

Forest Fire Dynamics: Ecological Consequences, Prevention, and Community-Based Management

Sanath Kumar N ^{1*}, Sanjeet Kumar ² and Susanta Kumar Biswal ¹

¹ School of Applied Sciences, Centurion University of Technology & Management, Jatni, Khurda 752050, India

² Biodiversity and Conservation Lab., Ambika Prasad Research Foundation, Cuttack 753015, India

*(e-mail: sanathkumarphdapr@gmail.com)

(Received: 15 August 2025; Revised: 16 September 2025; Accepted: 9 October 2025; Published: 4 November 2025)

ABSTRACT

The present study investigated the drivers and ecological consequences of forest fires and proposes a community-based management framework, with a particular focus on Odisha state, India. A structured literature review on fire drivers, impacts, and governance was integrated with a policy analysis of national and international fire management approaches. Secondary analyses of satellite-based fire records from ISFR (MODIS/VIIRS; 2020–2024) were conducted alongside field surveys and photographic documentation in the Bonai Forest Division, Odisha (2021–2024), to assess burn severity, fuel loads, vegetation response, and ignition sources. Results indicate that India's Central Forest Cluster accounts for the largest burned area, especially within dry deciduous forests. Anthropogenic ignitions predominate, with increasingly hot and dry conditions exacerbating fire severity. High-severity fires were found to reduce seedling recruitment, facilitate invasive species proliferation, and degrade soil structure, moisture, and microbial activity. Habitat simplification and prey scarcity further intensify human-wildlife conflicts near settlements. Evidence highlights that prevention-first strategies such as prescribed patch burns, participatory fire lines, integrated early-warning systems, tiered response teams, and post-fire invasive control serve as the most effective interventions. Overall, the findings emphasize the need for transition from suppression-oriented responses to community-centered, technology-enabled prevention systems that can mitigate destructive fires while preserving the ecological functions of low-intensity burns.

Key words: Biodiversity, ecological balance, forest fire, threats to forest

INTRODUCTION

The global forest, covering 31% of the total land area (Adom et al., 2024), provides essential resources and services for life on Earth (Heino et al., 2015), including biodiversity, carbon storage, water supply, medicines, and foods (Aerts and Honnay, 2011; Zeng et al., 2022). These non-renewable resources are crucial for human existence, supporting biodiversity, and providing essential ecosystem services. In times of crisis, forests have provided socio-economic safety nets for people and communities (Rahimi et al., 2020). Even, they are most important aspects of life on the Earth surface, several natural and man-made threats are identified (Novacek & Cleland, 2001; Shackelford et al., 2018; Adebayo, 2019). Among them, one of the most burning global threats is forest fire or wildfire (Kumar et al., 2023). Forest fires are common and affects any ecosystem, have a detrimental impact on forests' health, productivity, and ability to generate goods and services (Archibald et al., 2013). Forest fire is defined in different forms by different countries. In US, it is any non-structure fire that happens in the wildland and includes

wildfire (Baltacı & Yıldırım, 2020). In Australia, any controlled vegetation fire is generally referred to as a "bushfire" (Neyişçi, 1999), while any uncontrolled vegetation fire, including grass fires, forest fires, and scrub fires is referred to as a "wildfire" (Pandey et al., 2023). The Canadian Interagency Forest Fire Center define a forest fire as any wildfire or managed fire burning in wooded areas or other similar environments (Neyişçi, 1999). Over time, forest fires have increased in frequency, causing global destruction on ecosystems, communities, and economies. Extreme fire incidences have raised concerns about the potential for destruction and the effects of forest fires on resources (Jhariya & Raj, 2014). Human dependency on forests has led to more fragmentation, worsening fire outbreaks for various causes (Cochrane, 2003). Studies showed extreme fires are becoming more frequent worldwide, impacting biodiversity, human life, climate change, and economic loss (Cochrane, 2003; Rahimi et al., 2020). Given the alarming rise in forest fires, it is imperative to identify and document their global and regional causes (Doerr and Santin, 2016). Authentic documentation will facilitate the development of effective strategies to mitigate forest fire-



related problems at both global and regional levels. Present study aims to compile information on the causes, ecological consequences, and proposed mitigation measures of forest fires through a comprehensive literature survey. Various databases, online and offline reports, published papers, and media prints were consulted. Authors have screened peer-reviewed articles, reports, and national assessments on fire drivers, ecological impacts, and management approaches, with emphasis on India and comparable tropical dry forests. Additionally, field surveys were conducted in Odisha, India, between 2021 and 2024 to collect photographic evidence. Opportunistic surveys and photo-documentation in Bonai Forest Division and adjacent landscapes recorded burn severity indicators, fuel profiles, visible soil alterations, invasive regrowth, and community interactions with fire.

