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# Global firestorm: Igniting insights on environmental and socio-economic impacts for future research

Laxita Soontha , Mohammad Younus Bhat *

*Energy, Economics and Sustainability Cluster, School of Business, University of Petroleum and Energy Studies, Dehradun, 248007, India*

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ABSTRACT

Forests are vital life-preserving assets, essential for biodiversity, human health, climate change mitigation, and economic stability. Yet, they are increasingly threatened by forest fires, which undermine these benefits. In the first half of 2025, forest fires in the United States burned over 810,000 acres, Canada lost 7.3 million hectares, while the 2020 Australian mega-fires, which caused an estimated US $20 billion in economic losses, illustrate the scale and urgency of the problem. Despite such impacts, research integrating the diverse dimensions of forest fires, including suppression costs, health effects, tourism, economic impacts, technological advancements, biodiversity, and ecosystem services, remains limited. This study systematically reviews 142 peer-reviewed publications from 2000 to 2023, underscoring the importance of applying theoretical frameworks to practical fire management strategies, bridging the gap between academic insight and real-world application. The findings show that forest fires generate cascading effects on economic growth, ecological services, biodiversity, human health, and macroeconomic stability, all critical for achieving sustainable development goals. Persistent research gaps include the scarcity of region-specific long-term studies, limited integration of opportunity costs into economic assessments, insufficient attention to chronic health impacts, lack of socio-ecological evaluations, minimal empirical work on indigenous populations, and inadequate practical assessment of fire management technologies. Addressing these gaps require investigation into demographic outcomes such as infant mortality and female fertility rates, adoption of advanced valuation methods including the Replacement Cost Method and the Avoided Cost Method, and systematic study of climate–fire feedback loops to ensure theoretical models are effectively translated into actionable strategies for sustainable development and resilience.

## 1. Introduction

Over the past few decades, there has been a great impact on the environment and human welfare, economic growth and tourism around the world due to forest fires, with prognostication pointing to deteriorating scenario (Cammelli and Angelsen, 2019; Fitch and Kim, 2018; Meier et al., 2023 [1]). Noticeably, the immensity repercussion of recent forest fires points out that these events have become more frequent and more severe and have overshadowed historical events; this indicates the importance of studying changes in fire

* Corresponding author.
*E-mail addresses:* laxita.soontha@ddn.upes.ac.in (L. Soontha), younus.bhat@ddn.upes.ac.in (M.Y. Bhat).

[1] Forest fires reduce regional GDP growth by 0.11–0.18 % annually in Southern Europe, with tourism jobs declining (−0.09 – 0.15 %). In the U.S., they burn 7–10 million acres yearly, increase respiratory hospital admissions by 7–10 %, and cause $20–100 billion in annual losses.

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frequency over time especially at moderate ecosystem zones (Hantson et al., 2022). It is crucial to understand how these forest fires effect wildlife habitats, carbon sequestration and plant life and eventually affects the behavior of humans (Feng et al., 2021; Seidl et al., 2014). Research has examined the extent of fire-affected areas, the factors contributing to previous forest fire and the pervasive impacts of climate change (Gonzalez-Olabarria et al., 2019). Forests offer essential services such as food, raw materials, medicine and water, while also playing a crucial role in regulating climate and reducing hazards (Hashida and Lewis, 2019; Baland et al., 2018; Unterberger and Olschewski, 2021). In addition (Taye et al., 2021), highlight the cultural services of forests, contributing to human well-being, leisure, travel, scientific understanding, and spiritual and cultural identity. The various functions forests serve highlight their value beyond being conventional natural resources. It is crucial to understand and acknowledge these contributions; however, the current trend of forest degradation presents a danger to vulnerable communities and humanity as a whole. Implementing strategies to protect, restore and responsibly manage forests can positively impact human welfare and livelihood opportunities. Forest fires are getting more intense and prevalent in a variety of ecosystems throughout the world. The escalating forest fires are causing substantial ecological damage, consequences on human health, and infrastructure devastation (UNEP - United Nations Environment Programme, 2022). A notable case is the Menderes region in İzmir, Turkey, where over a 20-year span, 63,724 forest fires damaged around 320,000 ha, with over 90 % attributed to human activities and 75 % affecting productive forests. The 2017 fire exemplifies the interaction of anthropogenic pressures and climatic stressors in Mediterranean fire-prone regions (Çolak and Sunar, 2020). These fires disrupt ecosystems and endanger lives, underscoring the importance of resilient forests for development, especially in developing nations (Fekete and Nehren, 2023; Belavenutti et al., 2022; Tian and Liu, 2011; Provencher et al., 2008). Conversely, forest degradation and loss hinder long-term economic growth, undermining development objectives (Woldemedhin et al., 2022). Recognizing the trade-offs and opportunities in forest-related policies can lead to more informed decision-making, aligning economic interests with the myriad benefits that forests offer (Saha et al., 2022; Saarikoski et al., 2022). See Fig. 1 for a visual representation of the rising forest fires from 2000 to 2019.

The primary objective of this review is to provide a structured and multi-dimensional synthesis of the dynamic repercussions of forest fires on economic growth, human psychology, health, and sustainable livelihoods within the framework of forest economics. Addressing a critical gap in the literature, where studies often focus on isolated aspects without a holistic perspective, the review synthesizes insights from various scholarly sources to explore the multifaceted impacts of forest fires. It aims to recalibrate cost estimation methods, particularly in relation to suppression costs and firefighting expenses, by integrating economic and physical damage metrics and emphasizing the value of ecosystem services provided by forests. The review contributes to the existing body of knowledge by offering a broad analysis of economic impacts, ecosystem services, and social implications, while also examining the health, biodiversity, tourism, and climate change effects of forest fires. Drawing on a global evaluation spanning from 2001 to 2024, fires destroyed a staggering 152 million hectares of global tree cover, and 2024 alone saw 13.5 million hectares lost to fires (45 % of that year's total loss) (GFW, 2025), the review underscores the growing severity of forest fires in the context of economic growth and sustainability. The novelty of this review lies in its holistic approach, combining economic, social, and environmental dimensions to offer practical recommendations for policymakers in forest fire suppression, rehabilitation, and risk mitigation, while addressing the need for more accurate cost estimations and highlighting the importance of ecosystem service valuation. In doing so, the review identifies key research gaps, including the lack of region-specific, long-term empirical studies; limited integration of opportunity costs; and insufficient exploration of demographic vulnerabilities such as impacts on infant mortality and female fertility.

Highlighting the need to investigate health indicators and engage communities, the review underscores forest fires as a collective challenge requiring community involvement. Inspired by successes like the Chipko movement—a non-violent resistance in India where villagers, mainly women, hugged trees to prevent them from being cut down; community engagement is crucial. The argument for expanding analytical and empirical dimensions of forest fire literature aims to fill gaps in understanding the comprehensive relationship between forest fires and sustainable livelihoods. This approach guides practical strategies for mitigation, community involvement, and sustainable forest management.

## 2. Theory

### *2.1. Unraveling complexity: goals and strategies in forest fire management*

The discourse surrounding forest fire management involves the nuanced adjustment of behaviors, actions, and decisions within ecological, social, and built systems, responding to the multifaceted impacts of these fires on both the environment and human well-being (D'Evelyn et al., 2022). This adaptive process of reactive measures addresses past fire events, as well as anticipatory strategies to help combat future fire occurrences. However, akin to the challenges encountered in climate change discussions, the definition of forest fire management is an understanding that has remained contingent upon the specific events or conditions with these fires and lacks fundamental clarity (Hesseln et al., 2010). The forest fire events are experienced and defined in different ways among individuals, further complicating how to manage these fires. The complexity of forest fire management is primarily because of the difficulty in defining the core objectives of fire management. These are supported by key aims: improving the ability to manage fires, enhancing the resilience of ecological and social systems to fire pressure and reducing susceptibility to reduce their impact during periods of major fire activity (Moore, 2019). Rooted in disciplines such as ecology, geography, and sustainability science, these goals converge within the realm of forest fire management research. Crucially, these objectives are interrelated; a system bolstered in coping capacity is inherently less vulnerable and more resilient in the face of forest fire risks.

However, if the stated goals of the forest fire management definition aren't put in context, they tend to be ineffective. Vulnerability, usually seen as exposure to fire risk, is closely allied with social-political processes, as well as economic and ecological factors. For

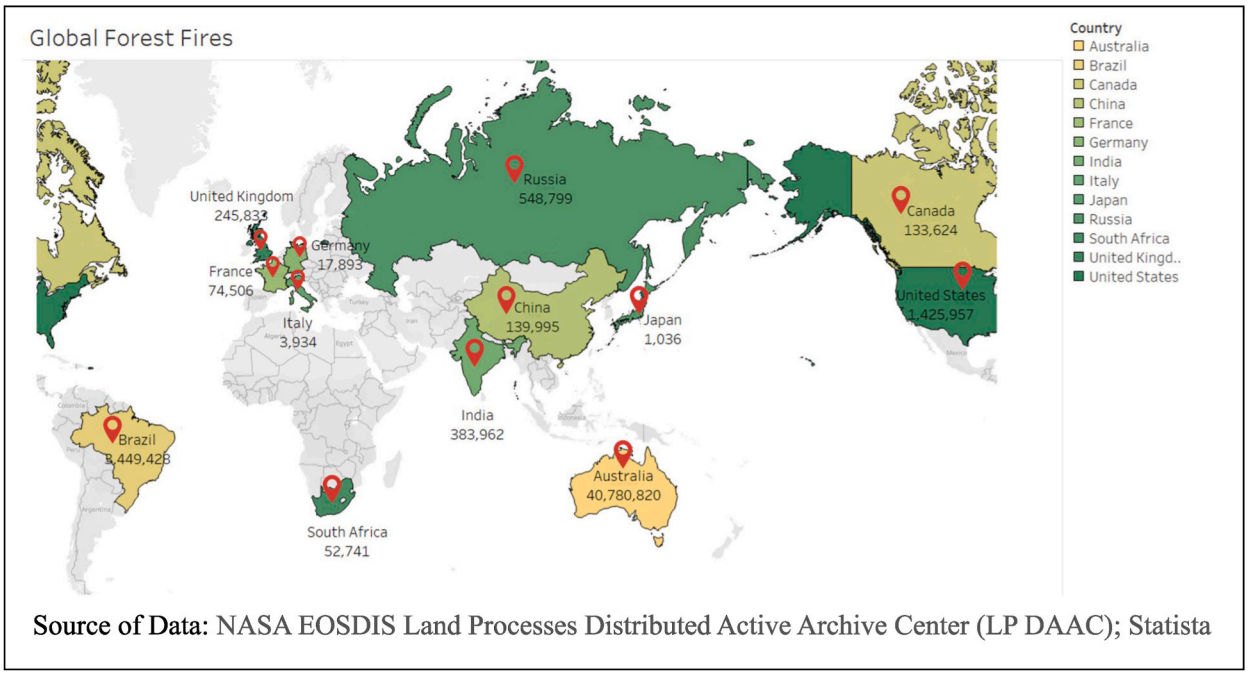


**Fig. 1.** Global forest fires: A visual overview (2000–2019).
Source of Data: NASA EOSDIS Land Processes Distributed Active Archive Center (LP DAAC); Statista

