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Economic costs of U.S. wildfires: A meta-analysis

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ABSTRACT

Wildfires in the U.S. are increasing in size, severity, and frequency, leading to a wildfire crisis where at-risk communities are experiencing rapidly escalating wildfire damages. The wildfire crisis necessitates adapting to evolving natural disasters and implementing efforts to mitigate the economic costs of wildfire. Better understanding of the type and magnitude of economic costs, along with trends over time, can provide valuable information for avoiding or reducing wildfire damages. The research presented herein comprises two critical first steps of this larger research agenda. First, we performed a thorough review of published wildfire cost studies and used the results to develop a comprehensive wildfire cost categorization structure. The literature review bore costs from 29 individual wildfires, almost all with multiple types of costs (yielding 131 individual wildfire costs in total). Using the categorization structure, we classified the 131 wildfire costs into nine categories: Suppression, Evacuation, Structures & Contents, Structure-Related, Infrastructure, Mortality & Morbidity, Market Impacts, Ecosystem Services, and Rehabilitation. Second, we used multilevel modeling techniques to conduct a meta-analysis of the documented wildfire costs. We found that wildfire cost categories contribute to total costs at different rates, with economic costs being greatest for Structures & Contents (37%), Suppression (22%), and Ecosystem Service costs (18%). Our results show that wildfire costs have been increasing over the last two decades and human-ignitions are contributing to greater costs. Post-wildfire flooding costs, when present, represent a secondary natural disaster and tend to be greater than wildfire costs themselves. Overall, wildfire costs are infrequently and poorly documented, leading to deficient understanding of wildfire cost components.

1. Introduction

Wildfires are increasing in size, severity, and frequency across the U.S., particularly in the Western U.S. (Schoennagel et al., 2017; Wasserman and Mueller, 2023). Coupled with rapid expansion of the wildland-urban interface (WUI) and greater residential development (Radeloff et al., 2018), wildfire damages are escalating (Thomas et al., 2017). The most costly fires to date are the recent 2025 Los Angeles wildfires that resulted in a conservatively estimated $62 billion in costs.[1] Wildfire damages represent economic costs to a multitude of people and organizations, such as affected residents, businesses, utilities, governments, and society at large. To limit wildfire damages, governments and property owners are investing in resilience efforts like home and infrastructure hardening, creation of defensible space, pre-suppression fuel treatments, and community education and awareness (Moritz et al., 2022). Yet the rapid escalation of the wildfire crisis has led to mostly reactive measures, and our understanding of the scale and trends in wildfire costs is incomplete (Hjerpe et al., 2026).

Understanding wildfire costs is critical for sound management of forest fuels and other preventive measures, suppression efforts, and rebuilding activities. Best practices for all facets of forest fuels, wildfire, and recovery management will likely differ by region due to variability in topography, vegetation, weather patterns, property rights, liability standards, and other factors. Federal funding for fuels management, suppression, and other wildfire-related activities has increased dramatically in recent years. For example, between 2010 and 2020 the US Department of Agriculture Forest Service (henceforth, Forest Service) annual wildfire funding increased by 60 percent to nearly $5 billion and comprised 60 percent of the total Forest Service budget (Aldrich and Hjerpe, 2022). But multiple factors – including climate change (Balch et al., 2022; Westerling et al., 2006), increasing low-severity

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[1] Climate Central U.S. Billion-Dollar Weather and Climate Disasters Database.

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fire deficits compared to historical conditions (Parks et al., 2025), and greater human-caused ignitions (Balch et al., 2017) – are overwhelming agency resources (Thompson et al., 2023) and community resilience efforts (McWethy et al., 2019).

Suppression and containment costs (such as the costs of firefighters, air tankers, helicopters, and bulldozers) are the most frequently reported wildfire cost category. News agencies also often report on fatalities and destroyed homes, but the economic costs associated with these losses are rarely quantified. Other wildfire costs, such as species and habitat losses, physical and mental health impacts, evacuation operations, impacts on water supplies, and business disruptions are rarely mentioned by the media. Economists and other researchers have studied the costs of some wildfires in detail, though the few published studies often focus on the same costs reported by the media. Although some studies have assessed broader and more complete wildfire costs (e.g., Hjerpe et al. 2023), most studies are published soon after the wildfire event and do not capture additional costs that can accrue for multiple years, such as enduring infrastructure, ecosystem service, and post-wildfire flood damages. Even studies conducted long after a wildfire tend to underestimate total wildfire costs, as numerous costs are either unknown, not researched, or not reported.

In the present era of increasing wildfire frequency and size, understanding the full breadth and magnitude of total wildfire costs is of growing importance (Bayham et al., 2022) and can inform decisions regarding the allocation and distribution of limited wildfire management funds. Our research undertakes two initial steps in meeting critical research needs. Information obtained through a thorough review of published wildfire cost studies was used to elucidate the breadth of wildfire costs and develop a coherent, comprehensive, and consistent cost categorization. We applied the categorization structure to 131 published individual wildfire costs resulting from 29 U.S. wildfires and then employed multilevel modeling techniques to conduct a wildfire cost meta-analysis. Regression results were subsequently used to calculate and compare the magnitudes of different wildfire cost types. Our research broadens the understanding of the full spectrum of wildfire costs and illustrates the magnitude and importance of frequently undocumented wildfire costs. The following sections provide the background for our research hypothesis, detailed methods, meta-regression results, and discussion of wildfire cost categories.