FOREST FIRE SCENARIO IN INDIA

Forest fires in India are a recurring environmental challenge, influenced by

climatic conditions, anthropogenic activities, and forest dependency among local communities (Kumar et al., 2023). According to India State of Forest Report, satellite-based monitoring detected 52,785 fire incidents using MODIS (Moderate Resolution Imaging Spectroradiometer) and 345,989 using SNPP-VIIRS (Suomi National Polar-orbiting Partnership Visible Infrared Imaging Radiometer Suite) during the fire season from November 2020 to June 2021 (ISFR, 2021; Figure 1). India's forests are divided into four clusters. North Himalayan, North-Eastern, Southern, and Central, with the Central cluster being the most vulnerable, accounting for 56% of total burnt forest area despite covering only 28% of forest land (Sewak et al., 2021). The highest fire incidences have been recorded in northeastern states, followed by Chhattisgarh, Odisha, Madhya Pradesh, Maharashtra, and Andhra Pradesh with a high percentage of forest-dwelling tribal communities (Srivastava & Garg, 2013). Research indicates that dry deciduous forests are the most fire-prone, whereas evergreen, semi-evergreen, and montane temperate forests are less affected (ISFR, 2015).

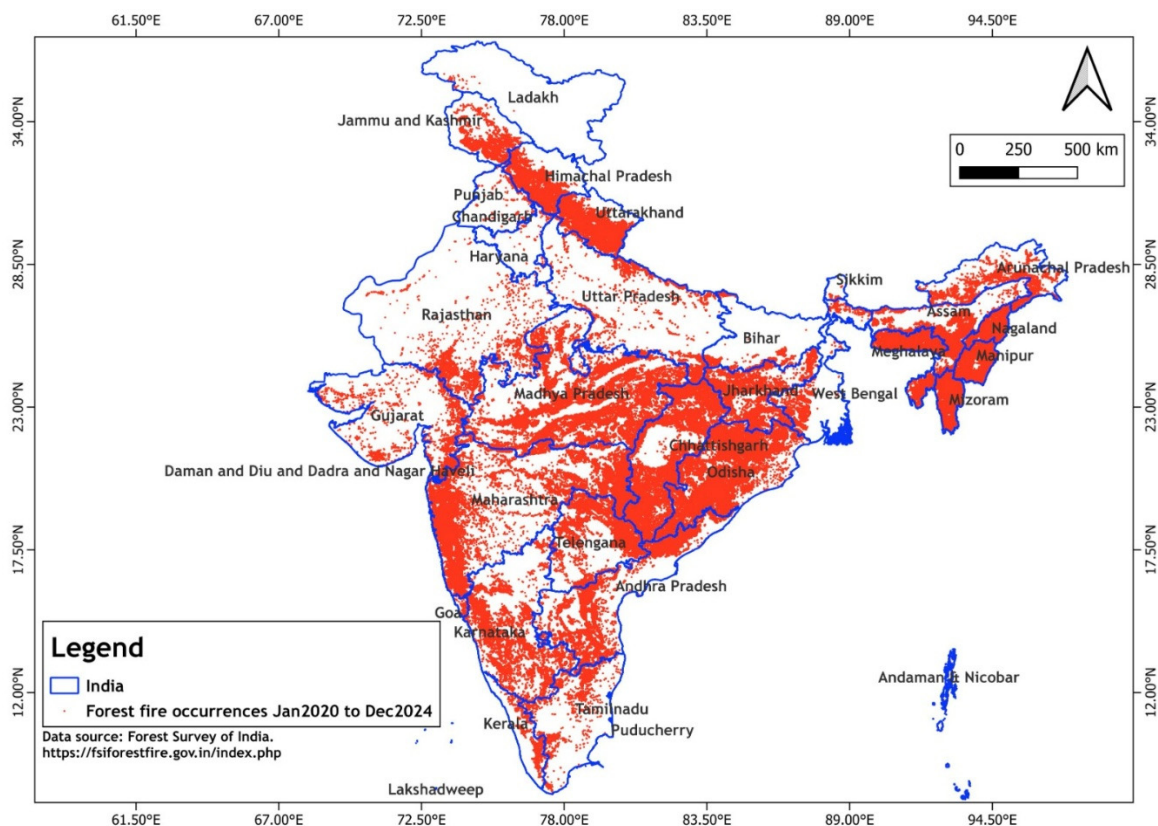


Fig. 1. Forest Fire in India from 2020–2024 (Source: ISFR, 2023).

Furthermore, over 36% of India's forest cover is prone to recurrent fires, with nearly 4% classified as extremely fire-prone and 6% as

highly fire-prone (ISFR, 2019). The increasing frequency and intensity of forest fires are linked to prolonged dry spells, rising temperatures,

and human-induced factors, highlighting the urgent need for effective forest fire management strategies (Jhariya & Raj, 2014). While policies like the National Action Plan on Forest Fires (NAPFF) and community-based fire management initiatives aim to mitigate the issue, weak enforcement, lack of funding, and insufficient inter-agency coordination continue to hinder effective implementation (GFRA, 2020).

CAUSES AND DRIVERS OF FOREST FIRE