instance, community residents whose property is affected by forest fires change their land use habits to reduce the risk of future fire occurrences, yet their overall vulnerability to forest fires is shaped by political and economic factors (Purnomo et al., 2017). Local zoning laws allow development in fire-prone areas without proper firebreaks, and increase community vulnerability; corruption and bureaucratic inefficiencies aggravate fire hazards rather than curbing them. Forest fire management is not just about solving the problems created by vulnerability; it also calls for action at the root cause.

An illustrative example is the experience of communities dealing with forest fires and climate change; these communities have experienced "double exposure" (Burrell et al., 2022). Different strategies should be adopted by communities that are already facing forest fires and extreme weather events. Factors such as insufficient firefighting resources, restricted availability of advanced early detection technologies, and inadequate community preparedness. To comprehensively address global and regional goals in the forest fire scope of work, genuine strategies for regional areas must be delineated in recognizing the level of forest fire risk. Forest fire management is not necessarily a completely unified field when it comes to definitions and objectives among its practitioners; however, more important is to clearly state goals and adapt strategies to the specific context.

### *2.2. Challenges in assessing the effectiveness of forest fire management*

It is difficult to assess the effect of forest fire management complications. The assessment of forest fire initiatives involves the use of practical means of monitoring progress and change, based on both quantitative and qualitative indicators, which will help in highlighting the observable impacts of these initiatives. However, it is difficult to choose the right metrics to assess the success of forest fire management initiatives as there are different perspectives on what "success" looks like. The need to assess efforts in forest fire management is primarily driven by economic considerations. Standardized metrics will provide a way to compare the efficacy of interventions globally and help guide decision-making on how funding should be allocated.

The assessment of forest fire management is not confined to economic efficiency and includes a broader range of criteria such as ecological health, community well-being or sustainable resource management. The simultaneous and interconnected nature of forest fire impacts makes a practical challenge for establishing causality between action and outcomes. Factors like land use policies, community engagement and climatic conditions are contextual in nature and make it more challenging to attribute outcomes to individual forest fire management activities. Also, the effects of forest fires operate on longer timescales; it may take years for outcomes to show. These fires have lingering effects on ecological recovery, soil regeneration, and carbon cycling, all such processes might take years to even decades to fully emerge from these flames. The success of forest fire management often involves demonstrating the prevention of anticipated problems or impacts.

Although the knowledge is rapidly increasing on many environmental issues, relatively few studies address forest fires and their impacts. The literature on this topic is comparatively limited, which indicates a gap to assess forest fire management operations and the outcomes of these efforts. This scarcity of studies underscores the need for more focused research to delve deeper into the complexities of forest fires and develop effective strategies for their mitigation. Examining the effectiveness of forest fire management through a

systematic analysis of published studies provides an opportunity to gain insights into current practices and challenges, contributing to the ongoing improvement of forest fire management strategies.

## 3. Review methodology

### 3.1. A systematic review protocol and literature search

Systematic reviews integrate the results of studies to answer a specified question by combining the results of many studies used in policy and practice (Gusenbauer and Haddaway, 2020). The standard procedures of systematic review process frequently cover (i) literature search which comprises extensive and structured searching through electronic databases to detect related sources; ii) Filtering the relevancy of studies retrieved; and iii) assessing eligibility for inclusion or exclusion based upon set criteria (Shaffril et al., 2020). So, to ascertain the integrity of the finding, a meticulous review of pertinent studies of forest fire-induced degradation was carried out. The literature search concentrated on earlier research that looked at how forest fires affect growth in the economy, climate changes, tourism, health, technology development, and other macro factors that were taken into account for the degradation of forests and the sustainable livelihood of indigenous people. To find pertinent papers on research on forest fires carried out globally from 2000 to 2023, the time frame of 2000–2023 was chosen to reflect a period of significant escalation in global forest fire events and growing scientific and policy attention towards climate-related environmental disturbances, the two scholarly databases ScienceDirect and Scopus were searched. Research published in 2000 or after is taken into account when comparing research on the same topic conducted in the last two decades. Keywords listed in Table 1 were used to perform literature searching.

### 3.2. Descriptive analysis of articles

This section provides an overview of the key characteristics of the reviewed articles, encompassing year-wise publications, geographical distribution, journals, and document types. The analysis extends to the examination of publication patterns across different countries. The deliberate choice of the term 'forest fires' over 'wildfires' in this study's search strategy aimed to focus on the specific impacts of fires within forested areas. While 'wildfires' is a broader term, often encompassing fires in non-forest environments, concentrating on 'forest fires' allows for a detailed review of studies addressing the ecological, economic, and social dimensions within forest ecosystems, thus enhancing the depth and specificity of the analysis. The review revealed a scarcity of literature specifically on forest fires. Incorporating studies on forest fires mitigates this limitation, ensuring a comprehensive review and avoiding research gaps. While there is a considerable volume of publications on wildfires, there is a noticeable scarcity of literature specifically on forest fires, highlighting the novelty and significance of this study in contributing to this underexplored research area. Fig. 2 encapsulates the trends related to forest fires, presenting a comprehensive visualization of the research landscape.

### 3.3. Literature selection, inclusion, and exclusion criteria

The methodological framework and selection procedure for the systematic examination of literature is shown in the flow diagram in (Figs. 3 and 4). Following the criteria for inclusion and exclusion, pertinent studies were chosen and incorporated into this analysis. Publications that provide original data that were available in an English-language, peer-reviewed journal and made accessible online in the full-text form are required to be considered. However, to ensure the caliber of the research that was included, the thesis, dissertation and other unreleased publications were eliminated. Research that is included primarily examines how forest fires affect economic growth, public health, climatic changes, tourism, and the overall impact on indigenous cultures. A total of 2,20,321 records were initially identified across the two databases. ScienceDirect and Scopus were selected as the primary databases for this review due to their broad interdisciplinary coverage, high indexing quality, and relevance to the environmental, economic, and public health dimensions of forest fire research. Together, they offered access to a robust body of peer-reviewed literature while allowing for methodological consistency and efficient screening. After removing duplicates, 67,234 publications remained for screening. Titles, abstracts, and keywords were assessed for relevance, resulting in the exclusion of 16,774 studies that did not meet the inclusion criteria. obtained. In addition to fulfilling the predefined inclusion criteria, the retained studies were appraised for quality based on

**Table 1**
Keywords and publication counts by database.

| No. | Keywords used for both databases | Number of articles in each database | |
|---|---|---|---|
| | | Science Direct | Scopus |
| 1. | "Forest Fire" AND "Forest Degradation" | 31,119 | 1648 |
| 2. | "Forest Fire" AND "Ecosystem Services" | 20,823 | 1139 |
| 3. | "Forest Fire" AND "Climate Change" | 46,608 | 6507 |
| 4. | "Forest Fire" AND "Economic Development" | 31,308 | 617 |
| 5. | "Forest Fire" AND "Human Health" | 25,779 | 758 |
| 6. | "Forest Fire" AND "Tourism" | 6226 | 178 |
| 7. | "Forest Fire" AND "Suppression Cost" | 3505 | 194 |
| 8. | "Forest Fire" AND "Technology" | 39,789 | 1023 |
| 9. | "Forest Fire" AND "Psychology" | 3041 | 59 |

