent of observed preterm births during this period. Results suggest that each additional day of exposure to wildfire smoke during pregnancy was associated with a 0.49 percent increase in risk of preterm birth (<37 weeks) or a 3.4 percent increase in risk, relative to an unexposed mother. This research has important implications for understanding the costs of increasingly frequent wildfire smoke exposure, and for understanding the benefits of smoke-mitigation measures.

While property and health costs of wildfire have received much of the focus in the literature, numerous other categories of monetary costs and losses from wildfires are more difficult to quantify. These include the costs of treatment for psychological effects, the costs of evacuating people from affected areas, agricultural losses attributed directly to wildfire, costs of service interruption, and others. Challenges to overcome include lack of data, methodological barriers, and gaps in knowledge about valuation and the drivers of damages.

Non-market impacts

Non-market impacts are related to outcomes that are not reflected in market prices, as is the case for many natural resources and ecosystem services. Consequently, non-market benefits and costs are not directly observed and are often not considered in decision-making or policy-making. Non-market impacts often arise in the context of public goods, such as environmental quality and public lands. Lands and waters managed by DOI encompass many resources that cannot easily be valued using market prices, such as conservation areas, critical habitat for threatened and endangered species, Class I airsheds, recreation areas, Tribal lands and resources, and cultural resources. WFM generates non-market impacts that vary by the scale, scope, and intensity of the actions and particular wildfires. Since these values are not reflected in market prices, it can be difficult to quantify the related benefits and costs.

Decision-making in WFM is often focused on risk, or the negative impacts of fire. However, fire can also produce benefits, particularly in fire-adapted and fire-dependent ecosystems. Wildfires can contribute to habitat diversity by creating new habitat, such as open habitats that benefit shade-intolerant plants and animals. It can also increase habitat heterogeneity (Pausas & Keeley, 2019), which may benefit generalist species that use a wide variety of habitats. Wildfire can increase water yields by reducing the amount of woody vegetation that would have otherwise consumed water, increasing water availability in wells and springs. Forest clearings created by fires can allow for deeper winter snowpacks, which melt later in the spring and release water more slowly throughout the spring and summer (Pausas & Keeley, 2019). And fires remove accumulated surface fuels, reducing the probability of large, catastrophic fires.

Wildfire can be seen as an ecosystem service in and of itself, such as in the examples provided above. It can also be seen as a natural process that affects the services of a particular ecosystem. For example, the annual flow of services from a forest ecosystem could include timber production, recreation, hunting, scenery, habitat, clean freshwater, and carbon sequestration. Fires can increase or decrease those services, and the magnitude and direction of fire's impacts on those services can change over time. For example, recreation can be negatively affected in the immediate aftermath of a fire, but a forest recovery process that includes a showy rebirth of wildflowers can create a new stream of recreation benefits (Kline, 2004). Similarly, some visitors may seek out the unusual sight of a burned landscape. Wildfires in grassland and shrubland ecosystems can have similar impacts on the provision of services.

Wildfires that exceed the historic frequency, intensity, and severity of an ecosystem's wildfire regime can result in long-term ecosystem service losses if they create situations where habitat recovery is hampered or otherwise diminished. For example, wildland fire (even managed fire) can leave landscapes exposed and vulnerable to mudslides where vegetation no longer holds soils in place.

Taking carbon storage as another example, catastrophic fires can shift forest, sage-steppe, peatland, and taiga/tundra/permafrost ecosystems from sinks to sources of atmospheric carbon. This can result in a positive climate feedback loop in which increased GHG emissions contribute to climate change and further increase wildfire risk. For example, coniferous forests are important for carbon sequestration, holding more than one-third of all carbon stored on land (Venn & Calkin, 2011). Over the decades following a fire, decomposition of burned vegetation can release up to three times as much carbon as that lost in the initial combustion (Frame, 2010). If the forest regenerates, carbon storage in the ecosystem increases, eventually allowing the ecosystem to become a carbon sink again, rather than a source. The ability of the forest to regenerate is critical to maintaining this service; forests that are badly damaged may lose this ability permanently. Regeneration is particularly critical in fire-prone grassland and shrubland ecosystems (Newman et al., 2018). Increased documentation is improving our understanding of this effect., and this area of research is evolving rapidly; see e.g., Jerrett et al., 2022 (Box 1).

Table 2. Appropriations for the Department of the Interior Wildland Fire Management, 2018-2023 ($ thousands, not adjusted for inflation) have increased steadily since 2018 and include several sources in addition to regular annual appropriations.