1.1. Literature review

The literature contains several studies that provide estimates of multiple types of costs resulting from a single wildfire event (e.g. Batker et al. 2013, Graham 2003, and Hjerpe et al. 2023, with multiple case studies presented in Headwaters Economics 2018, Lynch 2004, Morton et al. 2003, and Troy et al. 2022). This body of literature provides valuable information that we synthesized to yield a better understanding of the composition, characteristics, and determinants of wildfire costs. Other studies provide estimates of various costs stemming from a combination of many wildfires, typically clustered within a state (e.g., Butry et al. 2001, Kochi et al. 2016, Wang et al. 2021). Nationally, Thomas et al. (2017) detailed 22 types of wildfire losses, showing that annual wildfire losses range from $85 billion to $380 billion (updated to 2024 dollars). Although such studies provide important contributions and document wildfire costs from clusters of wildfires across regions and years, they are not included in our cost synthesis, as individual wildfire characteristics and other potential explanatory variables are unavailable in these studies.

Suppression costs fall under the cost category of initial fire containment and response (as do evacuation costs) and are the most widely documented wildfire cost. An analysis of the costs of five Western US wildfires found that suppression costs, while considerable, typically account for only nine percent of total wildfire costs (Headwaters Economics, 2018). Similarly, in their analysis of the Schultz Fire, Hjerpe et al. (2023) found that suppression costs accounted for ten percent of total costs incurred over ten years. However, there is wide variation in suppression costs; in an analysis of six wildfires (Dale, 2010) documented suppression costs that range from 3 to 53 percent of total wildfire costs. Suppression costs are generally higher for WUI-area fires, though due to the sizable structure and infrastructure costs associated with WUI-area fires, they tend to be a smaller percentage of total costs than for fires in undeveloped areas (Gude et al., 2013).

Costs associated with the damage or destruction of structures and infrastructure can be substantial. For the five fires analyzed by Headwaters Economics (2018), structure and infrastructure losses constituted an average of 21% and 4% of total wildfire costs, respectively. Structural losses have increased over time; Higuera et al. (2023) found that structure losses increased 246% between 1999–2009 and 2010–2020 in the Western U.S. The increase in structural losses is in part due to the increased popularity of living in the WUI (Syphard et al., 2007). In addition to the destruction of homes, businesses, and other structures, wildfires also decrease the property values of remaining homes; Loomis (2004) and Mueller et al. (2009) found that home prices in adjacent communities decreased 10% to 23% after a wildfire. Likewise, Mueller et al. (2018) found reductions in home values from the Schultz Fire were considerable and ultimately constituted 10% of total wildfire costs (as reported in Hjerpe et al. 2023).

Wildfires can cause physical injuries, fatalities, illnesses from smoke, and adverse effects on mental wellbeing in adjacent community populations, firefighters, and first responders. These wildfire damages to human health can result in large economic costs (Fann et al., 2018) and can be the greatest of all wildfire cost categories (Dittrich and McCallum, 2020). Initial wildfire fatalities are often reported but, in many cases, do not capture all deaths attributable to the fire. Paglino et al. (2025) estimated that 440 deaths were attributable to the 2025 Los Angeles wildfires when smoke exposure and health care disruptions were considered – a more than tenfold increase in mortality than reported in the media (30 deaths). While underestimation of wildfire costs is commonplace in the literature, a more pervasive problem is a lack of economic quantification of certain wildfire costs (especially human health costs). For example, studies on costs of the 2018 Camp Fire in California did not include monetary cost estimates of the reported 85 fatalities (Matt, 2024).

Similarly, health effects from wildfire smoke exposure are rarely quantified (Richardson et al., 2012) owing largely to estimation complexity due to temporal and spatial dispersion of smoke effects that can harm people living many states away from the wildfire (Moeltner et al., 2013; Wen et al., 2023). Kochi et al. (2016) estimated mortality costs from smoke exposure to 14 southern California wildfires to be a billion dollars. Holder et al. (2023) illustrate that wildfire smoke becomes even more toxic in WUI wildfires when structures and vehicles are burned. Wen et al. (2023) provide methods for estimating smoke exposure and asthma-related impacts from individual wildfires, finding that most smoke particulate matter comes from wildfires from outside the local jurisdiction – 87% coming from fires in other counties and 60% from fires in other states. Additional methods, such as using the Environmental Benefits Mapping and Analysis Program (BenMAP) software[2] to estimate the cost of smoke-related illnesses, are furthering economic research on human health costs of wildfire and the ability to use benefits transfer methods to increase documentation of these costs (Dittrich and McCallum, 2020; Jones et al., 2017).

Ecosystem services are benefits human populations derive, directly or indirectly, from ecosystem functions (Costanza et al., 1997). The ecosystem service categories most commonly affected by wildfire are provisioning services (e.g., food, water, timber), cultural services (e.g., recreation, spiritual, nonuse), and regulating and supporting

[2] Environmental Benefits Mapping and Analysis Program - Community Edition (BenMAP-CE). Available at: https://www.epa.gov/benmap. Last accessed on 01/04/2026.

services (e.g., erosion control, climate regulation, air quality, and habitat provision). Fire is a necessary and natural disturbance in many forests, particularly the arid mixed conifer forests of the American West, and is therefore essential for the production of many ecosystem services (Pausas and Keeley, 2019). But due to past and continuing fire suppression, along with climate change and fuels accumulation, wildfires today are burning more severely than they typically burned in pre-industrial eras (Kreider et al., 2024). Thus, a wide array of ecosystem services may be impacted (either positively or negatively) by wildfire (Vukomanovic and Steelman, 2019), though the high-severity fires that are the new normal generally result in more negative than positive effects on ecosystem services.[3]

Direct commodities, like timber or agriculture products, are ecosystem services that can lose their market value if devastated by wildfire, becoming economic costs (Bousfield et al., 2023; Kabeshita et al., 2023). One of the most prevalent examples of wildfire effects on provisioning ecosystem services relates to the supply of drinking water and water quality (Wibbenmeyer et al., 2023), though in the wildfire cost literature these effects are often categorized as infrastructure damages. Other ecosystem service damages from wildfire include damages to artifacts (Deal et al., 2012) and reduced consumer surplus from recreationists (Bawa, 2017). Finally, the loss of carbon storage is another type of ecosystem service cost resulting from wildfires. Although the cost of carbon storage losses is rarely documented in the literature, Sweeney et al. (2023) estimated the cost of carbon emissions from the Eagle Creek Fire in Oregon in 2017 to be $230 million (updated to 2024 dollars).