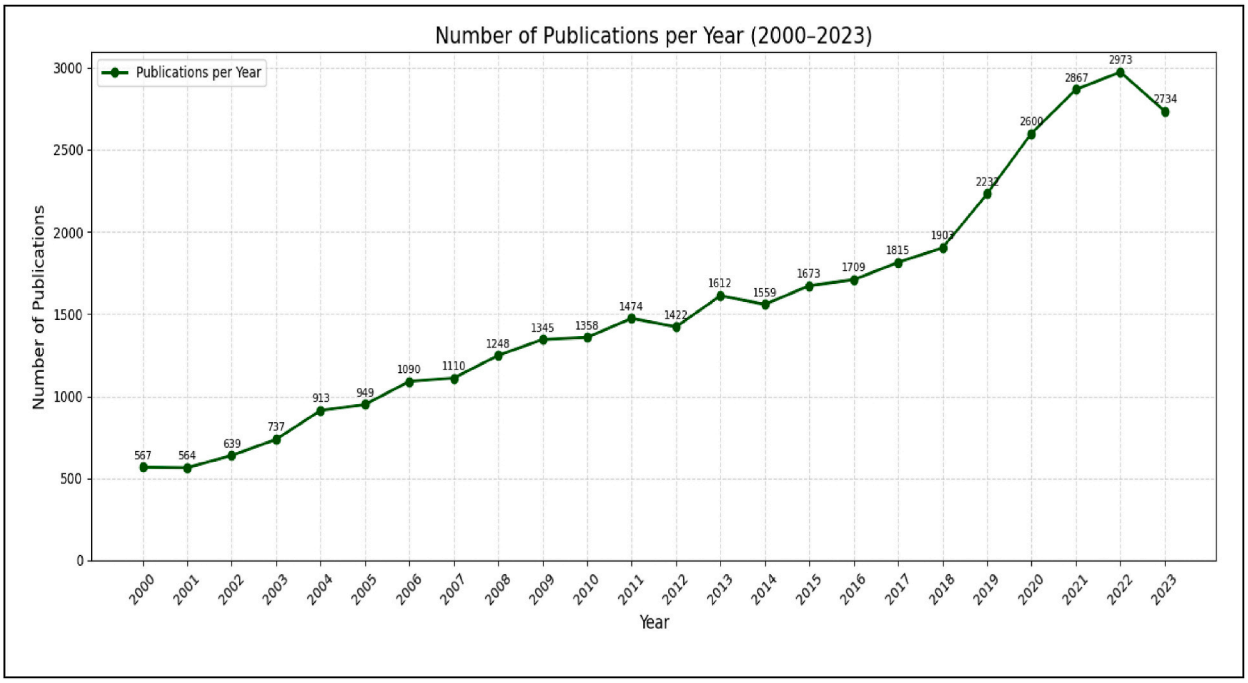


**Fig. 2.** Publications on forest fires by year.

methodological transparency, analytical depth, and relevance to the research objectives. Although all studies were sourced from peer-reviewed journals, further assessment considered whether the research clearly articulated objectives, used sound data collection and analysis techniques, and provided substantive insights into ecological, economic, health, or social impacts of forest fires. Studies that lacked sufficient methodological detail, demonstrated low analytical rigor, or were purely descriptive without contextual linkage to fire-related outcomes were excluded to maintain the robustness and credibility of the synthesis. As a result, 1097 studies were kept for the subsequent full-text evaluation. Following the first evaluation, a detailed text analysis of the research papers that succeeded was carried out. As a result, 142 papers altogether were kept for the conclusive synthesis. This study has also incorporated several reports and government-led projects aimed at improving forest fire mitigation efforts, highlighting their crucial role in addressing the growing threat of forest fires.

### *3.4. Insights from key journals, geographic distribution, and research contexts*

Figs. 5–7 offer valuable insights into the literature review, derived from the papers utilized in this analysis. Fig. 5 highlights the leading journals that are frequently cited, showcasing the primary sources influencing the discourse. Fig. 6 illustrates the geographical regions where research has been conducted, demonstrating the global distribution of studies. These figures enhance our understanding of the key journals and diverse locations that are prominent in the literature, emphasizing the extensive and collaborative nature of forest fire research. Fig. 6 further classifies selected studies according to the contexts in which they were published. This figure illustrates the different document types and subject areas of the research that have been used in the review, highlighting the variety and scope of the studies analyzed.

## 4. Results

### *4.1. Forest fires and climate change*

Climate change and forest fires are linked in a self-reinforcing loop. Forest fires are caused by increasingly severe climate change, but in turn, these fires increase the intensity of this phenomenon. This feedback loop also demonstrates the compounding nature of climate change and underscores why emission reduction is so critical. Forest fires pose a high risk to human lives and have severe ecological implications also, contributing towards climate change (Burke et al., 2021; Ertugrul et al., 2021). Various studies have shown the influence of climate change on fire season length, frequency and burnt area (Westerling, 2016). Annually, these fires emit aerosols and greenhouse gases into the environment and destroy hundreds of thousands of acres of land (Korísteková et al., 2020; Williamson and Menounos, 2021). Lozano et al. (2016) used simulation modelling to reveal an increased likelihood of fires in the future, particularly from 2071 to 2100, as supported by higher Fire Weather Index (FWI) levels and more extreme fire days. Forest fires play a dual role, significantly contributing to greenhouse gas emissions, including carbon dioxide ($CO_2$), methane ($CH_4$), and nitrous

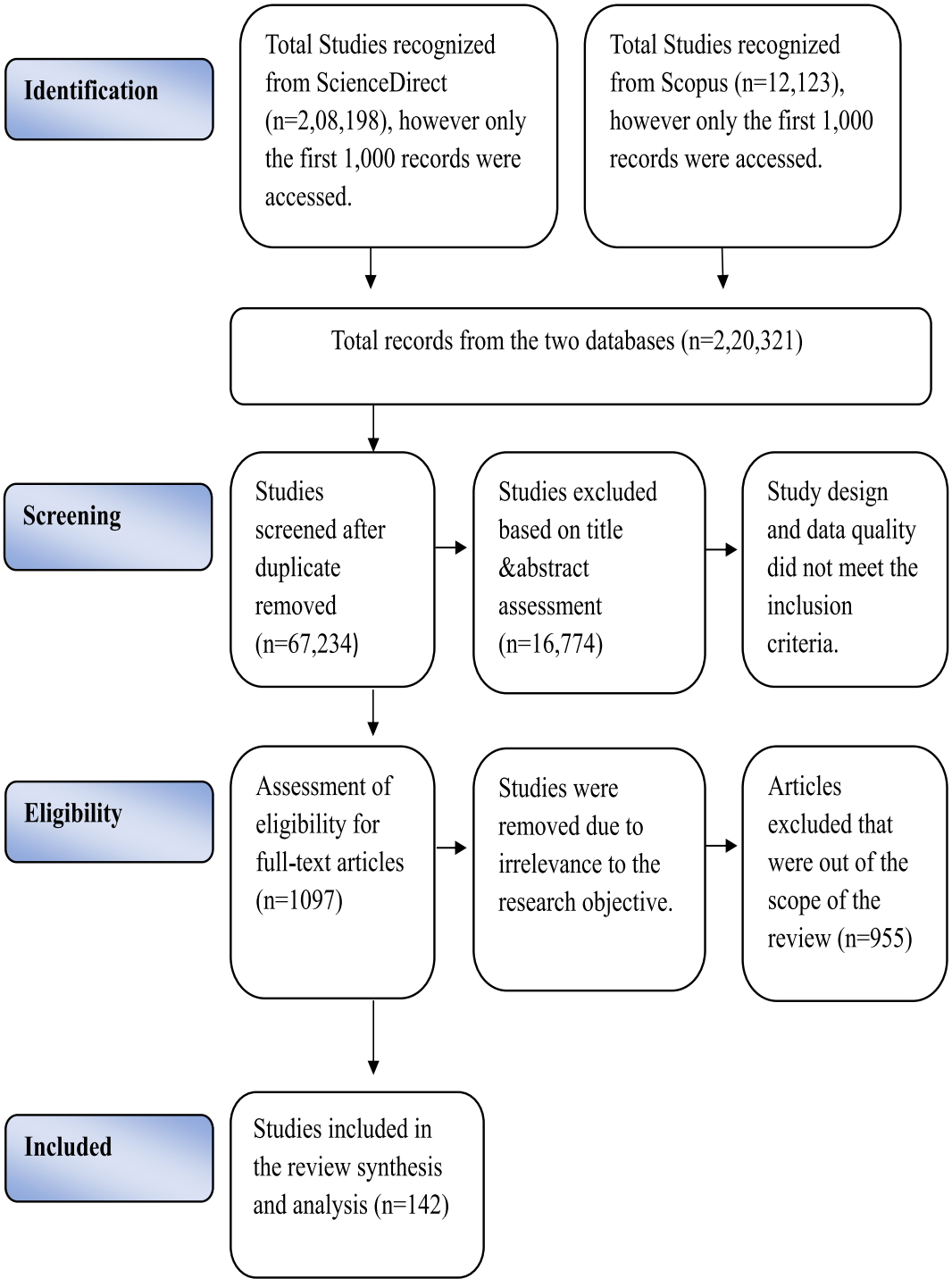


**Fig. 3.** Schematic Figure outlining the methodology phases as well as the selection standards for the systematic literature review.

oxide ($N_2O$), thus positioning them as both consequences and contributors to the complex climate change equation (Volkova et al., 2019; Ribeiro-Kumara et al., 2020). As forests burn, stored carbon is released, further elevating atmospheric GHG concentrations and exacerbating climate change. Climate change and land development's influence on lightning-sparked fires were assessed by Li et al. (2020), finding an increased occurrence in Canada due to human-induced climate change (Gillett et al., 2004). Mansoor et al. (2022) provided recommendations for forest fire control and forest management based on Halofsky et al. (2020) framework. Moris et al. (2020) examined methodological stances on lightning's impact on forest fires. Xu et al. (2020) studied the relationship between forest


**Fig. 4.** Document Selection and Screening Process
Note: CC: Climate Change; BD&ES: Biodiversity and Ecosystem Services; EI: Economic impact; SC: Suppression cost; HH: Human health; TR: Tourism Relation; TD: Technological development.

degradation, fire vulnerability, and climate variability, revealing that forest cover reductions exceeding 40 % led to increased fire activity in over 80 % of affected areas. Bowman et al. (2020) highlighted reduced water storage in vegetation due to high evaporation and low precipitation, increasing fire risk. Flannigan et al. (2009) emphasized that climate change, weather conditions, combustible fuels, and ignition agents will impact future forest fires. Additionally, human activity, government regulations, and societal objectives will influence global fire trends. Williams et al. (2019) noted a potential strengthening of the link between human-made climate