Appropriation	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023 (Request)
Wildland Fire Management account*	$948,087	$941,211	$952,338	$992,622	$1,026,097	$1,199,630
Suppression Operations Reserve Fund			300,000	310,000	330,000	340,000
Supplemental Suppression Funding	50,000					
Disaster Relief Funding					100,000	346,000
Bipartisan Infrastructure Law Funding*					407,600	262,600
Total Appropriated Funding	**998,087**	**941,211**	**1,252,338**	**1,302,622**	**1,863,697**	**2,148,230**
% Change from Prior Year (all funding)		-6%	33%	4%	43%	15%
% Change 2018 to 2022 (all funding)					87%	
% Change 2018 to 2022 (annual appropriations only)					43%	

* Does not include funding transfers.
Source: https://www.doi.gov/wildlandfire/budget

Expenditures on WFM

Federal expenditures on WFM are substantial; suppression costs alone have exceeded $1 billion annually in most years since 2000 (Figure 1). WFM costs for both agencies have risen dramatically in recent decades, with average annual expenditures exceeding $3 billion in the 2000s and 2010s. USFS activities have accounted for 60 to 80 percent of this spending since the 1980s, with USFS spending increasing more than DOI spending in recent years.

In addition to Federal spending on WFM activities such as suppresion, FEMA provides assistance to state, local, Tribal and territorial governments to help with mitigation, management, and control of fires. FEMA coordinates across Federal agencies to help State, local, Tribal, and territorial partners respond to wildfires nationwide. We found no National-level estimates of State, Tribal, or private spending on wildfire suppression.

While these high-level expenditure data for wildfire suppression are generally available, we found no disaggregated data on mitigation, suppression, fuels management, burned area rehabilitation, preparedness, facilities, or research. *Suppression* and *rehabilitation* expenditures are related to responding to or recovering from wildfires, and *fuels management* is targeted in specific areas to reduce the risk of potential wildfires. *Preparedness* covers readiness and response; spending on *facilities* provides infrastructure support for WFM; and *research* expenditures improve our understanding of wildfire and how to manage it. New investments will be needed to collect, manage, and use disaggregated data to advance policy and program management needs.

Costs to the Department of the Interior

Total appropriations for DOI WFM more than doubled between 2018 and 2022, including supplemental funding such

Box 1: Wildfire and greenhouse gas emissions

Jerrett et al. (2022) analyzed California's 2020 wildfire season, the State's most disastrous wildfire year on record, estimating that wildfires emitted 127 million metric tons (mmt) of CO_2-e (carbon dioxide equivalent) that year—seven times the 2003–2019 mean. This level of emissions is double California's total greenhouse gas (GHG) emissions reductions, and would account nearly half of the State's 2030 total GHG emissions target of 260 mmt CO_2-e. A comparison of sectoral GHG emissions in 2019 showed that wildfires were the second-largest source in the State (after transportation), exceeding industrial and electrical power generation. Results for the entire United States are not available as of this writing.

Table 3. Department of the Interior Wildland Fire Management appropriations by activity or sub-activity, 2018-2023 ($ thousands, not adjusted for inflation).

Appropriation	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023 (Request)
Preparedness*	$332,784	$322,179	$332,784	$347,105	$370,543	$477,159
Suppression Operations*	389,406	388,135	383,657	383,657	383,657	383,657
Fuels Management*	184,000	189,000	194,000	219,964	227,000	304,344
Burned Area Rehabilitation (BAR)	20,470	20,470	20,470	20,470	22,470	20,470
Fire Facilities	18,427	18,427	18,427	18,427	18,427	10,000
Joint Fire Science Program (JFSP)	3,000	3,000	3,000	3,000	4,000	4,000
Wildland Fire Management account*	**948,087**	**941,211**	**952,338**	**992,623**	**1,026,097**	**1,199,630**
Suppression Reserve Funding			300,000	310,000	330,000	340,000
Suppression Supplemental Funding	50,000					
Disaster Relief Funding (several activities/sub-activities)					100,000	346,000
Bipartisan Infrastructure Law Funding* (several activities/subactivities)					407,600	262,600
Total Appropriated Funding	**998,087**	**941,211**	**1,252,338**	**1,302,623**	**1,863,697**	**2,148,230**
% Change from Prior Year (all funding)		-6%	33%	4%	43%	15%
Fuels Management as a % of WFM	19%	20%	20%	22%	22%	25%

* Does not include funding transfers.
Source: https://www.doi.gov/bpp/budget-briefs

as from the 2022 Bipartisan Infrastructure Law and 2022 disaster relief supplemental funding (Table 2). The Wildfire Suppression Operations Reserve Fund provides additional funding for emergency wildfire response and suppression when needed (up to $330 million for FY 2022). These increases reflect the growing challenges related to WFM in an era of increasing wildfire frequency and intensity, particularly in the Western United States.