Behaviour of Forest Fire strongly depends on vegetation, weather and topography, creating the three sides of what is usually known as the fire triangle (Fatih et al., 2014). Predicting fire risk involves identifying levels influenced by weather conditions, vegetation, and topography. Hotter, drier, and longer weather conditions increase the risk of forest fires (Jain et al., 1996). Forest fires are driven by a combination of natural and anthropogenic factors, with climate change, vegetation type, and human activities playing significant roles. Natural causes include lightning strikes, spontaneous combustion due to dry conditions, and volcanic eruptions, though these are relatively rare in tropical regions (Jhariya & Raj, 2014). Anthropogenic activities, however, are the dominant drivers, with agricultural expansion, shifting cultivation, illegal logging, and accidental or intentional ignitions by local communities contributing to the majority of fire incidents (FAO, 2020). Climate change exacerbates fire risk by increasing temperature, reducing humidity, and altering precipitation patterns, leading to prolonged dry seasons and higher fuel availability (ISFR, 2019). Additionally, land-use changes such as deforestation and forest fragmentation disrupt ecosystem balance, making forests more susceptible to fire outbreaks (Sewak et al., 2021). Socioeconomic factors, including population pressure and traditional land management practices, also influence fire frequency, particularly in regions where forest-dependent communities rely on fire for agriculture and resource extraction (Srivastava & Garg, 2013).

ECOLOGICAL CONSEQUENCES ON GLOBAL BIODIVERSITY

At the global scale, forest fires are a significant source of emitted carbon, contributing to global warming which could lead to biodiversity changes (Nasi et al., 2002). Frequent forest fires in the forests around the

globe have been blamed for forest deterioration. It is known that frequent fires on large scales cause air pollution, affect quality of stream water, threaten biodiversity and spoil the aesthetics of an area, but fire also plays an important role in forest ecosystem dynamics. Hence, forest fires exhibit a dual role within ecosystems, acting both as destructive forces and essential ecological processes. On one hand, they can rapidly consume large amounts of biomass, leading to negative impacts and on the other hand, fire is also responsible for maintaining the health and perpetuity of certain fire-dependent ecosystems (Pausas & Keeley, 2009). The impact of forest fires on global diversity has been extensively reviewed, emphasizing both detrimental consequences and ecological adaptations, as outlined below.