A commonly documented wildfire cost is the amount spent on post-wildfire soil stabilization and rehabilitation efforts (e.g., the Forest Service's Burned Area Emergency Rehabilitation account). Activities such as seeding and replanting native species, noxious weed management, and flood mitigation are undertaken to protect ecosystem services and avoid further damages to structures and infrastructure. A substantial component of ecosystem service values comes from public willingness to pay to protect wildlife, endangered species, and ecosystems from severe and uncharacteristic wildfire (e.g., Loomis and González-Cabán 1998). Thus, landscape damages from severe wildfire result in an economic cost to society, though accommodating non-market values and determining how they are affected by wildfire in benefit-cost analysis is challenging (Loomis and González-Cabán, 2010; Venn and Calkin, 2011).

Business disruptions from wildfires can be associated with both positive and negative impacts on employment, wages, and regional output. Many local businesses may be negatively impacted, especially over time, but others may benefit in the short term due to increased federal funds for firefighters and other emergency responders (Davis et al., 2014; Nielsen-Pincus et al., 2013, 2014). Tourism and recreation are two industries likely to be hard hit by wildfire and ones which will likely take considerable time to recover. Walls and Wibbenmeyer (2023) empirically examined economic impacts of wildfires in Western U.S. communities, finding greater employment growth at the county-level for the year following the wildfire (primarily in the construction sector as communities rebuilt), but a slight decline in employment growth at the sub-county level closer to the wildfires. It is important to note that market impacts from wildfire, such as business disruption or displacement, are not included as costs in benefit-cost analysis of fire accounting and management (Hjerpe et al., 2026); due to their distributional behavior, regional market impacts are treated as economic impacts, not as benefits or costs.

Most wildfire cost studies are published relatively soon after the fire. However, many wildfire costs, particularly those associated with structure and infrastructure damages, can linger and endure for years. Likewise, post-wildfire flooding can occur for several years following a wildfire event. Thus, most wildfire cost studies understate total costs as they are published prior to the culmination of all wildfire damages. The cost assessment of Arizona's 2010 Schultz Fire published by Hjerpe et al. (2023) 13 years after the fire provides one of the most thorough assessments of wildfire costs, as the authors were able to capture and estimate long-term costs resulting from post-wildfire flooding. California's 2017 Thomas Fire is another fire for which longer-term costs have been documented, as heavy rains occurred a month after the fire started, resulting in flash floods that killed 21 people and caused significant structure, infrastructure, and other costs (Troy et al., 2022). Climate change is expected to increase the prevalence and magnitude of post-wildfire flooding costs, as wildfires occur more frequently and rainfall intensity increases (Cannon and DeGraff, 2009).

2. Methods and data

2.1. Cost categorization

Our review of the literature revealed that researchers have used inconsistent terminology when categorizing wildfire costs.[4] The inconsistencies cause specific costs to be categorized differently across studies, which hampers the development of a comprehensive understanding of the breadth, magnitude, and determinants of wildfire costs. We therefore perform a critical first step in furthering our knowledge of wildfire costs – we develop a wildfire cost categorization structure that is comprehensive, has clear delineations, and does not include the potentially ambiguous direct/indirect categorization used in some other studies. The wildfire cost categories depicted in Fig. 1 and used in our analysis are based upon a comprehensive review and assessment of wildfire costs (and avoided wildfire costs) and categories used in previously published studies (particularly Thomas et al. 2017, Hjerpe et al. 2024, 2026).

We grouped wildfire costs into distinct cost types, starting with broad cost categories of wildfire related to fire **response** and containment, the **built environment**, **human health**, **business disruption**, **biophysical effects**, and assisted **land recovery**. Within these broad fire cost categories there exist multiple unique cost subcategories. For example, wildfire costs associated with the built environment can be for damaged structures or damaged infrastructure (such as transportational, water delivery, or recreational infrastructure). Similarly, wildfire costs associated with business disruptions can capture costs associated with effects on GDP, tax revenues, or wages.

The order in which costs are presented (left to right) reflects both a chronological order of when costs are incurred and, often, the frequency with which different cost types are discussed and recognized in both the media and the literature. The six broad categories of wildfire costs (all caps) are divided into the nine wildfire subcategories (bulleted) used in our meta-regressions. In some cases, even greater detailed examples of cost categories are provided (check marks); these more detailed cost types were aggregated by fire and entered as cost data points under the main nine subcategories (bulleted). It is important to note that not every wildfire cost type will occur for every fire. For example, some wildfires may be contained prior to burning structures or may have limited adverse effects on human health.

[3] We acknowledge that the existing economic research on wildfire costs and benefits is dominated by investigations of the costs of wildfires, as we are not aware of any full quantification of the economic benefits of wildfire.

[4] For example, Dale (2010) categorizes costs as either direct, indirect, rehabilitation, or additional, whereas Lynch (2004) categorizes costs as direct, rehabilitation, impact, or special value, and Troy et al. (2022) use direct, indirect, and indirect mitigation investments.