Considering appropriations by program activity or sub-activity (see Table 3) shows that Suppression and Preparedness have traditionally been the activities for which DOI receives the most funding in annual appropriations. However, in recent years, funding for fuels management has received an increasing share of annual appropriations, from 19 percent in FY 2018 to 25 percent in the FY 2023 request. In addition, the 2022 disaster relief supplemental funding ($100 million total) was for fuels management ($55 million) and burned area rehabilitation ($45 million). Bipartisan Infrastructure Law appropriations include about $1.5 billion for DOI's WFM over 2022-2026 (to be coordinated with USFS, who will receive an additional $3.5 billion). 60 percent of DOI's portion ($878 million) is for fuels management, and 22 percent ($325 million) is for burned area rehabilitation, while the rest of the funding will fund workforce improvements ($164 million), technology and equipment ($72 million), and supporting science ($10 million).[5] To provide context for these amounts, in FY 2021, DOI spent $220 million to treat fuels on 1.9 million acres.[6]

Conclusions

Wildland fire is a natural phenomenon and one that is essential to many ecosystems, yet it can impose costs on society. The number, extent, and intensity of wildfires has increased in recent decades, leading to significant damage to ecosystems, regional evacuations, property destruction, and deaths.

[5] https://www.doi.gov/wildlandfire/meet-bil-how-bipartisan-infrastructure-law-supports-wildland-fire-management

[6] www.doi.gov/wildlandfire/fuels

In our rapid review of the recent literature, we found an incomplete picture of the costs and benefits of wildfire and WFM (and how those costs are distributed across various populations), yet we can draw several conclusions. First, the monetary costs and losses from wildfire in the United States are very large, on the order of tens to hundreds of billions of dollars per year. We found scant information on non-market impacts of wildfire, but these potentially include large losses of valuable ecosystem services such as carbon storage, habitat provision, and climate regulation (Venn & Calkin, 2011; Jerrett et al., 2022). Even without a complete accounting, costs and losses related to wildfire are much larger than WFM spending by the Federal government, including DOI. We conclude that ongoing additional investments in building DOI's WFM workforce capacity and capabilities could be a cost-effective way to reduce society's losses associated with catastrophic wildfire.

Society would benefit from a more complete understanding of the connections among workforce capacity, other aspects of WFM, human health and safety, and ecosystem health. This requires investments to develop reliable data sources (and systems to collect, analyze, and store data) on the direct and indirect monetary costs and non-monetized effects of wildland fire as well as expenditures across the full range of WFM activities. With such data and systems, economists, policy experts, and practitioners would be able to link natural systems—fire and ecosystem dynamics—with the Nation's governance and budgetary systems to better manage our relationship with wildland fire.

Methods

We conducted a literature review to compile insights and data related to the core question, "What are the estimated annual investments in and costs of wildland fire in the United States?" Appendix B presents our review plan. In brief, we searched Google Scholar using the terms:

1. "wildland fire" OR "wildfire" AND "economics"
2. "wildland fire" OR "wildfire" AND "costs"
3. "wildland fire" OR "wildfire" AND "benefits"
4. "wildland fire" OR "wildfire" AND "ecosystem services"

We also compiled data from the websites of Federal agencies and from the National Interagency Fire Center. The results were supplemented with personal communications with other wildland fire experts. We restricted our search geography to the United States and focused on research from 2013 to the present. We developed a plan for organizing and storing data extracted from the literature but found the data too sparse to warrant such a structure.

The data used to generate figures for this report, associated R scripts, and copies of papers and reports referenced here are archived at https://doi.gov/ppa.

Acknowledgements

We thank staff at DOI's Office of Wildland Fire (OWF), the U.S. Geological Survey (DOI) and Forest Service (U.S. Department of Agriculture) for helpful peer review of earlier drafts of this *Report*.