Impacts of Forest Fire on Plant Diversity

The extent of fire damage and plant response depends on various fire parameters, including intensity, severity, soil heating, season of burn, and time since the last fire. Additionally, physical (fuel condition, weather, slope, and aspect) and biological factors (plant morphology and physiology) influence post-fire effects on plant communities (Jhariya & Raj, 2014). A comprehensive review of the effects of forest fires on floral diversity based on various published papers is as detailed below:

- (a) *Vulnerability of different forest types*: Of the 16 forest types classified under the Champion & Seth classification, tropical deciduous forests are most impacted by recurrent fires. Among the six major vegetation types, dry deciduous forests exhibit the highest burnt area, followed by thorn forests, broadleaved forests, dry savannah, scrub, and grasslands (Krishna & Reddy, 2012). Seasonally, dry tropical forests face the greatest threats due to natural fires, land use changes, and escaped fires from slash-and-burn agriculture (Murphy & Lugo, 1986; Kauffman et al., 1994). In non-fire-adapted rainforests, wildfires cause severe damage by killing nearly all seedlings, sprouts, lianas, and young trees that lack protective bark (Woods, 1989). Boreal forests, though capable of regeneration, are disrupted by frequent high-intensity fires, such as those in Russia in 1998 that affected over two million hectares (Shvidenko & Goldammer, 2001).
- (b) *Shifting plant distribution*: Global warming and changing climate patterns have significantly influenced plant distribution,

with forest fires acting as a major driver of this shift. Rising temperatures and prolonged dry seasons have increased fire frequency and intensity, leading to alterations in vegetation composition and structure. In the Himalayan regions, wildfires have been identified as a critical factor affecting natural flora, causing shifts in species distribution and ecosystem dynamics (Chitale & Behera, 2019).

- (c) *Effect on vegetation succession*: Forest fires impact early successional stages, deciduous tree populations, and deadwood formation. The concern over salvage logging, particularly in Indonesia (1997–1998), lies in its potential adverse effects on post-fire vegetation succession (van Nieuwstadt et al., 2001). Species at the northern limits of their range are especially vulnerable to severe fires, which can drastically reduce populations of vascular plants, fungi, lichens, and mosses (Shvidenko & Goldammer, 2001).
- (d) *Role of fire in shaping ecosystems*: Although forest fires cause immediate destruction, they historically play a crucial role in shaping forest flora and fauna (Chandra & Bhardwaj, 2015). Some species depend on fire for survival. Fires act as natural disturbances in temperate forests, influencing vegetation composition and promoting fire-tolerant species over time (Nasi et al., 2002). However, seedling diversity is significantly lower in fire-affected plots than in fire-excluded areas (Saha & Howe, 2003).
- (e) *Adaptations and fire-resistant species*: Certain tree species have evolved fire-resistant traits such as thick bark, fire-stimulated sprouting, germination, seed dispersal adaptations, and heat-resistant buds. However, fire also facilitates the invasion of exotic species. *Imperata cylindrica*, a highly invasive perennial grass, rapidly expands after fire disturbances (Fusco et al., 2019). Similarly, invasive species like *Lantana camara*, *Eupatorium glandulosum*, and *Parthenium hysterophorus* threaten forest biodiversity.
- (f) *Effect on endemic taxa*: Frequent and recurring forest fires in specific habitats of endemic species can have devastating consequences. The repeated exposure to fire can lead to a significant decline in population numbers, pushing these unique species to the brink of extinction. If left unchecked, the continued threat of forest fires could ultimately result in the

loss of these endemic taxa, irreparably damaging the biodiversity of the affected ecosystem (Neeraja et al., 2021).

- (g) *Long term impacts on vegetation*: Forest fires not only cause immediate damage but also make plants vulnerable to pests and diseases (Syaufina et al., 2018). Frequent fires temporarily weaken shrub canopies while promoting herbaceous cover (Sheuyange et al., 2005). When surface fires occur alongside canopy disturbances, increased light availability and enhances understory vegetation growth (Mallik, 2003). Moderately disturbed ecosystems often show higher species diversity than undisturbed ones (Azizi et al., 2006).

Impacts of Forest Fire on Faunal Diversity

Forest fires have a profound impact on faunal diversity, causing widespread devastation to wildlife habitats and populations. The immediate effects of forest fires include mortality, injury, and displacement of animals, while the long-term consequences lead to habitat loss, fragmentation, and degradation. Many species, especially those with specialized habitats or limited mobility, are unable to escape the fires, resulting in population declines or even local extinctions. Furthermore, forest fires also disrupt the delicate balance of ecosystems, altering food webs, and disrupting the dynamics of predator-prey relationships, ultimately threatening the very survival of faunal diversity.