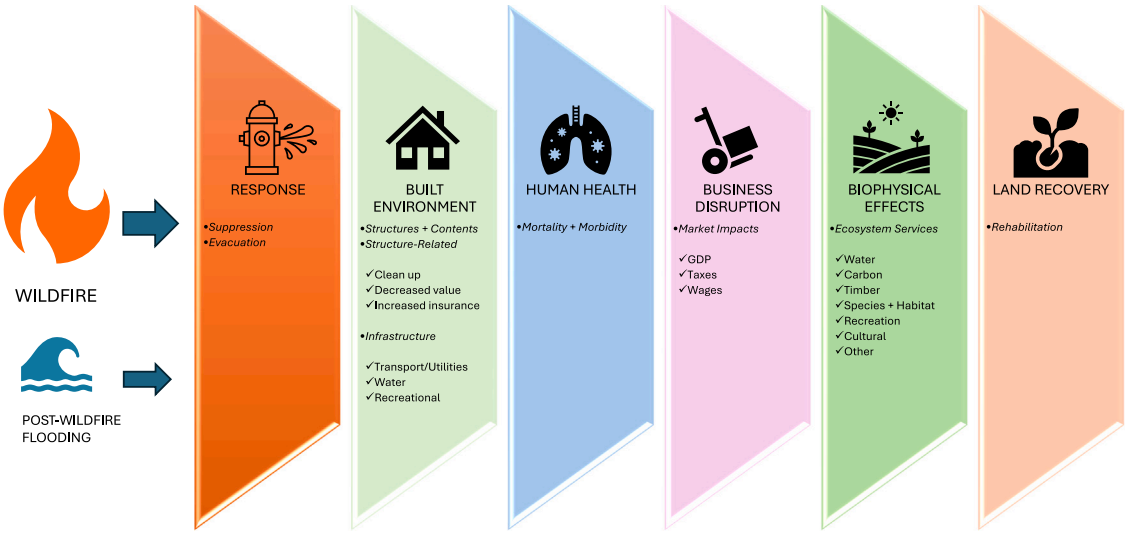

Fig. 1. Economic costs of wildfire.
The figure depicts the chronological order of costs (left to right) as well as the typical order of prevalence in documentation. Subsequent post-wildfire flooding can cause similar types of damages.

2.2. Data

We used the structure depicted in Fig. 1 to categorize cost estimates extracted from each of the 16 cost studies of 29 individual wildfires. Although some studies analyze the costs of multiple fires (such as Wang et al. 2021, who estimate the economic costs of all 2018 California wildfires), we restricted our review to studies that quantify costs of individual wildfire events. This focus allowed us to investigate the relationship between fire attributes and costs. Online searches using Google, Google Scholar, and Treesearch yielded 75 reports and articles that we screened for relevance. We also applied snowball techniques to references in relevant studies and review papers. Finally, we contacted researchers who have published in this area to inquire about relevant missed publications.

Costs associated with a particular wildfire are sometimes discussed in multiple studies. We reviewed such cases to ensure costs were not duplicated in our final dataset. Studies regularly provide a single cost estimate that encompasses multiple cost types. For example, a cost estimate might include costs for trail and road construction, campground construction, and heritage site restoration. In the absence of additional details, we distributed the cost equally between the listed categories. While some costs are generally incurred at the time of the fire (e.g., structure losses), others occur over several years (e.g., recreation impacts and tax revenue impacts due to decreased housing). Most studies do not present multi-year costs as net present values, but instead provide only the first year's cost. In cases where annually recurring costs are presented without details regarding expected recovery periods or the rate of recovery, we estimated a linear recovery and imposed conservative (fast) recovery periods.[5] Additionally, many studies noted various wildfire impacts but did not provide associated cost estimates.[6] Finally, some cost types are difficult or costly to quantify and are thus rarely captured in studies of wildfire costs, (e.g., the costs of GDP and other market impacts, recreation impacts, post-wildfire flooding, and the health impacts of wildfire smoke).

In total, 16 primary studies provided wildfire cost estimates pertaining to 29 US wildfires (see Table 1). The Consumer Price Index for All Urban Consumers was used to convert all cost estimates to constant 2024 dollars.[7] We collapsed the cost data for each wildfire into the nine (bulleted) cost subcategories depicted in Fig. 1: suppression, evacuation, structure & contents, structure-related, infrastructure, morbidity & mortality, market impacts, ecosystem services, and rehabilitation. The resulting dataset contains 131 observations nested within wildfires. For each wildfire included in our meta-analysis, Table 2 lists the number of estimates in each of the nine cost subcategories. In addition to cost estimates, we also extracted information from primary studies pertaining to wildfire year, cause, location, and whether costs were incurred by the wildfire or by post-wildfire flooding.

2.3. Model and diagnostics

Because costs from a single wildfire share common latent wildfire attributes (e.g., response timing and strategy), the wildfire cost dataset may contain group-level latent effects. If latent group-level effects are present, traditional regression analysis methods will yield underestimated standard errors and invalid statistical significance inferences (Finch et al., 2019). We therefore use multilevel modeling (MLM) techniques to estimate a two-level mixed-effects model with random wildfire-level intercepts. Our econometric model specifies wildfire costs as

$$\boldsymbol{FC} = \boldsymbol{CC}\boldsymbol{\beta} + \boldsymbol{FA}\boldsymbol{\gamma} + \boldsymbol{Z}\boldsymbol{u} + \epsilon,$$

where FC is the documented individual wildfire cost, $\boldsymbol{CC}$ is a set of dummy variables for the nine wildfire cost categories, $\boldsymbol{FA}$ is a set of wildfire attributes (e.g., size and location), and $\boldsymbol{Z}$ denotes wildfire random effects. (Table 3 provides definitions for the variables used in the analysis.) Formulating the model in this manner (with cost categories included as dummy variables) enables us to use $\hat{\boldsymbol{\beta}}$ to estimate the magnitude of costs for each wildfire cost category. Specifically, we calculate the average marginal effect for each of the k wildfire cost categories as

$$\frac{1}{N}\sum_{i=1}^{N}\left(\boldsymbol{CC}_{i,k}\hat{\boldsymbol{\beta}} + \boldsymbol{FA}_i\hat{\boldsymbol{\gamma}}\right),$$

[5] For example, we assume structures and infrastructure are rebuilt within three years and ecosystems fully recover within ten years.