References

Allianz Group & World Wildlife Fund. (2006). Climate Change and Insurance: An Agenda for Action in the United States. Prepared by Anderson, M., Dobardzic, S., and Gardiner, D. David Gardiner & Associates, LLC. Arlington, VA. https://wwfint.awsassets.panda.org/downloads/allianz_wwf_climate_change_and_insurance_embargoed_oct_2006.pdf

Barrett, T. M., & Robertson, G. C. (2021). Disturbance and sustainability in forests of the Western United States. Gen. Tech. Rep. PNW-GTR-992. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 231 p.

Bartuska, A., & Wibbenmeyer, M. (2022). Managed Fires Can Help Mitigate the Risks Posed by Increasing Frequency of Wildfires. Washington, DC: Resources for the Future. https://www.resources.org/common-resources/managed-fires-can-help-mitigate-the-risks-posed-by-increasing-frequency-of-wildfires/

Burke, M., Driscoll, A., Heft-Neal, S., Xue, J., Burney, J., and Wara, M. (2021). The changing risk and burden of wildfire in the United States. *Proceedings of the National Academy of Sciences,* 118, e2011048118. https://doi.org/10.1073/pnas.2011048118

Calkin, D. E., Cohen, J. D., Finney, M. A., and Thompson, M. P. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proceedings of the National Academies of Science*, 111 (2), 746–751. DOI:10.1073/pnas.1315088111

CRS (Congressional Research Service). (2022). Federal Assistance for Wildfire Response and Recovery. CRS Report. Washington, DC: Congressional Research Service. https://crsreports.congress.gov/product/pdf/IF/IF10732

Cullen, D. (2020). *The Health Cost of Wildfire Smoke*. Unpublished study from doctoral dissertation. Santa Barbara, CA: University of California, Santa Barbara.

Dennison, P. E., Brewer, S. C., Arnold, J. D., & Moritz, M. A. (2014). Large wildfire trends in the western United States, 1984–2011. *Geophysical Research Letters*, 41, 8, 2928-2933. https://doi.org/10.1002/2014GL059576

Di Virgilio, G., J.P. Evans, S.A.P. Blake, M. Armstrong, A.J. Dowdy, J. Sharples, and R. McRae. (2019). "Climate Change Increases the Potential for Extreme Wildfires." *Geophysical Research Letters,* 46, 14, 8517–26. https://doi.org/10.1029/2019GL083699

Donovan, G. H., and D. B. Rideout. 2003. A reformulation of the cost plus net value change (C+NVC) model of wildfire economics. *Forest Science*, 49, 2, 318-323. https://doi.org/10.1093/forestscience/49.2.318

Fell, J. M., C. N. Davis, and R. M.Crandall. (2019). Climate change lengtchens southeastern USA lightning-ignited fire seasons. *Global Change Biology,* 25, 10, 3562-3569. https://doi.org/10.1111/gcb.14727

Frame, C. (2010). Sink or source? Fire and the forest carbon cycle. *JFSP Briefs Fire Science Brief, 86*. https://digitalcommons.unl.edu/jfspbriefs/44/

Gorte, J. K., & Gorte, R. W. (1979). Application of economic techniques to fire management: A status review and evaluation. Ogden, UT: U.S. Forest Service, Intermountain Forest and Range Experiment Station.

Grossi, P. (2008). The 2007 U.S. Wildfire Season: Lessons from Southern California. Newark, CA: Risk Management Solutions, Inc. https://forms2.rms.com/rs/729-DJX-565/images/wf_2007_us_wildfire_season.pdf

Headwaters Economics. (2018). Full Community Costs of Wildfire. Bozeman, Montana: Headwaters Economics. https://headwaterseconomics.org/wildfire/homes-risk/full-community-costs-of-wildfire/

Heft-Neal, S., Driscoll, A., Yang, W., Shaw, G., & Burke, M. (2022). Associations between wildfire smoke exposure during pregnancy and risk of preterm birth in California. *Environmental Research*, *203*, 111872. https://doi.org/10.1016/j.envres.2021.111872

Insurance Information Institute. (2021). Facts + Statistics: Wildfires. New York: Insurance Information Institute. https://www.iii.org/fact-statistic/facts-statistics-wildfires

Jerrett, M., Jina, A. S., & Marlier, M. E. (2022). Up in smoke: California's greenhouse gas reductions could be wiped out by 2020 wildfires. *Environmental Pollution, 310,* 119888. https://doi.org/10.1016/j.envpol.2022.119888

Jolly, W. M., Cochrane, M. A., Freeborn, P. H., Holden, Z. A., Brown, T. J., Williamson, G. J., & Bowman, D. M. (2015). Climate-induced variations in global wildfire danger from 1979 to 2013. *Nature Communications*, 6(1), 1-11. https://doi.org/10.1038/ncomms8537

Kline, J. D. (2004). Issues in evaluating the costs and benefits of fuel treatments to reduce wildfire in the Nation's forests. Res. Note PNW-RN-542. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 46 p.