- (a) *Direct and indirect effects*: Forest fires can have severe consequences for both vertebrates and invertebrates, leading to direct mortality, habitat destruction, stress, and loss of essential resources such as shelter and food. The loss of key organisms, including pollinators and decomposers, can significantly slow down forest regeneration.
- (b) *Impacts on mega fauna*: Fire-induced habitat degradation affects mega mammal populations by reducing prey and fodder plants availability. In Minnesota, USA, wildfires have limited the populations of grey wolves by diminishing their primary prey, including beavers, moose, and deer, which depend on fire-resistant plant communities (Kramp et al., 1983). Additionally, burned forests tend to be avoided by large carnivores due to the scarcity of prey.
- (c) *Effects on tree depending faunal species*: The destruction of trees and fallen logs due

to forest fire negatively impacts small mammals and nesting bird species. Territorial faunal species may also be displaced, leading to population declines when suitable habitats are unavailable. Amphibians, with their permeable skin and moisture-dependent eggs, are highly vulnerable to fire-induced habitat changes (Fredericksen & Fredericksen, 2002).

- (d) *Behavioural and physiological responses:* The reaction of small mammals to fire is concerning, as the resulting shifts in plant and animal communities alter foraging behavior and resource distribution (Smucker et al., 2005). The immediate effects of wildfires include death due to burns, heat exposure, or smoke inhalation (Whelan et al., 2002). However, indirect consequences such as habitat loss and environmental changes can have a long-term impact on animal populations, influencing their survival and behaviour (Engstrom et al., 2010). When habitat structure and resource distribution are altered by fire, animals face significant challenges in adapting to the new conditions while also dealing with increased predation risk (Lawes et al., 2015).

Impacts of Forest Fire on Soil Quality

Sustainable management of forests depends on healthy soils and the ability to identify soil change indicators that reflect soil health. One of the main factors known to be responsible for soil degradation in forest ecosystems is forest fire (Ghazoul et al., 2015). Forest fires have a negative impact on soil quality and nutrient levels through multiple mechanisms such as volatilization, oxidation, ash transfer, and erosion (Pellegrini et al., 2018). The impact of wildfires on the properties of soil has been documented by multiple researchers (Jhariya & Singh, 2021).

- (a) *Effects on physical properties:* Several studies have examined how forest fires affect soil physical properties (Alcañiz et al., 2018; Dove et al., 2020). Soil texture remains largely unchanged due to the high temperature tolerance of sand, silt, and clay, though a reduction in clay content relative to silt and sand is observed (Scharenbroch et al., 2012; Heydari et al., 2017). This occurs as clay lattice structures collapse, leading to the aggregation of sand and silt particles (Alcañiz et al., 2016). The collapse of soil

aggregates due to fire and ash filling cavities can slightly increase bulk density, reducing soil porosity and permeability (Alcañiz et al., 2016). Some studies report about a 50% reduction in hydraulic conductivity in burned soils (Valzano et al., 1997). Forest fires also alter soil color, turning it red due to Ironoxide transitions or black/gray in cooler climates due to high ash content (Ulery et al., 1993). Burned soils generally have lower moisture content, as vegetation responsible for moisture retention is destroyed, leading to increased evaporation (Creighton et al., 2002). Fire-induced changes in soil water repellence (SWR) reduce water infiltration and increase runoff and erosion (Wells et al., 1981).

- (b) *Effects on biological properties:* Forest fires influence soil biological properties, leading to reductions in microbial biomass carbon (Akburak et al., 2018) and enzymatic activities (Fernández-García et al., 2019). However, fire may promote fungal populations and alter microbial community structures (Renbuss et al., 1973).