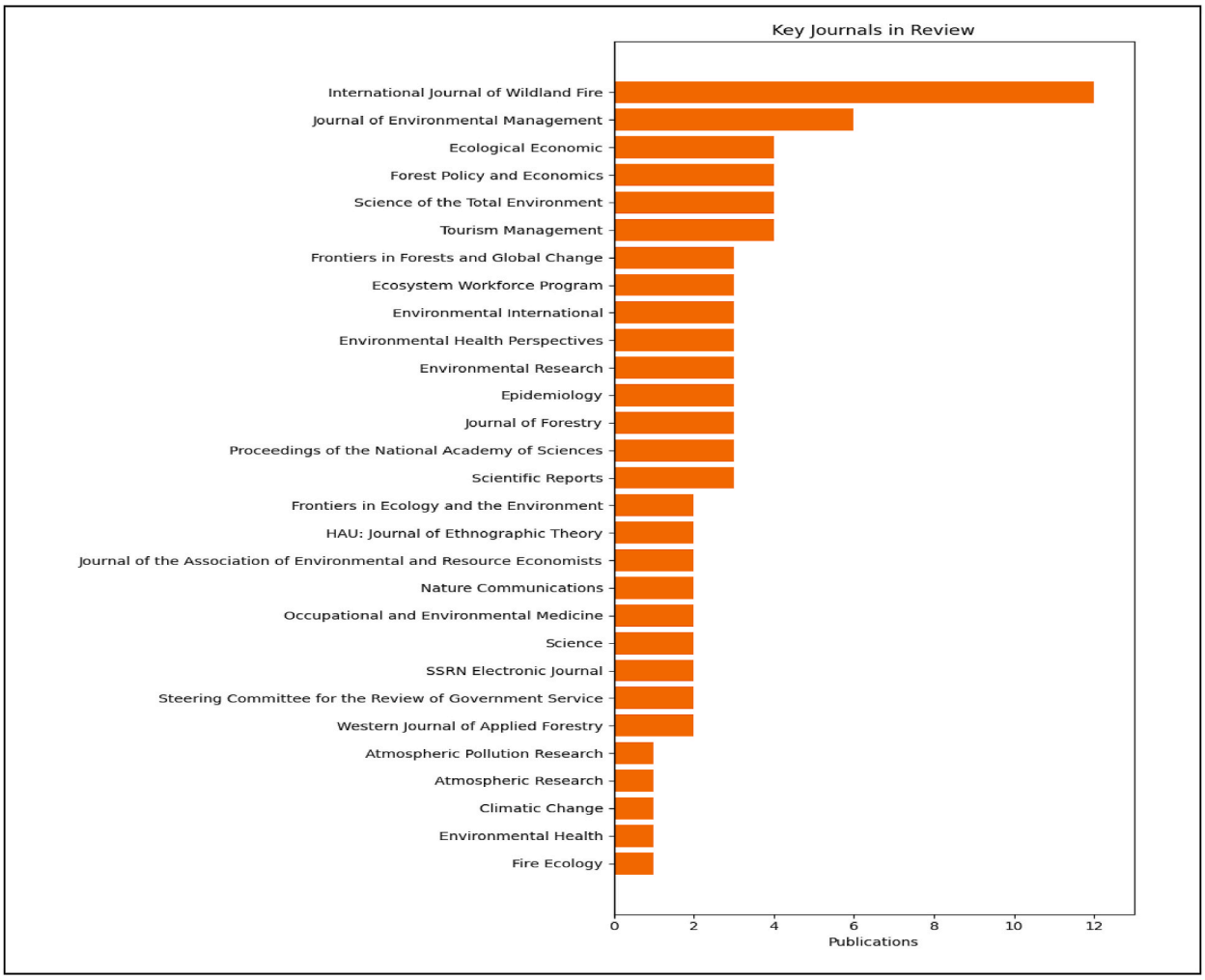


**Fig. 5.** Leading lights: Key journals in Review

change and autumn forest fires as temperatures rise, potentially offsetting decreased offshore winter fires. A substantial research gap in the field of climate change and forest fires lies in the development and implementation of comprehensive, proactive, and region-specific mitigation and adaptation strategies. While there is a wealth of research on the impacts of climate change on forest fires, there is a limited focus on practical measures that can effectively reduce the risks and consequences of such fires in various ecological and geographical contexts. Closing this gap is vital, as it would empower communities and policymakers with evidence-based strategies to mitigate the increasing threat of forest fires in a changing climate.

### *4.2. Forest fires, biodiversity, and ecosystem services*

Forest fires are widely recognized as a major driver of disturbances in multiple types of ecosystem processes (Bixby et al., 2015; Roces-Díaz et al., 2021), and the impact on ecosystem services has been poorly assessed. Widespread, high-severity forest fires can disrupt critical ecological functions like changes in the soil properties, disrupting the carbon and water cycles and consuming vast quantities of biomass (Shakesby and Doerr, 2006; Santín et al., 2015). Moreover, intense forest fires lead to reduced biodiversity and population declines in a number of species (Pastro et al., 2011; Lindenmayer et al., 2014; Lawes et al., 2015; Leahy et al., 2015; González et al., 2022). Furthermore, forest fires change the behavior of animals, community dynamics and climatic conditions all of which may as well affect the immune system of animals and vulnerability to pathogens (Albery et al., 2021). Pausas and Keeley (2019) argue that when viewed across a broader evolutionary and socioecological spectrum, fires are beneficial to humanity in most environments. However, Sil et al. (2019) counter this point by suggesting that instead of "wildfire", refer to it as simply “fire” to enable a more balanced view of its impact towards human well-being. The articles also underscore the intricate relationship of fire with other ecosystem features and processes and how it can interact to drive social benefits and drawbacks. An integrated ecosystem services–disservices approach to understand and manage practical implications of fire (Pausas and Keeley, 2019). Harper et al. (2018)