Kochi, I., Champ, P. A., Loomis, J. B., & Donovan, G. H. (2016). Valuing morbidity effects of wildfire smoke exposure from the 2007 southern California wildfires. *Journal of Forest Economics* 25, 29–54. https://doi.org/10.1016/j.jfe.2016.07.002

Lotan, J. E., Brown, J. K., & Neuenschwander, L. F. (1985). Role of fire in lodgepole pine forests. Lodgepole pine: the species and its management. Cooperative Extension Service, Washington State University, Pullman, 133-152.

Mason, C. L., Lippke, B. R. Zobrist, K. W., Bloxton Jr., T. D., Ceder, K. R., Comnick, J. M., McCarter, J. B., & Rogers, H. K. (2006). Investments in Fuel Removals to Avoid Forest Fires Result in Substantial Benefits. *Journal of Forestry* 104:1, 27–31, https://doi.org/10.1093/jof/104.1.27 .

Miller, C., Landres, P. B., & Alaback, P. B. (2000). Evaluating risks and benefits of wildland fire at landscape scales. In

Neuenschwander, Leon F.; Ryan, Kevin C., tech. eds. Crossing the millennium: Integrating spatial technologies and ecological principles for a new age in fire management: Proceedings, Joint Fire Sciences conference and workshop; June 15-17, 1999, Boise, ID. Boise, ID: U. of Idaho. https://srs.fs.usda.gov/pubs/23564

NIFC (National Interagency Fire Center). (2022). Total Wildland Fires and Acres (1983-2021). https:// www.nifc.gov/fire-information/statistics/wildfires

Newman, E. A., Potts, J. B., Tingley, M. W., Vaughn, C., & Stephens, S. L. (2018). Chaparral bird community responses to prescribed fire and shrub removal in three management seasons. *Journal of Applied Ecology*, *55*(4), 1615-1625. https://doi.org/10.1111/1365-2664.13099

Pausas, J. G., & Keeley, J. E. (2019). Wildfires as an ecosystem service. *Frontiers in Ecology and the Environment*, 17, 5, 289-295. https://doi.org/10.1002/fee.2044

Penman, T. D., Eriksen, C. E., Horsey, B., & Bradstock, R. A. (2016). How much does it cost residents to prepare their property for wildfire?. *International Journal of Disaster Risk Reduction*, 16, 88-98. https://doi.org/10.1016/j.ijdrr.2016.01.012

Rhoades, C. C., Nunes, J. P., Silins, U., & Doerr, S. H. (2019). The influence of wildfire on water quality and watershed processes: New insights and remaining challenges. *International Journal of Wildland Fire*, 28, 10, 721-725. https://doi.org/10.1071/WFv28n10_FO

Richardson, L. A., P. A. Champ, and J. B. Loomis. (2012). The hidden cost of wildfires: Economic valuation of health effects of wildfire smoke exposure in southern California. *Journal of Forest Economics*, 18, 1, 14-35. https://doi.org/10.1016/j.jfe.2011.05.002

Simon, B., Crowley, C., & Franco, F. (2022). The costs and costs avoided from wildfire fire management—A conceptual framework for a value of information analysis. *Frontiers in Environmental Science*, *10*, 804958. https://doi.org/10.3389/fenvs.2022.804958

Thomas, D., Butry, D., Gilbert, S., Webb, D., & Fung, J. (2017). The costs and losses of wildfires: A literature review. NIST Special Publication 1215. Gaithersburg, MD: National Institute of Standards and Technology. https://doi.org/10.6028/NIST.SP.1215

Troy, A., Pusina, T., Romsos, S., Moghaddas, J., & Buchholz, T. (2022). The True Cost of Wildfire in the Western U.S. Western Forestry Leadership Coalition. https://www.thewflc.org/sites/default/files/TrueCostofWildfire.pdf

U.S. EPA (Environmental Protection Agency). (2010). *Guidelines for Preparing Economic Analyses*, Appendix B: Mortality Risk Valuation Estimates. Washington, DC: National Center for Environmental Economics, Office of Policy, U.S. Environmental Protection Agency.