Impacts of Forest Fire on Global Environmental Conditions

Global carbon emissions due to forest fire are a key driver of climate change and are directly linked to global warming (Singh, 2022). Biomass burning from forest fires is the largest contributor to total biomass combustion emissions (Singh, 2022). Forest fires destroy millions of acres annually, leading to biodiversity loss and significantly contributing to greenhouse gas and aerosol emissions (Gajendiran et al., 2024). These emissions are a major factor in global warming. Carbon released from wildfires has profound implications for the global and regional carbon cycle and atmospheric carbon concentrations (Byrne et al., 2024). Unlike anthropogenic emissions, wildfire emissions vary annually due to the dynamic nature of fire events. Forest fires are one of the largest sources of atmospheric trace gases and aerosols (Moore et al., 2021). Global particulate matter emissions from forest fires have been linked to 65.6 million deaths annually (Chen et al., 2021). Despite a global decrease in burned area, forest fire emissions are increasing (Singh, 2022). Large fires could potentially transform forests from carbon sinks to carbon sources (Clarke et al., 2022). Improved carbon impact estimates are necessary to assess the severity of emissions, non-tree responses, and below-ground

processes (Johnston et al., 2012). While trees do not completely disappear in wildfires, their resilience is significantly affected (Bizzarri et al., 2025). Dense ground vegetation regrowth can partially mitigate ecosystem carbon loss in the first years after disturbance, similar to clear-cutting scenarios. Quantifying regenerating biomass is crucial for calculating carbon flows and assessing future fire risk. Burned areas are often rapidly recolonized by pioneer species, increasing understorey vegetation diversity, abundance and reducing nutrient leaching (Maren & Thilo, 2025).

Impacts of Forest Fire in Human life & Human-Wildlife Conflicts

Forest fires inflict devastating damage on human habitations in and around forest areas, often engulfing homes and reducing them to ashes (Weinhold, 2011). It also reduces the forest biomass. Furthermore, these fires lead to the loss of valuable resources, including medicinal plants (Figure 2), fodder plants, and firewood, thereby disrupting human life and upsetting the ecological balance of forest ecosystems. Frequent forest fires significantly deplete the population of prey and fodder plants, crucial for wildlife sustenance. The subsequent scarcity of food forces wildlife to alter their migratory routes and venture into human settlements in search of easier prey, thereby leading to increased Human-Wildlife Conflict (AFF, 2021; MRFF, 2021; FFIMM, 2023).



Fig. 2: Loss of forest biomass due to wild fire in Bonai Forest Division, Odisha state (Photographs taken during field survey by authors).

GLOBAL MANAGEMENT STRATEGY OF FOREST FIRE

The global management strategy for forest fires involves a multi-faceted approach that includes prevention, detection, suppression, and rehabilitation (Calkin et al., 2014; Carta et al., 2023). This strategy emphasizes international cooperation, technology, and innovation to reduce the risk and impact of forest fires. Key components include public awareness and education, prescribed burning, aerial surveillance, and firefighting teams, as well as rehabilitation efforts to restore ecosystems and support affected communities. Additionally, the strategy leverages advanced technologies, such as fire prediction modeling, unmanned aerial vehicles, and artificial intelligence, to enhance forest fire management decision-making and response (FFIMM, 2023). Some global best practices are mentioned below (Kumar et al., 2023; Bousfield et al., 2025; Meraj et al., 2025; Rafaqat et al., 2025).

- (a) *Public awareness*: Educating the public on forest fire prevention and safety through campaigns, signage, and community outreach programs.
- (b) *Fire restrictions*: Implementing fire restrictions, such as campfire bans, during periods of high fire danger.
- (c) *Prescribed burning*: Conducting controlled burns in fire-prone areas to reduce fuel loads and promote ecosystem health.
- (d) *Aerial surveillance*: Utilizing aircraft and drones equipped with sensors and cameras to detect and monitor forest fires.
- (e) *Ground-based sensors*: Installing sensors and cameras in high-risk areas to detect fires early.
- (f) *Satellite imagery*: Leveraging satellite data to monitor forest fires and track their spread.
- (g) *Firefighting teams*: Deploying trained firefighting teams, including ground crews and aerial support, to suppress forest fires.
- (h) *Firebreaks*: Creating firebreaks, such as clearing vegetation, to contain fires and prevent their spread.