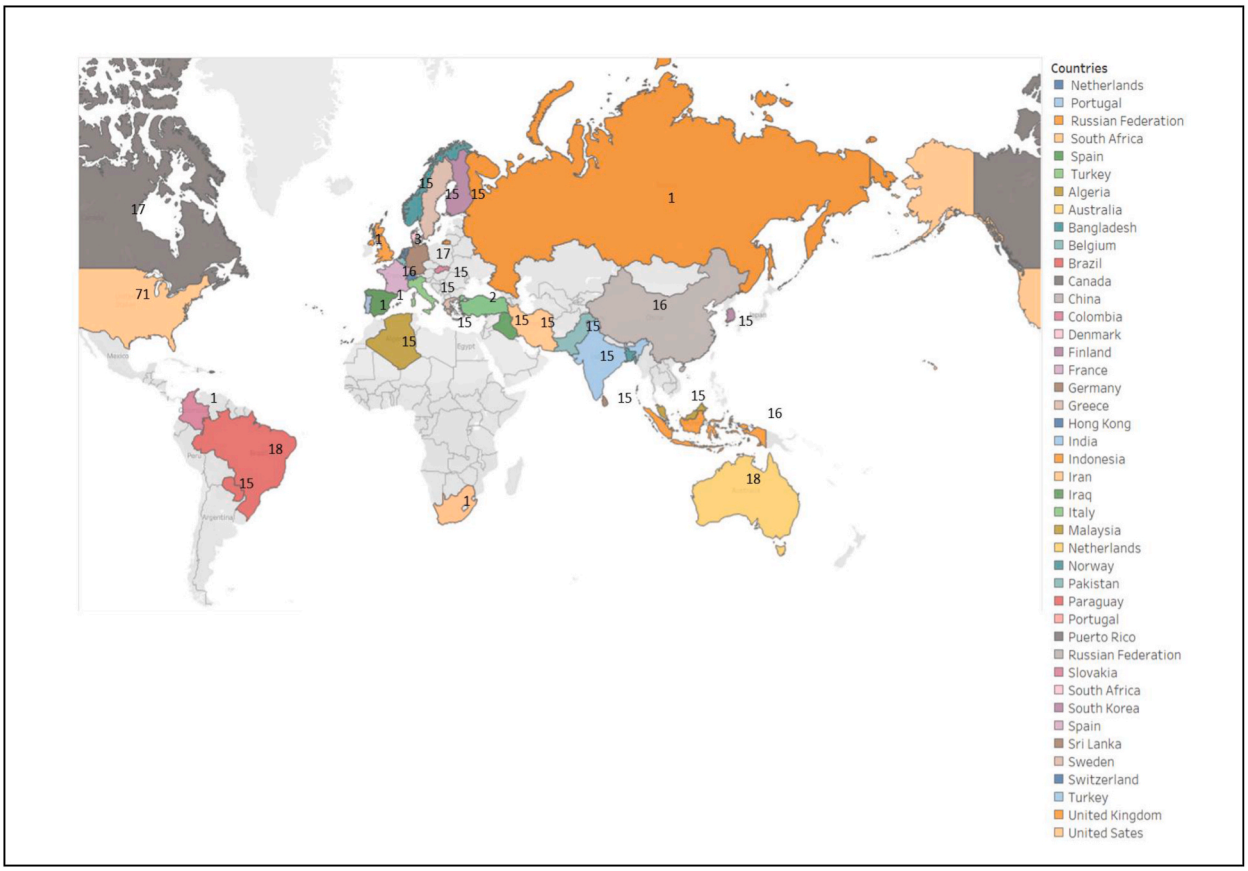


**Fig. 6.** Leading nations in forest fire research publications.

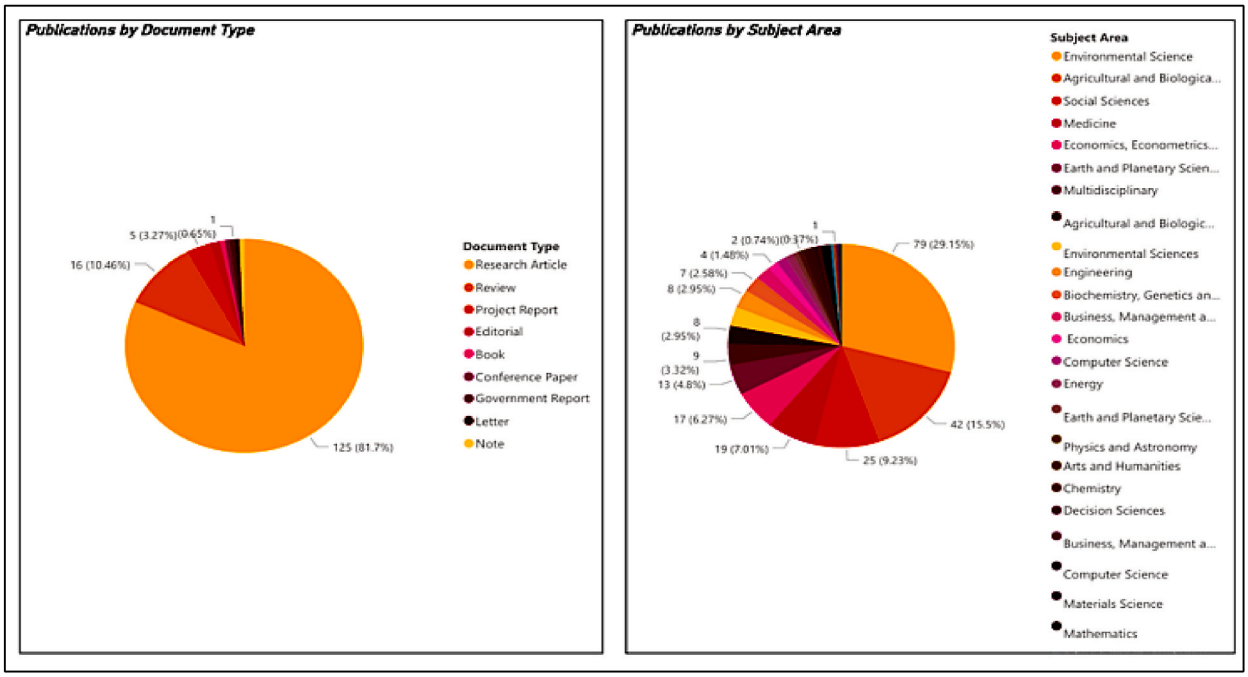


**Fig. 7.** Classification of publications: Document types and subject areas.

reviewed a range of essential ecosystem services affected by prescribed fire, such as water quality, carbon dynamics, and habitat structure. Schmerbeck et al., 2015 show the importance of fire-driven ecological services (FDES) in tropical dry forests in Andhra Pradesh, India and also demonstrate large economic losses due to forest fires in this region. Roces-Díaz et al. (2021) globally assessed the effects of persistent fires in the last 30 years on ecosystem services, obtaining mixed results, finding improvements in water supply but negative effects on water quality, climate regulation, and erosion control. Mediterranean climate has become a vulnerable site of forest fires that pose potential threats to both the landscape and human welfare (Çoban and Erdin, 2020; Sivrikaya and Küçük, 2022). These fires are hazardous for humans, environmental fauna and flora (Garbolino et al., 2017; Naderpour et al., 2019). Bo et al. (2020) underscored the role of forest fires in desertification, deforestation, land degradation and carbon dioxide absorption. However, despite the crucial part played by forest fires in maintaining ecosystem health, they have posed growing threats to biodiversity globally (Barlow et al., 2019; Feng et al., 2021). De Barros et al. (2022) assessed the substantial habitat loss caused by the mega-fires in 2020 especially by jaguars. Ward et al. (2020) highlighted that Australia's 2019–2020 mega fires burned 97,000 $km^2$ of vegetation, destroying habitats for 832 vertebrate species and severely threatening biodiversity. Species composition can shift with forest fires as the fire mortality rate changes (Brando et al., 2014; Massad et al., 2015). Post-fire succession is influenced by plant preferences and lifespan (He et al., 2019). In conclusion, forest fires have multifaceted effects on ecosystems, impacting ecosystem services, biodiversity, and human well-being. An integrated perspective that considers both the positive and negative consequences of fire is crucial for understanding, managing, and communicating its real implications. Existing research predominantly emphasizes ecological aspects, yet a conspicuous gap exists in comprehending the broader, interconnected ramifications of forest fires on ecosystems and human well-being. Thorough socio-ecological assessments are required, encompassing the evaluation of social, economic, and cultural impacts alongside ecological consequences. A socio-ecological perspective can illuminate the extensive effects of forest fires, encompassing economic losses, cultural upheaval, and shifts in community dynamics.

### 4.3. Economic impact of forest fires

In the global effort to combat forest fires, the "Geospatial-based Environment for Optimization Systems Addressing Fire Emergencies" project emerges as a notable initiative with a total cost of €1,386,000.00 (GEO, 2023; Gallego et al., 2019). This project leverages geospatial technology to optimize systems addressing fire emergencies, utilizing advanced mapping and analysis for more precise and efficient emergency response strategies (European Commission, 2023). Alongside this project, various countries have implemented innovative financial strategies to address the threat of forest fires. Indonesia's 'Social Forestry Program', which is supported by the World Bank, empowers communities to sustainably manage forests themselves, ultimately cutting down fire risk (World Bank Group - International Development, Poverty and Sustainability, 2023; Aryal, 2020). The "Amazon Fire Fund" is part of the Amazon Fund; its mission is to prevent deforestation in the Brazilian Amazon. It allocates resources for research, satellite monitoring, and community initiatives to strengthen the rainforest's defenses against fires and promote sustainability by raising non-reimbursable contributions (Amazon Fund, 2023). In California, the "Forest Resilience Bond" takes a proactive approach by funding critical restoration projects, including controlled burns and brush removal, to address fire risks (Blue Forest Conservation, 2023). The billion-dollar NASA program "Global Fire Monitoring System", uses real-time fire data to assist with early warnings and rapid response actions (Global Fire Monitoring, 2023). Together, these financial firewalls are a powerful example of the critical importance that financial assistance can play a strong role in protecting forests from fires on an ever-growing scale. However, forest fires are still causing short-term economic losses and increasing firefighting costs. They lead to long-term, chronic economic damages through impacts on timber resources, ecosystems and habitats that often require expensive restoration or mitigation. Both short-term and long-term implications have been done, for instance, studies on economic costs of forest fires, in 2018 California forest fires generated $148.5 billion in short run which is enough to save 1.5 % of the state's annual GDP as well. Similarly, the Australian fires in 2020 led to economic losses estimated at roughly $20 billion (Filkov et al., 2020). Silva Rodríguez et al. (2012) investigated ten large fires in Andalusia and found an 89.41 % degradation of timber resources, with stand vulnerability estimated at €157,420,809. The short-term economic benefits of reducing energy poverty due to forest fires in Nepal were considerably lower, estimated at $0.12 million, compared to the expected economic benefit of $2.9 billion (Paudel, 2021). Nielsen-Pincus et al. (2011) observed an increase in federal salaries due to forest fire suppression, but private industry employment and earnings declined significantly. Nielsen-Pincus et al. (2012) reported positive short-term impacts of large forest fires on local employment and wages in the western U.S. Conversely, long-term financial costs associated with U.S. Forest fires were substantial, ranging from $71.1 billion to $347.8 billion in 2016 (Thomas et al., 2017). Mosley et al. (2013) noted that Trinity County's Forest fires in 2008 led to suppression costs exceeding $1 million and over $2 million in private timber losses, resulting in road and forest closures. The tourism market also experienced a considerable decline in annual revenue for rural areas in the long run due to forest fires (Davis et al., 2011). In the long run, forest fires can have both positive and negative economic impacts, influencing regular business operations and economic activity (Hystad and Keller, 2008). Additionally, a systematic review of forest fire suppression cost estimation by Mattioli et al. (2022) indicated that the cost of battling fires is steadily increasing due to the indirect impact of climate change and the rise in human activities. In India, Sewak et al. (2021) estimated revenue retention of INR.1101 crore due to forest fire damages. Moreover, economic consequences of forest fires also include significant losses in ecosystem services. For instance, Lee et al. (2015) estimated that preserving ecosystem services through forest fire mitigation strategies could generate economic benefits of approximately $3.5 billion in the United States, underscoring the substantial value of avoided degradation. Similarly, Sánchez et al. (2021) estimated that $CO_2$ emissions resulting from forest fire-induced biomass loss in California forests from 2003 to 2012 had a cumulative social cost of up to $5.2 million, with per-hectare losses reaching as high as $16,662, based on SC-$CO_2$ calculations. These figures highlight the long-term and often underappreciated economic burden of ecosystem degradation following severe forest fire.

One of the most critical research gaps is related to the absence of comprehensive works on region-specific empirical case studies that also address in-depth the compromising mechanism among the short-term and long-term economic consequences. Additionally, there is limited empirical work on the opportunity costs of forest fire-induced land degradation, such as lost productivity or ecosystem service value, highlighting the need for more comprehensive economic assessments.

### 4.4. Forest fires and suppression cost

Recognizing the critical importance of understanding the environmental impact of forest fires for effective management (CIFFC, 2022), much research has traditionally centered on the economic aspects of fire control. While many studies have explored the causes of forest fires, such as air pollution Tariq et al. (2023) and fire incidence, including ignition potential Couto et al. (2020), and considered variables like forest fire size distribution Ning et al. (2022), policy tools Morello et al. (2017), and structural damage Alcasena et al. (2022), there has been relatively limited research Plantinga et al. (2022); Hesseln et al. (2010) addressing suppression costs and firefighting expenses in the context of economic versus physical damage metrics. Suppression costs represent a significant portion of the expenses associated with forest fire management (Report on government services, 2015). Studies have focused on identifying the main factors influencing these costs and the reasons behind their increase over the past two decades (Calkin et al., 2005; Thompson et al., 2013b; Gude et al., 2013). Notably, a critical research challenge involves identifying factors, interventions, and regulations that exhibit delayed responsiveness to "significant" fires in terms of magnitude (Gebert et al., 2007; Liang et al., 2008). The increment in suppression cost will keep on increasing due to higher frequencies of these catastrophic climatic events (Barbero et al., 2015). Marshall et al. (2023) found that per-hectare suppression costs decline with an increase in fire area because of the reduction in perimeter-area ratio, whereas total suppression costs per fire rise. As the area increases with the growing population there is an increment in suppression cost and forest fires in these regions, leading to intensified suppression efforts (Sharples et al., 2016). It is perhaps no surprise that suppression costs in Spain have rocketed over the past two decades. Statistics from significant fires in the southern part of the country between 1993 and 2012, as reported by Molina et al. (2016), that despite reduced burnt areas, suppression expenses more than doubled. For instance, the cost of extinguishing a large fire in Beas in 1993 was estimated at €180,660 (or $205, 750 in 2012), whereas extinguishing a fire in Con-Marbella in 2012 was projected to cost €510,000 (or $580,829) and resulted in an 8230-ha catastrophe. Global fire management faces the challenge of curbing fire suppression costs while addressing increasingly devastating fires with limited resources. This challenge has led to increased government funding for urgent suppression (Campos et al., 2019; Fisher, 2021; Mendes, 2010). Annual fire suppression costs in the United States are projected to increase by 67 % over the next decade (Topik, 2015), having already surpassed $4 billion in 2021 (National Interagency Fire CenterExternal Affairs Office – NIFC, 2021). Other nations also allocate substantial resources to combat fires, with Spain budgeting €600 million annually (MAPA, 2019), Portugal allocating €78.1 million (Comunicar, 2017), and Australia spending $553 million in 2019 (NSW, 2019). In Brazil, the average fire suppression budget in the Amazon and Cerrado biomes is $0.51 $ha^{-1}$ $year^{-1}$ and $5.32 $ha^{-1}$ $year^{-1}$ respectively. Brazil's fire suppression budget varies by biome (Oliveira et al., 2021). The escalation of using aircraft assets for rapid fire suppression, while seeking to extinguish fires promptly, can lead to ecological drawbacks, particularly in ecosystems adapted to regular fires. This situation underscores the need to balance immediate suppression efforts and the long-term ecological impact of fire control, especially in fire-adapted ecosystems. Despite significant research, the practical application of proposed frameworks and decision support tools for suppression cost management remains limited. Addressing these challenges may necessitate reevaluating current concepts to encompass broader implementation options.