U.S. EPA (Environmental Protection Agency). (2021). Comparative Assessment of the Impacts of Prescribed Fire Versus Wildfire (CAIF): A Case Study in the Western U.S. EPA/600/R-21/197. Washington, DC: U.S. Environmental Protection Agency.

U.S. DOI (Department of the Interior). (2021). Fiscal Year 2022 The Interior Budget in Brief. Washington, DC: U.S. Department of the Interior. https://www.doi.gov/sites/doi.gov/files/2022-highlights-book.pdf

Venn, T. J., & Calkin, D. E. (2011). Accommodating non-market values in evaluation of wildfire management in the United States: challenges and opportunities. *International Journal of Wildland Fire*, 20, 3, 327-339. https://doi.org/10.1071/WF09095

Zybach, B., Dubraisch, M., Brenner, G., & Marker, J. (2009). U.S. wildfire cost-plus-loss economics project: the "One-Pager" checklist. Wildland Fire Lessons Learned Center. http://www.wildfire-economics.org/Library/Zybach_et_al_2009a.pdf

Appendix A. A brief overview of wildland fire

Fire is a natural phenomenon that plays a necessary role in ecosystems. Periodic low-intensity fires speed up the process of forest decomposition, create open patches for new plants to grow, improve habitat and food for animals, and improve nutrient availability for plants. These fires build ecosystem resilience to large and high-intensity fires by reducing fuel loads, and create a mosaic of burned, partially burned, and unburned areas. Some trees and ecosystems depend on fire for their natural function, such as lodgepole pine (*Pinus contorta*; Lotan et al., 1985). Some fires may improve groundwater recharge and water flow to aquatic habitats and improve other ecosystem functions. Wildfires with the right characteristics are a beneficial part of these ecosystems, while wildfires with different characteristics (e.g., higher intensity, frequency, or extent) may be harmful (Jolly et al., 2015).

While wildland fire is a natural phenomenon, its characteristics have changed dramatically over the past four decades. For example, during this time the extent of wildland fires in the United States has increased steadily (Figure A1). Though extensive data on fire intensity are lacking, observations suggest the intensity of wildland fires in the United States (and around the world) has increased dramatically in recent decades. These changes in wildfire size and intensity may be the results of various stressors, like:

- Climate change, as many lands become warmer and drier and the growing season lengthens (Di Virgilio et al., 2019; Fell et al., 2019);
- An increase in the WUI, where human development meets undeveloped wildland (U.S. EPA, 2021), which is growing by two million acres per year (U.S. DOI, 2021) and one million houses every three years (Burke et al. 2021);
- Invasive species, with infestations weakening or killing trees, or with flammable species (e.g., cheatgrass) displacing fire-adapted native vegetation (Barrett & Robertson, 2021); and
- Build-up of fuels from decades of fire suppression (Dennison et al., 2014; Miller et al., 2000).

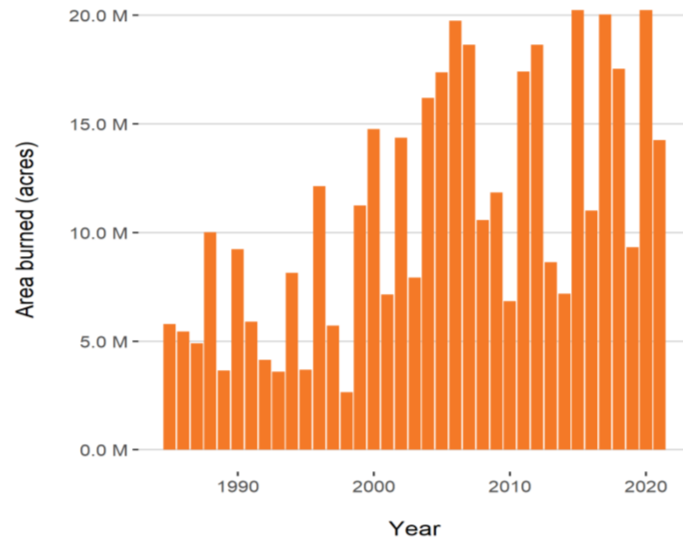

Figure A1. The extent (acres per year) of wildland fire in the United States has increased over the past four decades. This increase is attributable to drivers including climate change, the consequences of decades of fire suppression, invasive species, and the expansion of the wildland-urban interface. Measures of fire extent do not capture the intensity of wildland fire, which observationally has been increasing over this time as well. Source: National Interagency Coordination Center data (https://www.nifc.gov/fire-information/statistics/wildfires).