- (i) *Ecosystem restoration*: Implementing restoration efforts, such as reforestation and habitat rehabilitation, to promote ecosystem recovery.
- (j) *Soil erosion prevention*: Implementing measures to prevent soil erosion and landslides in burned areas.
- (k) *Community support*: Providing support to affected communities, including assistance with rebuilding and economic recovery.
- (l) *Global fire monitoring*: Collaborating with international partners to share data and best practices on forest fire monitoring and management.
- (m) *Cross-border firefighting*: Coordinating with neighboring countries to share resources and expertise in suppressing forest fires that cross international borders.
- (n) *Capacity building*: Providing training and capacity-building programs for countries to enhance their forest fire management capabilities.
- (o) *Fire prediction modeling*: Utilizing advanced modeling and simulation tools to predict forest fire risk and behavior.
- (p) *Artificial intelligence (AI)*: Applying AI and machine learning algorithms to analyze data and improve forest fire management decision-making.
- (q) *Regional forest fire policies*: Developing and implementing national policies and strategies for forest fire management.
- (r) *Collaborations with regional and local organizations*: Collaborating with NGO and other stakeholders to develop and implement action plan on forest fire management.
- (s) *Community engagement*: Encouraging community involvement and participation in forest fire management decision-making processes.
- (t) *Advancement in tools and training*: There is a need of periodic technical advancement in mitigating tools and organizing training program for local community & field staffs to mitigate forest fire

AN ANALYSIS OF FOREST FIRE POLICIES IN VARIOUS COUNTRIES

A comprehensive policy approach is crucial for sustainable forest management and wildfire mitigation, addressing climate change challenges through effective fire management (Synolakis & Karagiannis, 2024). Different countries have different policies as per landscapes and causes of forest fire. Policies of forest fire management of selected 10

countries (Australia, Canada, France, Greece, India, Italy, Portugal, South Africa, United Kingdom and United States of America) are discussed. Australia's wildfire management policies prioritize adaptive governance, integrating risk reduction with biodiversity conservation. Case studies highlight planning processes that incorporate ecological and social considerations (Clement et al., 2024). The National Bushfire Management Policy Statement for Forests and Rangelands focus on maintaining appropriate fire regimes, mitigating environmental impacts, and recognizing Indigenous fire management practices as integral to sustainable land stewardship (Forest Fire Management Group, 2014). Canada's wildfire management policies have evolved toward integrating fire suppression with ecological and risk-based approaches. The Canadian Wildland Fire Prevention and Mitigation Strategy promotes comprehensive wildfire management, focusing on prevention, mitigation, preparedness, response, and recovery (CWFPMP, 2024). France's Vulcain strategy in the southern region prioritizes fire prevention over suppression, but its limited implementation, inadequate funding, and weak enforcement hinder its effectiveness. While policies such as the Forest Code have been strengthened, climate change is intensifying wildfire risks (Curt & Frejaville, 2017). Greece's wildfire management framework is governed by laws such as Forest Law 998/1979 and the National Action Plan for Forest Fire Prevention. The framework aligns with the EU Forest Strategy to ensure sustainable forest management (Koundouri & Tsani, 2022). India's forest fire management policy encompasses a range of strategies aimed at preventing, detecting, and controlling forest fires to protect its rich biodiversity (MoEF, 1988). The National Forest Policy of 1988 provides the foundation for these efforts, emphasizing forest protection, ecological balance, and community participation (MoEF, 1988). To operationalize these objectives, the government launched the Forest Fire Prevention and Management Scheme (FFPMS), which supports state governments in fire prevention through early warning systems, capacity building, and infrastructure development (MoEFCC, 2018). Additionally, the National Action Plan on Forest Fires strengthens coordination among agencies, enhances fire danger rating systems, and promotes community involvement (MoEFCC, 2018). The Joint Forest Management (JFM) program further reinforces these initiatives by fostering collaboration between forest