### 4.5. Forest fires and human health

Forest fires have significant ecological impacts, one of the most significant being the pollution of the air, especially through particulate matter known as $PM_{2.5}$. These contaminants may result in increased health issues like respiratory and cardiovascular illness (Stowell et al., 2019; Reid et al., 2016). Several detailed studies have investigated the relationship between forest fire smoke inhalation, specifically $PM_{2.5}$, and a heightened risk for asthma, along with bronchitis, chronic obstructive pulmonary disease (COPD), and pneumonia (Gao et al., 2023; Liu et al., 2015). For instance, Cobelo et al. (2023) conducted a 16-year study that analyses the effects of forest fires on air quality and health, they concluded that $PM_{2.5}$ can contribute to thousands of more deaths. Clarke et al. (2022) went into great detail on forest fires, stressing the importance of climate change mitigation. Matz et al. (2020) examined the consequences of forest fires at a local, national and global scale, and emphasized the need for efficient anthropogenic climate change mitigation to prevent such outcomes. Meanwhile, Fann et al. (2018) highlight the adverse economic effects of forest fires in the United States, estimating billions of dollars in healthcare costs. Delfino et al. (2009) investigated the relationship between particulate matter ($PM_{2.5}$) and cardiorespiratory hospital admissions during forest fires in Southern California. In particular, they concluded that there is a strong association between $PM_{2.5}$ and respiratory hospitalization events during fires, particularly among specific age groups. Examining the impact of forest fires on outdoor personnel, Evoy et al. (2022) reported increases in injuries during forest fire smoke episodes, particularly among those with more heat exposure and agriculture and construction workers. Henderson et al. (2011) were able to show a straightforward association between the occurrence of health problems for patients with pre-existing respiratory diseases and high levels of PM10. Morgan et al. (2010) investigated the correlation between bushfire PM10 and hospital admissions, notably finding significant increases in respiratory diseases like asthma and chronic obstructive pulmonary disease. Künzli et al. (2006) assessed the health of children during forest fires, finding a strong relationship between exposure to forest fire smoke and an array of general symptoms that are most severe in children without pre-existing asthma. Furthermore, Hanigan et al. (2008) estimated daily emergent hospitalizations for cardio-respiratory diseases during fire Events PM10 which showed that associated hospitalization rates were

higher, with a marked effect observed among the native population. Xue et al. (2021) evaluated the impact of landscape fire smoke on children's health in low to middle-income countries, revealing an increased risk of newborn deaths associated with $PM_{2.5}$ exposure. In 2010, during Moscow's heat wave and forest fires, Shaposhnikov et al. (2014) analyzed daily deaths, pollution, and temperatures from 2006 to 2009. They found nearly 11,000 extra non-accidental deaths, spanning different age groups. Roberts and Wooster (2021) estimated the annual mortality caused by landscape fire smoke, attributing millions of premature deaths to this phenomenon, with a significant portion affecting children under the age of five. Wettstein et al. (2018) analyzed emergency department visits for cardiovascular and cerebrovascular diseases linked to forest fire smoke exposure in California, reporting increased rates forest fire smoke exposure led to a 5–9 % increase in cardiovascular and cerebrovascular emergency visits, with the strongest effects seen for heart failure and ischemic heart disease, older adults (65+) were particularly vulnerable. Alman et al. (2016) highlighted an association between $PM_{2.5}$ from forest fires and hospital visits and stays for respiratory Forest fire-related $PM_{2.5}$ exposure was significantly associated with increased respiratory ED visits, especially for asthma/wheeze (OR = 1.07, 95 % CI: 1.04–1.10) and COPD (OR = 1.07, CI: 1.02–1.12). Studies by Faustini et al. (2015) and Requia et al. (2021) highlighted the relationship of forest fire with PM10 or $PM_{2.5}$ and increased mortality rates. Requia et al. (2021) reported increased respiratory and cardiac hospitalizations for $PM_{2.5}$ associated with forest fires by 23 % and 21 %, respectively in Brazil (2008–2018).Kollanus et al. (2017) particularly examined the effect on public health in Europe from $PM_{2.5}$ emissions through vegetation burning, resulting in premature mortalities. Datar et al. (2013) concluded that natural disasters, including forest fires, are likely to have detrimental consequences on health problems and growth retardation in children. Liu et al. (2017) highlighted that Californian counties that experience more days of elevated $PM_{2.5}$ from forest fires are associated with births and asthma-related emergency room visits. A significant research gap in forest fire-related health outcomes is the lack of large-scale and long-term studies investigating the chronic health impacts of exposure to forest fires. Existing research often focuses on immediate or short-term health impacts, but a deeper investigation into the lasting consequences, especially in vulnerable populations, is essential for effective public health planning and intervention strategies.

### 4.6. Forest fires and Tourism Relationship

The impact of forest fires on tourism should be distinguished from their broader economic effects. Tourism is uniquely sensitive to visitor perceptions of safety and desirability, with immediate declines in bookings and cancellations. Reputation recovery is slow, affecting local businesses. Tourism's time-sensitive nature further sets it apart, requiring targeted mitigation strategies. Tourism is essential for the economic growth of various nations, particularly emerging economies (Bhat et al., 2021). However, the tourism industry is increasingly vulnerable to the rising threat of forest fires, leading to immediate repercussions like asset devaluation and decreased recreational appeal. Yet, quantifying the comprehensive economic costs associated with future declines in tourist numbers remains a significant challenge. Research by Otrachshenko and Nunes (2021) indicates that regions affected by forest fires have a substantial negative impact on both domestic and international tourist arrivals. For Portugal, they project economic losses of €17.03 to 24.18 million for domestic visitors and €18.26 to 38.08 million for foreign visitors by 2030, with these costs expected to multiply by at least four by 2050. Kim and Jakus (2019), examined the impact of neighboring forest fires on visitor patterns in Utah's national parks, revealing economic losses ranging from $2.66 million to $4.50 million due to reduced visitor spending. Hystad and Keller (2008) found that forest fires can influence travellers' decisions, with 25 % of respondents willing to postpone vacations due to forest fires. Thapa et al. (2013) explored the impact of forest fires on tourist behavior in Florida, where a catastrophic blaze in 1998 resulted in significant losses for hospitality and other sectors (Butry et al., 2001). Forest fires have diverse effects on recreational demand and hiking, with post-fire hiking demand increasing but mountain biking demand decreasing in some cases (Loomis et al., 2001; Hesseln et al., 2004). Rosselló et al. (2020) found that forest fires are the second most economically damaging category of disasters, with each million dollars allocated to disaster assessment resulting in a 0.03 % reduction in tourist numbers. Bauman et al. (2019) stressed the importance of travellers with a higher natural catastrophe empathy scale, and especially against the background of natural disasters. To sum up, forest fires can generate significant economic consequences for tourism, which fully justify the need to implement appropriate measures of prevention. An important research gap is the need for the development of sustainable long-term strategies to offset the economic impacts on tourism by forest fires while focusing on adaptability, risk communication and infrastructural resilience. A more comprehensive evaluation of the economic importance of tourism, which also examines a broader base of employment types and revenue characteristics, is required.

### 4.7. Forest fires and technological developments

The domain of forest fire management holds many scientific and technological breakthroughs that prove to be instrumental in limiting the losses due to these fires. Including technology advances in prevention, surveillance, suppression, land use planning and post-fire restoration indeed offers a set of powerful management tools for the development of more adaptive fire policies. For instance, Olmo (2022) delve into cutting-edge fire-fighting and forest fire control technologies, covering these innovations in their patented documents. They also expound on the essential programs and guidelines that Iberian organizations have implemented to combat and manage forest fires. Meanwhile, Gnusov et al. (2020) are dedicated to enhancing the efficiency of ground-throwing machines in forest fire prevention, employing techniques like the removal of combustible topsoil layers. Furthermore, Bouguettaya et al. (2022) prioritize early forest fire detection in forested and wilderness areas. They achieve this through the utilization of deep-learning computer vision systems, driven by artificial intelligence and UAV-based visual mapping, which markedly improve fire suppression by enabling the early detection of flames in these natural settings. Dampage et al. (2022) propose an efficient strategy for forest fire detection that relies on wireless sensor networks and machine learning. Their approach results in precise findings, aiding in early detection and response to

forest fires. Moreover, Cao et al. (2019) introduce the Attention Enhanced Bidirectional Long Short-Term Memory Network (ABi-LSTM) for recognizing forest fire smoke in video footage. This model incorporates spatiotemporal attributes and adjusts attention to different patches in the video, enhancing the accuracy of smoke detection. Joshi and Sukumar (2021) employ artificial neural networks to explore the complex relationships between forest fires and the socio-environmental drivers that influence them. Their models outperform many contemporary fire models in terms of accuracy, revealing the intricate geographical variances in these linkages worldwide. In a tropical peatland setting, Mezbahuddin et al. (2023) examine the benefits of simulating peatland hydrological dynamics for predicting forest fire activity. Their data demonstrates that incorporating eco-hydrologic dynamics significantly enhances the accuracy of fire predictions, particularly during acute drought episodes in regions like Indonesia's Riau. Al-Dhief et al. (2019) thoroughly analyze contemporary mobile ad-hoc network (MANET) routing protocols for forest fire detection. The study

| Theme | Summary | Research Gap |
|---|---|---|
| **Forest Fires and Climate Change** | Climate change intensifies forest fires, and these fires, in turn, worsen climate change through emissions, establishing a self-perpetuating cycle. | A critical research gap exists in developing region-specific strategies to reduce forest fire risks and consequences, limiting evidence-based climate change mitigation. |
| **Forest Fires and Economic Impact** | Forest fires cause short-term economic losses from immediate damage and firefighting expenses and long-term economic impacts, affecting timber .resources, ecosystems, employment and regional economies. | Absence of studies comprehensively examining both short-term and long-term economic consequences of forest fires, and the opportunity costs of land degradation. |
| **Forest Fires and Human Health** | Forest fires highlight significant immediate and short-term impacts, including respiratory and cardiovascular issues resulting from fine particulate matter ($PM_{2.5}$) exposure. | Limited focus on long-term and chronic health effects of forest fire exposure, particularly in vulnerable populations. |
| **Forest Fires and Tourism** | Forest fires significantly impact tourism, necessitating the development of enduring strategies to mitigate their long-term consequences. | Absence of comprehensive, long-term strategies for addressing the impact of forest fires on tourism, including adaptation, communication, and infrastructure resilience. |