[6] For example, Troy et al. (2022) noted that New Mexico's Las Conchas Fire resulted in the destruction of 63 homes and 49 outbuildings but provided no cost estimate for the destroyed structures.

[7] Several studies do not stipulate the dollar year in which costs are expressed. In such cases we assumed the dollar year used in the primary study is equal to the year in which the wildfire occurred.

Table 1
Primary studies and US wildfires used in meta-analysis.

Primary study (year of publication)	Fire	State(s)	Year	Acres
Batker et al. (2013)	Rim	CA	2013	257,077
Christin et al. (2017)	Loma	CA	2016	4,380
Dale (2010)	Rodeo-Chediski	AZ	2002	461,753
Dunn et al. (2005)	Old, Grand Prix, Padua Complex	CA	2003	151,548
Economic & Planning Systems, Inc. (2021)	Camp	CA	2018	153,665
Graham (2003)	Hayman	CO	2002	129,404
Graham et al. (2012)	Fourmile Canyon	CO	2010	6181
Headwaters Economics (2018)	Hayman	CO	2002	129,404
Headwaters Economics (2018)	Rim	CA	2013	257,077
Hjerpe et al. (2023)	Schultz	AZ	2010	13,955
Hu (2024)	Hemit Peak/Calf Canyon	NM	2022	352,046
Lynch (2004)	Black Tiger	CO	1989	2,100
Lynch (2004)	Bobcat Gulch	CO	2000	10,599
Lynch (2004)	Buffalo Creek	CO	1996	11,900
Lynch (2004)	Hayman	CO	2002	129,404
Lynch (2004)	Hourglass	CO	1994	1,275
Mackes et al. (2007)	Missionary Ridge	CO	2002	68,921
Morton et al. (2003)	Battle Creek	SD	2002	15,035
Morton et al. (2003)	Biscuit	CA & OR	2002	495,302
Morton et al. (2003)	Canyon Ferry Complex	MT	2000	14,843
Morton et al. (2003)	Cerro Grande	NM	2000	44,280
Morton et al. (2003)	Double Trouble	NJ	2002	1,400
Morton et al. (2003)	Rodeo-Chediski	AZ	2002	461,753
Morton et al. (2003)	Shenandoah Complex	VA	2000	22,000
Morton et al. (2003)	Star	CA	2001	16,844
Santa Ana Watershed Project Authority (2003)	Old, Grand Prix, Padua Complex	CA	2003	151,548
Sweeney et al. (2023)	Eagle Creek	OR	2017	48,000
Troy et al. (2022)	Camp	CA	2018	153,665
Troy et al. (2022)	Carlton Complex	WA	2014	276,141
Troy et al. (2022)	East Troublesome	CO	2020	188,924
Troy et al. (2022)	Grizzly Creek	CO	2020	30,709
Troy et al. (2022)	Klondike/Taylor Creek	OR	2018	235,777
Troy et al. (2022)	Las Conchas	NM	2011	150,877
Troy et al. (2022)	Thomas	CA	2017	281,976
Troy et al. (2022)	Wallow	AZ	2011	563,657

Table 2
Summary of included wildfires by cost categories.

Wildfire	N_i	Wildfire cost category								
		ES	Evac	MM	Infra	Market	Rehab	StrRltd	StrCont	Suppr
Battle Creek	5	✓			✓		✓		✓	✓
Biscuit	4	✓			✓		✓			✓
Black Tiger	2								✓	✓
Bobcat Gulch	8		✓	✓	✓	✓	✓	✓	✓	✓
Buffalo Creek	4				✓		✓		✓	✓
Camp	6		✓		✓	✓		✓	✓	✓
Canyon Ferry Complex	4	✓					✓		✓	✓
Carlton Complex	3				✓				✓	✓
Cerro Grande	5				✓		✓	✓	✓	✓
Double Trouble	2				✓					✓
Eagle Creek	1	✓								
East Troublesome	4						✓	✓	✓	✓
Fourmile Canyon	3					✓			✓	✓
Grizzly Creek	4				✓	✓	✓			✓
Hayman	9	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hermit Peak/Calf Canyon	7		✓	✓	✓	✓	✓	✓	✓	
Hourglass	2								✓	✓
Klondike/Taylor Creek	2					✓				✓
Las Conchas	2					✓				✓
Loma	5	✓			✓		✓		✓	✓
Missionary Ridge	9	✓	✓	✓	✓	✓	✓	✓	✓	✓
Old, Grand Prix, Padua Complex	8	✓	✓	✓	✓		✓	✓	✓	✓
Rim	5	✓			✓		✓	✓		✓
Rodeo-Chediski	7	✓		✓	✓	✓	✓		✓	✓
Schultz	7	✓	✓	✓	✓			✓	✓	✓
Shenandoah Complex	3					✓	✓			✓
Star	3				✓		✓			✓
Thomas	4				✓	✓			✓	✓
Wallow	3							✓	✓	✓
Total	**131**	**11**	**7**	**7**	**19**	**12**	**17**	**11**	**20**	**27**

Notes: N_i = number of observations taken from primary wildfire j. Cost categories are: ES (Ecosystem Services), Evac (Evacuation), MM (Mortality & Morbidity), Infra (Infrastructure), Market, Rehab (Rehabilitation), StrRltd (Structure-Related), StrCont (Structures and Contents), Suppr (Suppression).

Table 3
Variable definitions.