These uncharacteristic wildfires can cause significant damage fundamentally different from the effects of natural fire regimes. For example, they can damage animal and plant habitats, decrease water quality and quantity, and in some instances, create conditions leading to increased overland water flow and flooding (Rhoades et al., 2019). At the same time, the combination of the growth of wildland fire extent and intensity and the rapid expansion of the WUI mean that American communities are increasingly exposed to wildfires that harm lives, infrastructure, and property.

Because of its power to shape landscapes, landowners, government agencies, and Indigenous land managers use fire to achieve specific land management outcomes. These may include returning nutrients to the soil, managing watersheds and habitat (for wildlife, plants, and other organisms), clearing brush and detritus, and managing wildfire intensity and severity (U.S. EPA, 2021). The methods of managing fire are often broken down among the major categories including fuels management before or during fires; suppression of active fires; and recovery and rehabilitation post-fire (see Troy et al., 2022).

Appendix B. Literature Review Protocol

Rationale

This review will provide a rapid survey and summary of current knowledge about benefits and costs of wildland fire, as a reference for practitioners, and to provide context for non-practitioners, e.g., for reviewing budget requests.

The near-term products are a 2,500- to 3,000-word report on (1) the benefits and costs of wildland fire, (2) investments required to reduce catastrophic wildland fire, and (3) information needs to improve wildland fire management outcomes, followed by a final draft and a 2-page brief of the review. Longer-term products could include expanded and targeted versions of the near-term products, and could involve registering this protocol e.g., with PROSPERO.

Research Questions

What are the estimated annual investments in and costs of wildland fire in the United States?

1. What are the **monetizable effects** on various categories of assets, such as loss of property, loss of life, healthcare costs, costs of evacuation, etc.? We seek to develop a typology of costs that can be valued based on out-of-pocket expenses, replacement costs, value of a disability-adjusted life year, etc.
2. What are the **investments and expenditures** in wildland fire management across the temporal sequence (i.e., fuels management applied before and during a fire, suppression, response, and post-fire recovery/rehabilitation)?
3. What are the non-market **welfare impacts**, including ecosystem services, of wildland fire? Note that effects to ecosystem services could be positive (e.g., fire-dependent ponderosa pine forests) or negative (conversion of landcover resulting in suboptimal fire intensity, frequency, or return intervals).
4. What are the costs specifically to the Department of the Interior?

Desired Outputs

We will summarize and survey available research and information to provide general insights. A 2,500- to 3,000-word *PPA Report*, excluding word counts for references and supplemental information, will use the *PPA Report* template. There will be a 2-page *PPA Brief* using the template.

Database Queries

The queries proposed below may be refined to restrict and better target search results. For example, to exclude studies of wildland fire's benefits to agricultural forestry, subjective impressions of wildland fire, or with a different interpretation of costs or benefits.

1. "wildland fire" OR "wildfire" AND "economics"
2. "wildland fire" OR "wildfire" AND "costs"
3. "wildland fire" OR "wildfire" AND "benefits"
4. "wildland fire" OR "wildfire" AND "ecosystem services"
5. Geographic restrictions for US areas could include "United States" OR "Alaska" OR "Hawaii" OR "U.S. Territories" OR "Minor Outlying Islands" OR "Guam" OR "Puerto Rico" OR "Virgin Islands"

Databases to Search

The databases to be queried to carry out this rapid systematic review are:

1. Tier 1 (we limit our search for the immediate product):
    a. Google Scholar
    b. Personal communication or best professional judgment, like "expert elicitations"
        i. Data sources
        ii. NIFC website
        iii. Reports
2. Tier 2 (future work could extend our search to additional resources):
    a. ISI Web of Science
    b. Semantic Scholar
    c. Science.gov
    d. EBSCO

e. Elsevier
f. US Forest Service Treesearch: https://www.fs.usda.gov/treesearch
g. Scopus: https://www.scopus.com/search/form.uri?display=basic#basic
h. EconLit: https://www.aeaweb.org/econlit
i. AgEconSearch: https://ageconsearch.umn.edu/?ln=en

Given time constraints, we will limit the depth of our search to the first page of search results.

Data Management

For the immediate tasks (2-page brief, and 5-page report), we'll assemble our resources in "Wildland Fire and Policy Analysis" Team's "Wildland Fire Budget Support" Channel, and a spreadsheet to document what we found, basic information, and how we use it.

In the future, we may develop a shared Zotero library (or similar, e.g., Mendeley, etc.) to collect, store, and share discovered studies and information document.