**Fig. 8.** Themes, summary and research gap.

| Theme | Summary | Research Gap |
|---|---|---|
| **Forest Fires and Technological Development** | Technological innovations in forest fire management, encompassing prevention, surveillance, extinguishment, land protection, and restoration, are pivotal for effective policies and strategies. | Limited exploration of the practical implementation and real-world effectiveness of technological innovations in forest fire management, including their challenges and successes. |
| **Forest Fires, Biodiversity and Ecosystem Services** | Forest fires have varied impacts on ecosystems, biodiversity, and human well-being, emphasizing the need for a comprehensive socio-ecological perspective to understand their broader consequences. | Absence of holistic socio-ecological assessments covering social, economic, and cultural impacts alongside ecological effects of forest fires. |
| **Forest Fires and Suppression Cost** | There's a need to balance suppression costs with economic and ecological considerations, especially in fire-adapted ecosystems. | The research gap involves understanding the link between suppression costs, economic/physical damage metrics, and ecological impact in fire-adapted ecosystems. |
| **Forest Fires and other effects** | Prior research on forest fires focuses on their profound psychological impact, emphasizing depressive disorders, sleep disturbances, and life satisfaction, as well as the importance of comprehensive fire prevention measures. | Understanding the long-term effects of repeated forest fires exposure on communities and individuals. |

**Fig. 8.** (*continued*).

reveals that the LARRR protocol, in particular, proves highly effective in enhancing the detection of forest fires in these networks. Alkhatib (2014) provide a comprehensive overview of various technologies employed for the detection of forest fires. Their analysis covers a range of methods, including human observation, satellite-based detection, optical sensors, and wireless sensor networks,

offering insights into their methodologies and techniques. The existing literature highlights various technological innovations in forest fire management. However, a critical research gap is the need for more in-depth exploration of the practical implementation and effectiveness of these technologies in real-world forest fire scenarios. This entails examining the challenges, limitations, and successes of technology-based approaches, offering insights for more efficient forest fire prevention and control strategies.

### *4.8. Forest fires and other effects*

The published literature on forest fires highlights the deeply transformative effect of these events on human psychology and overall life satisfaction. Literature from scholars such as Kountouris & Remoundou (2011) and Maida et al. (1989) studied the effects of fires on psychological health, with serious depressive disorders in the most widespread case, insomnia and fatalities. In addition, Kountouris and Remoundou (2011) explored in Spain, France, Italy and Portugal, the association between forest fires and individuals' happiness which revealed a signification reduction in life satisfaction. Maida et al. (1989) observed the effect of media coverage of fires on mental health status. Looking at this from a social perspective, Wunder et al. (2021) provide a systematic and scientifically accurate method for understanding how landscapes and communities might be resilient to fires by having an all-encompassing fire-prevention approach (Li et al., 2022). assessed how anthropogenic drivers influence the probability of forest fire occurrence by accounting for factors such as population density, urban proximity, precipitation, altitude, and topographic wetness index and forest type. Analysis in their study found that the risk of forest fire occurrence was strongly correlated with anthropogenic factors, especially population density and altitude during the 1990s. A recent study by Tariq et al. (2021) also looked at the effect of environmental (elevation, precipitation, forest types, terrain and moisture indices) as well as social-economic (population density, distance from roads and urban areas) on forest fire likelihood. This makes the risk of forest fires in the models almost exclusively an urban phenomenon and proves a sharp correlation between forest fires and factors like population density. Fox et al. (2018) concluded that forest fire occurrences are more in low-density areas. Moreover, Purnomo et al. (2017) talked about the political factors behind forest fires and H. Purnomo et al. (2019) highlighted the consequences of forest fires. They alter the water balance and increase levels of air pollutants in the atmosphere. For example., (Venkatesh et al., 2020), found that following fires causing vegetation loss, increased annual runoff by approximately 25 % relative to a typical non-fire year. Comprehensive studies have been performed worldwide, in the United States (Cerda, 2009); and southern Europe (Van Eck et al., 2016; Cerdà et al., 2017) in order to show the significance of this impact. Yarragunta et al. (2020) noted a sharp uptick in CO, NOx and $O_3$ during the peak fire activity phase in the western Himalayas. Although extensive literature provided valuable insights on the holistic impacts of forest fires, from various perspectives relating to human and environmental well-being, there is a clear lack of research that addresses long-term social and psychological consequences arising from repeated or chronic exposure to forest fires resulting from these events in affected communities and individuals. Understanding how prolonged exposure to such traumatic events influences mental health, community cohesion, and overall life satisfaction would contribute to a more holistic understanding of the consequences of forest fires. This research could aid in developing more effective support systems and policies for fire-prone regions, ensuring the well-being of communities facing recurrent fire threats. Fig. 8 provides an incisive summary of the themes and highlights the research gaps identified across the reviewed literature.

## 5. Discussion

The present study pioneers an investigation into the far-reaching consequences of forest fires, spanning ecological service damage, economic growth, and climate change. Forest fires generate complex, interconnected consequences that span economic, health, and ecological domains. The economic disruptions caused by fires, such as the loss of agricultural output, tourism revenue, and forestry products, not only diminish household income but also strain public resources, including health infrastructure. This economic vulnerability can reduce access to healthcare, heighten susceptibility to disease, and deepen long-term social inequities. Simultaneously, fires significantly degrade ecosystems by damaging air and water quality, disrupting biodiversity, and reducing essential ecosystem services. These ecological damages contribute to respiratory illnesses and food and water insecurity, thereby compounding public health burdens. Such, health impairments, particularly among labor-dependent rural populations, reduce workforce productivity and slow down economic recovery. Understanding the interplay between these impact categories is essential, as it reveals the cascading nature of fire-related damage and underscores the need for integrated, multi-sectoral strategies in both research and policy interventions. The latest data confirms that forest fires are becoming more widespread, burning at least twice as much tree cover as they did two decades ago. In the U.S., the ten-year average suppression cost has risen to $2.52 billion annually (NIFC, 2024), reflecting a growing burden on national budgets. Similarly, China's Heilongjiang region experienced the highest tree cover loss from fires between 2001 and 2023, with an average of 9.36 thousand hectares lost per year (GFW, 2023). In Brazil, 140,000 forest fires were registered in the Amazon in 2024, accounting for nearly half of all the forest fires in the country. (Statista, 2025).

The rising costs of fire suppression are straining national budgets, with forest fires frequency and intensity increasing despite substantial financial efforts. This highlights the inadequacy of current fire management strategies and the urgent need for policy reform. Traditional national income accounting methods focus only on commercial timber value, overlooking the broader environmental, social, and economic losses from fires, such as biodiversity decline, carbon emissions, and damage to ecosystem services. This narrow approach underestimates the true cost of forest fires, complicating mitigation strategies.

While earlier review studies have offered important insights into specific dimensions of forest fires such as the economic inefficiencies of suppression strategies (Bayham et al., 2022), public health impacts and environmental justice (D'Evelyn et al., 2022), and soil property changes (Agbeshie et al., 2022) they often treat ecological, economic, and health consequences separately, and are predominantly based in developed regions. In contrast, the present review adopts a more integrated and interdisciplinary perspective,

linking ecosystem degradation, socio-economic disruption, and climate feedback. Building on this broader perspective, it is crucial to explore four key areas that can enhance the effectiveness of forest fire management:

First, the preservation of forests is widely recognized as a paramount policy objective for environmental conservation, given their substantial ecological and climatic benefits. However, the degradation of forests due to fires underscores the need for strategies that prioritize mitigating, ecological damage and societal costs. Policymakers need to move beyond reactive suppression efforts, which have proven ineffective, and prioritize preventive measures, such as fire-resilient landscapes and sustainable land use planning. Without such reforms, fire suppression costs will continue to rise without addressing the root causes of forest fires. Comprehensive valuation frameworks and proactive strategies are crucial for sustainable fire management. For instance, the restoration of fire-affected ecosystems in California presents a compelling case study. The challenges encountered in this context, including soil erosion, invasive species propagation, and the unpredictability of natural regeneration, underscore the multifaceted nature of restoration endeavors.

Second, this study delves into existing literature on forest fires from a theoretical perspective. The application of theoretical models provides a framework to understand and explain the dynamics of forest fires. While multiple theories and conceptual frameworks have been utilized to study ecological degradation, no systematic review has integrated these theoretical foundations to elucidate the complex linkages between forest fires. For instance, the Environmental Kuznets Curve theory posits an inverse U-shaped relationship between environmental degradation and economic growth, suggesting that as nations progress, they should naturally curtail their negative environmental impacts and invest in ecological restoration. However, this theory has not been connected to forest fires, which invariably lead to significant economic, health, and environmental losses. Similarly, the tragedy of the common's theory has not been applied to present global scenarios, particularly in the context of forest fires. Considering forests as common resources and forest fires as a tragedy of the commons could provide valuable insights for pursuing sustainable forest management.