Variable	Definition
Dependent variable	
Cost	Cost (2024 $s) for cost category *i* from wildfire *j*
lnCost	Natural log of cost (2024 $s) for cost category *i* from wildfire *j*
Explanatory variables: Cost category dummy variables	
ES	Damages to ecosystem services (water, carbon, timber, species, recreation, and cultural).
Evac	Evacuation response costs.
Infra	Damages to transportation, utilities, water, and recreation infrastructure.
Mkt	Market impacts (reduced regional GDP, taxes, and wages).
MM	Morbidity and mortality impacts (fatalities, injuries, and decreased well-being).
Rehab	Costs of soil stabilization, replanting, etc. (e.g., Burned Area Emergency Rehabilitation activities).
StrCont	Damage and destruction of structures and contents.
StrRltd	Wildfire cleanup, value losses, and increased insurance for structures.
Suppr	Wildfire response and containment.
Explanatory variables: Wildfire attributes	
Year	Wildfire year.
AcresK	Wildfire size (thousands of acres).
Cause	Dummy variable. Cause = 1 if wildfire is human caused.
PWFperc	Percent of category costs per fire resulting from post-wildfire flooding.
East	Dummy variable. East = 1 if wildfire is located in neither West or IMWT.
IMWT	Dummy variable. IMWT = 1 if wildfire is located in AZ, CO, MT, NM, or SD.
West	Dummy variable. West = 1 if wildfire is located in CA, OR, or WA.

where $\boldsymbol{CC}_{i,k}$ signifies that the margin is calculated treating all observations as though they are wildfire costs of type k.

Although the existing literature is largely silent regarding the magnitude of most non-suppression wildfire costs, we hypothesize that wildfire cost categories differ in their magnitudes and thus contribute unequally to the total cost of wildfires. Our null hypothesis is therefore

$$H_0 : \beta_1 = \beta_2 = \beta_3 = \cdots = \beta_k,$$

where k denotes the kth wildfire cost type. Rejection of our null hypothesis would suggest the importance of documenting and collecting additional wildfire cost data with which to increase our understanding of wildfire cost components, magnitudes, and determinants. Knowledge (albeit preliminary) regarding the comparative magnitudes of wildfire cost categories can inform decisions regarding the categories on which to focus data collection and cost estimation efforts.

Model diagnostics included tests for skewness, outliers, multicollinearity, and heteroskedasticity. Wildfire cost data were skewed, requiring use of a semi-log model. Leverage plots and Cook's distance values were used to identify potential outliers, resulting in the identification and removal of one observation. The Bruesch-Pagan test and scatter plots were used to test for heteroskedasticity. Because results indicated statistically significant heteroskedasticity across wildfires, our final model was estimated using cluster-robust standard errors clustered by wildfire. Regression results ($\hat{\boldsymbol{\beta}}$ and $\hat{\boldsymbol{\gamma}}$) were subsequently used to estimate within-sample average marginal effects for each of the nine cost categories used in our meta-analysis.

Table 4 provides descriptive statistics for the 130 observations that remain after the removal of one outlier. The wildfires in our dataset occurred between 1989 and 2022, and the vast majority were human caused. Most wildfires (65%) occurred in the Intermountain West, 32% occurred on the West Coast, and the remaining 4% occurred in the Eastern US. Fires ranged in size from just over 1000 acres to almost 564,000 acres, with an average size of approximately 142,000 acres. Suppression costs were the most frequently documented wildfire cost type – composing approximately 20% of observations. Roughly 9% of costs contained post-wildfire flooding cost estimates.

3. Results

The nine wildfire cost subcategories were included as dummy variables with Structure & Contents used as the reference category. Our multilevel mixed-effects model has a pseudo-R^2 value of 0.65. Six of the eight cost category coefficients were significantly smaller than Structure & Contents costs (see Table 5), largely confirming our hypothesis of distinct variation among wildfire cost types. Suppression and Ecosystem Services were the only cost categories with coefficients not significantly different from the Structure & Contents. These results indicate that for a given wildfire, and after controlling for wildfire-level differences, documented Structure & Contents costs tend to exceed most other cost types, with Suppression and Ecosystem Service costs being nearly as large as Structure & Contents.

In terms of the other explanatory variables, more recent wildfires (captured by the *Year* variable) were associated with higher costs, reinforcing the notion that wildfire costs are increasing over time. The significant positive coefficient on *Cause* indicates that human-caused wildfires are generally more costly, likely because such fires generally occur in closer proximity to human populations, the WUI, and at-risk assets (Johnston and Flannigan, 2018). Not surprisingly, the positive coefficient for size of wildfires (*AcresK*) indicates that larger wildfires generally result in higher costs. Although the costs of wildfires in the West Coast region do not differ significantly from those of the Intermountain West, wildfires in the Eastern U.S. have significantly lower costs. Finally, the percentage of costs attributable to post-wildfire flooding is significant and positive, illustrating that when present, post-wildfire flooding costs tend to be even greater than wildfire costs themselves.

The final estimated meta-regression shows the relationship of each cost category to that of the reference, or comparison, dummy variable (Structure & Contents). Further comparisons amongst wildfire cost categories illustrate that some are not significantly different from others (e.g., Infrastructure versus Ecosystem Services). Table 6 illustrates each pairwise comparison, showing that about two-thirds of the pairwise comparisons exhibited significant differences. We attribute the mixed effects concerning differences among wildfire cost types to our limited sample size of documented wildfire costs and hypothesize that clearer delineation between fire cost types will be found with greater research on wildfire costs.

To help forecast wildfire costs, we estimated within-sample predictions for cost categories from our meta-regression. Fig. 2 illustrates final predictive estimates when grouping at the wildfire level and controlling for wildfire attributes. The predictive estimates were bound by 95% confidence intervals. Structure & Contents damages for a future wildfire that is representative of our sample were estimated to be around $84 million, with Suppression costs estimated to be approximately $50 million, and Ecosystem Services at approximately $40 million. Together these three cost categories thereby accounted for almost 80% of total predicted wildfire costs (see Table 7).