Study and Information Selection Criteria

The points below may be updated to reflect changes to the above portions of the protocol.

Research study inclusion criteria

1. Time range: last 10 years: (2013-present)
2. Geographic scope: Eastern US, Western US, and Alaska (future effort could expand to include all of North America, or other countries)
3. Language: English
4. Study quality: case study
   a. Due diligence of study completeness is apparent
   b. Data sources from reliable and reputable sources
      i. Peer-reviewed journal articles
      ii. Government agency reports
   c. Generalization and application of results are appropriate
   d. Discusses limitations
   e. Discusses uncertainties
   f. Recognizes potential biases
5. Study quality: sampled study, e.g., meta-analysis of costs (this may be outside the scope of the immediate task)
   a. Sample size adequate for reliable estimates given variance
   b. Data sources from reliable and reputable sources
   c. Estimation methods widely accepted in the field, or emerging methods that are well-founded
6. Frequency of citation in later work (this may not be outside the scope of the immediate task)
   a. Check scite.ai (requires paid membership) to check for supporting cites vs retractions or refutations

Data inclusion criteria

1. Official data from Federal, State, Tribal, or other sources (e.g., appropriations, expenditures)
2. Independently validated data (avoidance expenditures, health expenditures and impacts, insurance payouts)
3. Metrics sufficiently specific (e.g., dollar-year indicated)

Analytical Approach

Data extraction

Data to be extracted from the studies and information sources will depend on what we find, and may include:

1. Categories of costs and benefits
2. Amount Federal, State, Tribal, or other wildland fire funding / expenditure
3. Type of Federal, State, Tribal, or other wildland fire funding/expenditure
4. Sizes of wildland fires studied
5. Wildland fire attributes reported may include data like the following
   a. Geographical location

   b. Burn dates
   c. Intensity rating
   d. Location attributes (e.g., landcover, urbanization)
6. Types of outcomes evaluated may include data such as:
   a. Avoided costs
   b. Avoidance expenditures
   c. Mitigation costs (before or during a wildland fire), e.g., prescribed burning, mechanical thinning, hand thinning, mastication
   d. Direct suppression costs, e.g., aviation, engines, firefighting crews, and agency personnel
   e. Post-fire landscape rehabilitation costs
   f. Direct private property costs from damage to e.g., utility lines, recreation facilities, timber resources,
   g. Reduced private property values
   h. Aid to evacuated residents
   i. Number of people and homes evacuated
   j. Cost of illness and death
   k. Willingness to pay to avoid health impacts
   l. Lost or diminished willingness to pay for recreation
   m. Willingness to pay for fuels reduction and forest restoration

Data validation

Data validation is beyond the scope of the immediate task. For future work, we may apply a protocol like the following:

> Data for each study or source will be extracted by one member of the systematic review team and reviewed by another member independently. If a data point requires adjudication, a third team member will be consulted. Final disposition of inclusion / exclusion of a resource, or the value extracted from a resource, rests with the Chief Economist of Interior.

Statistics and graphics

If the literature and information discovery processes produce adequate data for analysis, we will calculate descriptive statistics including cross-tabulation of study characteristics, mean and standard deviation of values (e.g., fuel treatment costs), and other statistics that may be appropriate given the requirements and norms of the statistical field.

In the absence of adequate data, we will offer semi-quantitative and qualitative descriptions of the data and information discovered. Conceptual graphics (e.g., logic model, systems diagram, etc.) may be helpful for conveying ideas for relevant audiences.

We could potentially include a point map of wildland fires or fire-related actions (e.g., fuel treatments) discovered during the review and included for evaluation. Alternately, we could potentially develop a choropleth showing States or counties with high incidence, etc.

Future Knowledge Needs

Previous PPA reports have discussed the need for additional data on cost of treatments; market and nonmarket values, costs, and benefits. The near-term products will reprise those discussions.

Amendments

This section includes a log of any changes to the protocol, with a description of the change, date of change, and author.

Authors

- Christian Crowley, Economist, US Department of the Interior; Christian_Crowley@ios.doi.gov
- Ann Miller, Economist, US Department of the Interior; Ann_Miller@ios.doi.gov
- Robert Richardson, Chief Economist, US Department of the Interior; Robert_Richardson@ios.doi.gov

- Jacob Malcom, Director, Office of Policy Analysis, US Department of the Interior; Jacob_Malcom@ios.doi.gov

Support

This work was funded as part of regular DOI staff duties.