Third, despite the long history of ecological benefits provided by forests, limited attention has been paid to quantifying the value of these ecosystem services (ESs). ESs encompass a wide range of benefits that people derive from the environment, including provisioning services (e.g., water and food supply), cultural and recreational amenities, and supporting services (e.g., nutrient cycling) (Baskent, 2022). The urgency to quantify Ecosystem Service Values (ESVs) stems from intensified fire seasons, including a 376 % forest fire increase in Brazil linked to droughts, poor management, and land-use changes (Garcia et al., 2021). This quantification is crucial for human well-being, livelihoods, economies, and international trade. Commonly used valuation methodologies, such as market-based methods, cost-based methods, and stated preference methods, play a vital role in assessing the comprehensive value of forests' ESVs. These methods provide insights into economic considerations, restoration costs, and public preferences, contributing to

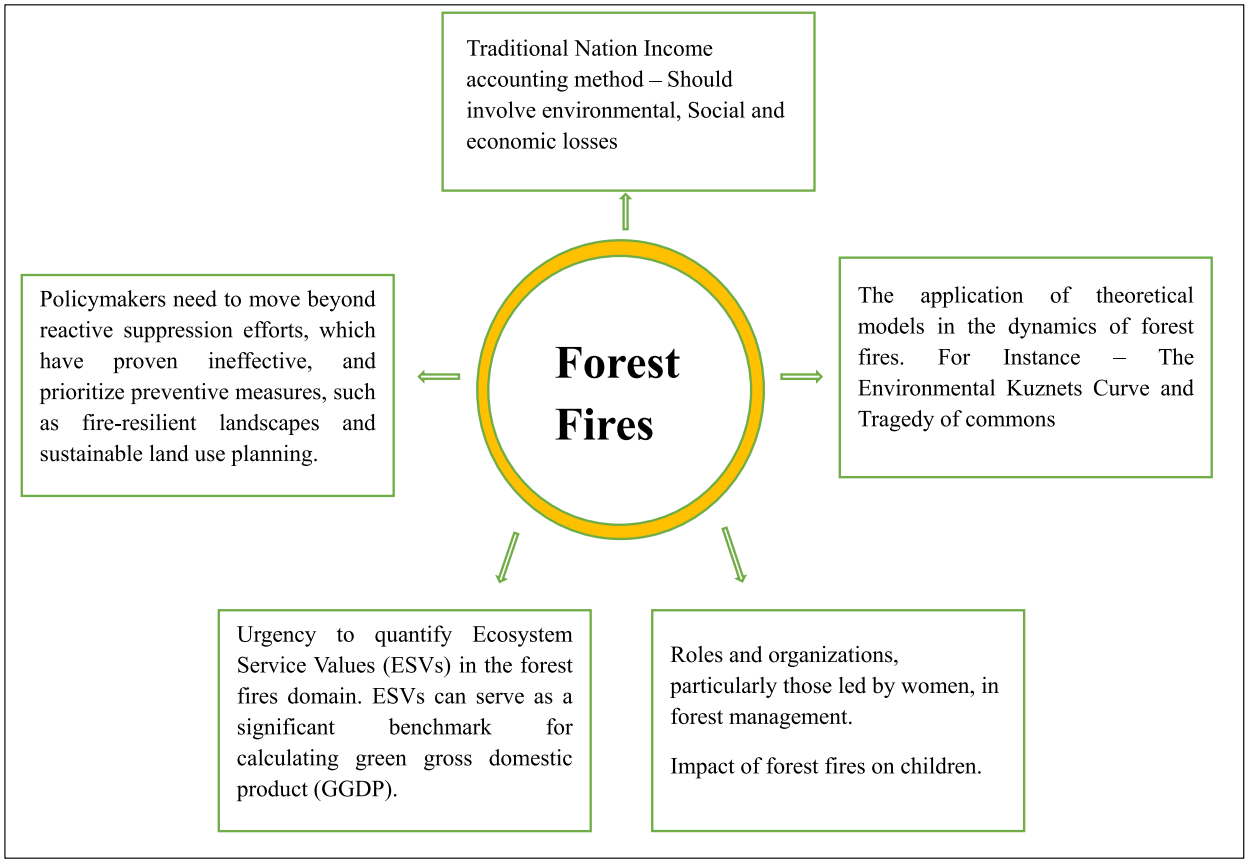


**Fig. 9.** Key points from the discussion.

informed decision-making for environmental sustainability and the responsible use of natural resources. These ESVs can serve as a significant benchmark for calculating green gross domestic product (GGDP) and representing a region's level of environmentally friendly development. The valuation of ESVs, particularly sustaining and cultural services offered by forests, could serve as a foundation for informed decision-making in favor of national environmental sustainability and the sustainable use of natural resources.

Fourth, research indicates that women in South Asian indigenous communities heavily rely on commons and forests. However, there is a dearth of literature that highlights the roles and organizations, particularly those led by women, in forest management. Women's contributions, such as those seen in the Chipko movement in India and the Green Belt movement in Kenya, have played a pivotal role in advocating for forest conservation and sustainable practices. Furthermore, the impact of forest fires on children, especially those aged 0 to 6, remains underexplored. Their vulnerability to forest fires due to limited coping abilities and their survival and well-being during and after such incidents make this an essential area of study. Fig. 9 represent summarized points in the discussion.

## 6. Conclusion

This study contributes significantly to the academic discourse on forest fires by reviewing 142 studies and highlighting key connections between forest fires and areas such as economic growth, public health, tourism, biodiversity, and ecological services. However, gaps remain, particularly in the study of forest fires' effects on infant mortality and female fertility rates. These demographic variables, though critical in understanding the direct and long-term impacts on vulnerable populations, require further exploration.

Importantly, the findings underscore the urgent need for sustained funding and inclusive, community-driven strategies to mitigate fire risks and support recovery. In particular, the active involvement of Indigenous populations, who often hold traditional ecological knowledge and are among the most affected, is essential for designing effective, context-sensitive fire management practices.

The findings call for targeted conservation and fire management policies, particularly those incorporating ecological service valuation to balance economic considerations in rehabilitation efforts. Land managers can benefit from case-specific ecological reconstruction strategies developed from real-world scenarios, while researchers are encouraged to design interventions focusing on sustainable forest management practices, particularly involving women and children.

### 6.1. Policy implications

Based on the synthesis of reviewed literature, several policy recommendations emerge. First, the integration of ecosystem service valuation, such as carbon storage, water regulation, and biodiversity, into post-fire planning can better inform resource allocation and cost–benefit analyses. Second, region-specific fire management frameworks should replace one-size-fits-all approaches, accounting for local land-use patterns, ecological vulnerability, and social dynamics. Moreover, regional and socio-economic imbalances significantly influence the effectiveness of forest fire management strategies. In developed countries, advanced monitoring systems, institutional preparedness, and access to fire suppression technologies contribute to more proactive fire governance. In contrast, developing countries often struggle with limited technical and financial capacity, fragmented governance, and greater vulnerability of local communities to fire-related losses. These disparities necessitate differentiated policy responses that reflect local capacities, socio-economic conditions, and resource availability, particularly in fire-prone regions. Third, policies should consider the opportunity costs of land degradation, including foregone agricultural productivity, recreational value, and timber outputs, which are often overlooked in conventional economic assessments.

Furthermore, investment in early warning systems, remote sensing, and community-based surveillance technologies is essential for shifting from reactive to proactive fire governance. However, the practical implementation of these strategies faces several challenges, including institutional fragmentation, limited technical expertise, lack of long-term funding, and uneven stakeholder engagement. Addressing these barriers will require cross-sectoral coordination, capacity-building initiatives, and inclusive governance frameworks that actively involve indigenous populations, women, and local land users.

Additionally, international cooperation in data sharing, funding mechanisms, and transboundary forest fire mitigation strategies will be critical, particularly in ecologically interconnected regions. These recommendations also align with global sustainability objectives, particularly Sustainable Development Goals (SDGs), 13 (Climate Action), 15 (Life on Land), and 1 (No Poverty), emphasizing the need for integrated fire governance strategies that are both socially inclusive and ecologically responsive. Real-world cases highlight effective fire governance. Indonesia's Fire-Free Village Program reduced burned areas by 90 % across 1.5 million hectares through community incentives, while Portugal's National Action Program aims to cut 47 Mt $CO_2$ emissions and gain €701M by 2030 via integrated, multi-level strategies.

### 6.2. Future research agenda

To address the identified research gaps and advance future scholarship, there is a pressing need for region-specific, longitudinal studies that assess the cumulative impacts of repeated fire exposure on socio-economic development, land degradation, and public health outcomes. Future research should also apply disaggregated methodologies that account for differences in vulnerability across gender, age, and economic strata.

The application of advanced valuation methods, Replacement Cost Method, which estimates the cost of replacing lost or damaged ecosystem services with equivalent alternatives and the Avoided Cost Method, which calculates the expenses that would be incurred in the absence of mitigation or preventive measures is essential for generating more accurate and comprehensive estimates of the

economic and environmental costs of forest fires. Additionally, dynamic risk assessment models that incorporate fire recurrence, climate variability, and land-use change are crucial for improving fire prediction and planning.

Emerging technologies, including AI-powered warning systems, UAV surveillance, and remote sensing platforms, should be systematically evaluated for feasibility, scalability, and regional adaptability. Likewise, adaptive fire management strategies, such as prescribed burning, fire-resilient infrastructure, and participatory planning require rigorous empirical assessment to determine their effectiveness in enhancing resilience at both community and landscape levels.

Future research should also strive to develop integrative frameworks that capture the dual influence of forest fires and climate change, thereby guiding both mitigation and adaptation policy at national and international levels. Crucially, collaboration across disciplines spanning ecology, economics, public health, and the social sciences will be essential to build holistic and actionable strategies for managing the growing risks posed by forest fires.

## CRediT authorship contribution statement

**Laxita Soontha:** Writing – original draft, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mohammad Younus Bhat:** Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization.

## 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.

## Data availability

Data will be made available on request.

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