4. Discussion and conclusion

Our synthesis of documented wildfire costs indicates that cost types can be broadly grouped into the following categories: fire response and containment, the built environment, human health, business disruptions, biophysical effects, and assisted land recovery. Within these six broad categories of wildfire costs, we found 21 subcategories of unique wildfire costs (see Fig. 1), though other detailed types of unique wildfire costs have not been documented for individual wildfires. For example, multiple unique types of human health costs from U.S. wildfires have been analyzed but have not been quantified for individual

Table 4
Descriptive statistics of analyzed variables.

Variable	Obs	Mean	Std. Dev.	Min	Max
Dependent variable					
Cost	130	5.76×10^8	2.74×10^9	6396.742	2.81×10^{10}
lnCost	130	16.812	2.883	8.764	24.059
Explanatory variables: Cost category dummy variables					
ES	130	0.085	0.279	0	1
Evac	130	0.054	0.227	0	1
HH	130	0.054	0.227	0	1
Infra	130	0.146	0.355	0	1
Mkt	130	0.092	0.291	0	1
Rehab	130	0.131	0.338	0	1
StrRltd	130	0.085	0.279	0	1
StrCont	130	0.146	0.355	0	1
Suppr	130	0.208	0.407	0	1
Explanatory variables: Wildfire attributes					
Year	130	2007.169	8.285	1989	2022
AcresK	130	142.465	156.552	1.275	563.657
Cause	130	0.877	0.330	0	1
PWFperc	130	0.086	0.239	0	1
East	130	0.038	0.193	0	1
IMWT	130	0.646	0.480	0	1
West	130	0.315	0.466	0	1

Table 5
Mixed regression results: Magnitudes and predictors of wildfire costs.

Effect	Coef.	Robust St.Err.	z	P > |z|	95% Conf LL	95% Conf UL	Sig
Dependent Variable: lnCost							
Cost Category (base: StrCont)							
ES	−0.731	0.671	−1.09	0.275	−2.046	0.583	
Evac	−3.809	0.475	−8.02	0.000	−4.739	−2.878	***
MM	−4.516	1.135	−3.98	0.000	−6.741	−2.291	***
Infra	−1.878	0.527	−3.56	0.000	−2.911	−0.844	***
Mkt	−2.892	0.799	−3.62	0.000	−4.459	−1.325	***
Rehab	−1.561	0.479	−3.26	0.001	−2.500	−0.623	***
StrRld	−1.861	0.722	−2.58	0.010	−3.276	−0.447	***
Supp	−0.514	0.509	−1.01	0.312	−1.511	0.483	
Wildfire Attributes							
Year	0.080	0.028	2.83	0.005	0.024	0.135	***
AcresK	0.005	0.002	2.77	0.006	0.001	0.008	***
Cause	1.357	0.451	3.01	0.003	0.473	2.241	***
PWFperc	1.784	0.734	2.43	0.015	0.346	3.221	**
East	−3.857	1.318	−2.93	0.003	−6.440	−1.275	***
IMWT	−0.630	0.740	−0.85	0.395	−2.081	0.822	
Constant	−143.210	56.430	−2.54	0.011	−253.811	−32.609	**
Mean dependent var		16.812		SD dependent var		2.883	
Number of obs		130		χ^2		607.688	
Prob > χ^2		0.000		Akaike crit. (AIC)		573.976	

*** p<.01, ** p<.05, * p<.1.

wildfires, including respiratory illnesses from smoke exposure,[8] averting behavior to avoid smoke exposure, adverse effects on mental health, and exposure to toxic chemicals from fire retardant and from burned water delivery infrastructure. Likewise, severe wildfire damages to the biophysical environment and ecosystem services are rarely quantified due to the complexity and resources required to monitor changes in ecosystem services before and after a wildfire, along with the complexity involved with subsequent economic valuations of these changes. Thus, even the most complete accounting of the economic cost of wildfire tends to be conservative and underestimates the real costs.

It is important to characterize the sample of wildfires used in our meta-analysis. The collection of documented wildfire costs in our meta-analysis primarily comes from large and destructive wildfires (i.e., megafires), but does include a few smaller, less costly, wildfires. Thus, our synthesis of wildfire costs represents the typical damages from more destructive wildfires, often originating in unnaturally dense forests and spreading into urban environments. On the other hand, there are numerous small and benign wildfires that generate minimal economic costs and may provide benefits to society by reducing the risk of uncharacteristic wildfire and restoring forest health, native flora and fauna, and ecosystem service production. The costs (or benefits) from these smaller wildfires are unlikely to be documented in the literature.

Our analysis of the synthesized wildfire cost data yielded several important findings. First, the regression model results illustrate that large U.S. wildfires come with substantial economic costs that systematically vary by cost type. We found that damages to the built environment tend to be the most expensive type of wildfire cost, followed by response and

[8] Richardson et al. (2012) provide 'per exposed person per day' health costs from California's Station Fire in 2009 but do not have estimates of total smoke health costs (i.e., the total number of people affected and days of high smoke exposure).

Table 6
Pairwise comparison of wildfire cost categories.

WFC	WFC reference category							
category	Evac	MM	Infr	Mkt	Rehab	StrCont	StrRltd	Suppr
ES	3.077 ***	3.785 ***	1.146	2.161 **	0.830	1.130	−0.731	−0.217
Evac		0.707	−1.931 ***	−0.916	−2.247 ***	−1.947 ***	−3.809 ***	−3.295 ***
MM			−2.638 **	−1.623 *	−2.954 ***	−2.654 **	−4.516 ***	−4.002 ***
Infra				1.015	−0.316	−0.016	−1.878 ***	−1.363 **
Mkt					−1.331	−1.031	−2.892 ***	−2.378 ***
Rehab						0.300	−1.561 ***	−1.047 **
StrRltd							−1.861 ***	−1.347 **
StrCont								0.514

Table 7
Within-sample wildfire cost predictions (2024 $MM).

Cost category	Predicted	Lower bound	Upper bound	% of total predicted cost	
				%	Cumulative %
Structure & Contents	84	33	214	37	37
Suppression	50	34	74	22	59
Ecosystem Services	40	10	158	18	77
Rehabilitation	18	8	39	8	85
Structure Related	13	3	61	6	91
Infrastructure	13	4	39	6	97
Market Impacts	5	1	22	2	99
Evacuation	2	1	4	1	100
Morbidity & Mortality	1	0	7	0	100

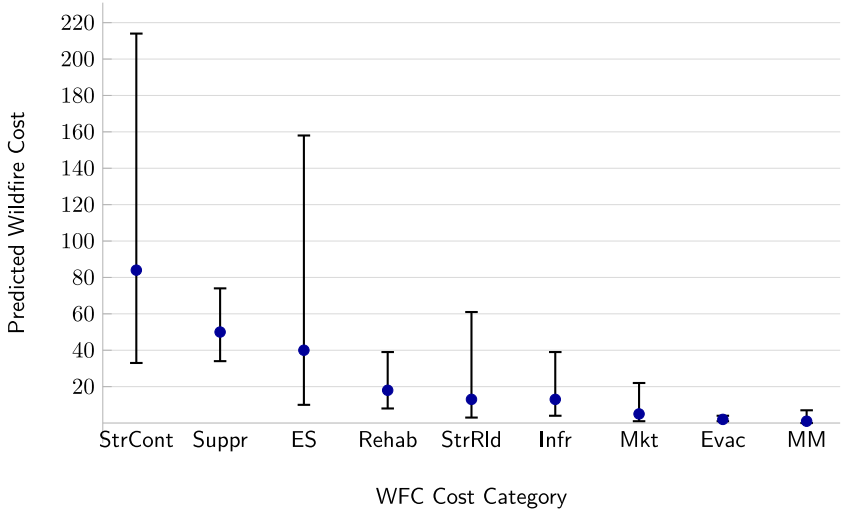

Fig. 2. Within-sample wildfire cost predictions (2024 $MM).
Within-sample wildfire cost predictions were calculated (and bracketed by 95% confidence intervals). The Human Health predicted cost for wildfire morbidity and mortality (MM) is severely underestimated because we were unable to find any smoke exposure cost estimates from individual wildfires.

biophysical effects costs. Second, our synthesis of documented wildfire costs also highlights that nearly all wildfire cost studies are missing important costs. The missing wildfire costs mean that human health costs, ecosystem service costs, and market impacts are likely quite understated. Finally, we found that post-wildfire flooding costs tend to be larger than wildfire costs. While post-wildfire flooding does not always occur following wildfires, the topography and slopes that accelerate wildfire spread and make suppression efforts more difficult also increase the risk of flooding and mudslides once a wildfire denudes the drainage. Increasing wildfire severity also primes soils for post-wildfire flooding. In such cases, post-wildfire flooding becomes a compounding natural disaster (Edgeley et al., 2025) that can cause all the same types of community damages caused by wildfires (see Fig. 1).

Our meta-analysis was conducted to derive a comprehensive wildfire cost categorization and to determine relative comparisons among cost categories. With better understanding of wildfire cost categories, the logical extension for future research is a focus on the drivers of these wildfire costs. While beyond the scope of this study, we did find preliminary drivers of wildfire costs to be wildfire size, year, cause (human-caused wildfires), and post-wildfire flooding. Previous research in this area has been mainly focused on drivers of wildfire suppression costs, finding that wildfire size, burn severity, and proximity to

aggregate housing values are primary drivers (e.g., Gebert et al. 2007). Drivers of structure losses from wildfire have also received attention (e.g., Higuera et al. 2023), but there has been little investigation of variables most influential on cumulative wildfire costs or associated with ecosystem service, human health, or infrastructure costs. In general, fires adjacent to more populated areas will tend to generate greater costs, especially in terms of costs to the built environment and human health.

Perhaps the most pressing future research needs have to do with strategies to limit and reduce wildfire costs, especially as related to pre-suppression fuel treatments. As wildfire severity and costs are escalating (Buechi et al., 2021), particularly in western US forests, forest management efforts have focused on reducing wildfire risk by implementing fuel reduction treatments such as mechanical thinning and prescribed fire. These pre-suppression activities are part of overall fire management costs but are conducted, in large part, to help reduce future wildfire damages and associated costs. Fuel treatments can be expensive to implement but are a means of reducing uncharacteristic wildfire costs (Jones et al., 2022) and can facilitate greater wildfire suppression. Specifically, fuel treatments in high-risk forests adjacent to communities can lead to avoided wildfire costs across all relevant cost categories (Hjerpe et al., 2024). Most research on avoided wildfire costs modeled the effect of fuel treatments on a reduction in fire severity and translated the reduced severity into a correlating reduced set of fire damages and costs. Our results can be used for benefits transfer to estimate expected wildfire costs with and without fuel treatments.

Ultimately, better understanding of wildfire costs allows for greater awareness of the wildfire crisis and can afford better estimates for forecasting potential types and amounts of wildfire damages. Likewise, syntheses of wildfire cost data can help further critical research in wildfire management benefit-cost analysis, especially the modeling of avoided wildfire costs that may come from fuel treatments. In the highest risk places for fuel-driven and wind-driven wildfire (Buechi et al., 2021), the more pertinent question is not whether a wildfire will happen but rather when it will happen. Understanding the economic costs of wildfire before the next major fire can inform community preparedness and resilience efforts.

CRediT authorship contribution statement

Evan E. Hjerpe: Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Gwendolyn A. Aldrich:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Formal analysis, Data curation. **Melanie M. Colavito:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition. **Andrew Sánchez Meador:** Writing – review & editing, Supervision, Resources, Project administration, Funding acquisition.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data availability

Data will be made available on request.

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