departments and local communities, allowing them to share responsibilities and benefits from sustainable forest management (MoEFCC, 2018). Technological interventions, particularly the use of satellite-based fire monitoring by the Forest Survey of India, have improved real-time detection and response mechanisms (FSI, 2022). Strengthening community engagement through education and incentives is crucial to ensuring proactive fire management at the grassroots level (Aggarwal & Dwivedi, 2022). Integrating emerging technologies, such as drones and artificial intelligence, can further enhance early warning systems and improve fire suppression strategies (Bari et al., 2023). Despite these efforts, challenges such as climate change, increasing human activities, and limited resources continue to hinder effective forest fire management (Aggarwal & Dwivedi, 2022). The intensification of extreme weather events exacerbates fire risks, while encroachments and agricultural practices often contribute to uncontrolled fires. Strengthening community engagement through education and incentives is crucial for ensuring proactive fire management at the grassroots level. Integrating emerging technologies, such as drones and artificial intelligence, can further enhance early warning systems and improve fire suppression strategies. Additionally, aligning forest fire policies with broader environmental and land-use planning is essential for a holistic approach to fire risk reduction. By continuously refining policies, adopting innovative solutions, and strengthening inter-agency coordination, India can mitigate the devastating impacts of wildfires and safeguard its forests for future generations (MoEFCC, 2018). Italy's regional fire management plans involve collaboration among various stakeholders and risk mitigation policies that consider cultural and ecological diversity. However, the absence of a National Forestry Authority leads to reduced coordination between ministries, inadequate investment in wildfire prevention, and weak regulation of fire use in agro-pastoral and forestry sectors. Legislation is difficult to enforce in remote areas and is often overly bureaucratic, hindering effective implementation (Kirschner et al., 2024). Portugal's wildfire management policies emphasize prevention, preparedness, and community engagement. The National Integrated Fire Management Plan (2020–2030), developed by the Agency for Integrated Rural Fire Management (AGIF), implements

fuel management and risk assessment strategies to reduce wildfire exposure (Alcasena et al., 2021). South Africa's wildfire management framework is governed by the Fire Brigade Services Act, the National Veld, Forest Fire and Disaster Management Act of the country. These regulations require municipalities, public and private entities, and Fire Protection Associations (FPAs) to implement fire prevention and response measures. FPAs play a crucial role in wildfire risk management but face challenges such as resource constraints and enforcement limitations, particularly in rural areas (Pandey et al., 2023). Nieman et al. (2021) reviewed fire management practices in African savanna-protected areas, identifying 15 distinct approaches and advocating adaptive fire management strategies. The UK's wildfire management policies have evolved from localized efforts to national recognition. The Climate Change Act and Countryside Stewardship Scheme aim to mitigate risks, while daily Hazard Assessments inform authorities about wildfire threats. Challenges persist due to fragmented government responsibilities. However, the Forestry Commission has adopted adaptive land management practices to enhance fire resilience (Gazzard et al., 2016; Pandey et al., 2023). U.S. Forest fire management has transitioned from a suppression-focused approach to adaptive strategies, balancing short-term suppression with long-term resilience while advocating policy reforms for improved prevention, management, and recovery (Schoennagel et al., 2017). The U.S. Government oversees wildland fire management through the Wildland Fire Mitigation and Management Commission and the National Cohesive Wildland Fire Management Strategy. These efforts are supported by legislative measures such as the FLAME Act of 2009.

CONCLUSIONS

Forest fires pose intertwined ecological and social risks that cannot be solved by suppression alone. Evidence from India and Odisha shows that aligning technology-enabled early warning with co-designed, community-led prevention and recovery reduces damaging fires while preserving the ecological role of low-intensity burns. By shifting budgets toward preparedness, legitimizing appropriate ecological fire, and embedding continuous learning in JFM institutions, managers can lower severe-fire frequency, protect

biodiversity and soils, and reduce human-wildlife conflict, delivering resilient landscapes and safer communities.

AUTHOR CONTRIBUTIONS

S.K.N. has written the manuscript; S.K.B. and S.K. have revised the manuscript.

FUNDING

This research received no external funding.

ACKNOWLEDGMENT

Authors are thankful to the forest watchers and community of Bonai Forest Division, Odisha, India.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

REFERENCES

- Adebayo, O. (2019). Loss of biodiversity: The burgeoning threat to human health. *Ann. Ib. Postgrad. Med.* **17**(1): 5–7.
- Adom, R. K., Reid, M., Afuye, G. A. and Simatele, M. D. (2024). Assessing the Implications of Deforestation and Climate Change on Rural Livelihood in Ghana: A Multidimensional Analysis and Solution-Based Approach. *Environ. Manag.* **74**(6): 1124–1144.
- Aerts, R. and Honnay, O. (2011). Forest restoration, biodiversity and ecosystem functioning. *BMC Ecol.* **11**: 29. <https://doi.org/10.1186/1472-6785-11-29>.
- AFF. (2021). *Assessment of Forest Fire in Rairangpur Forest Division, Odisha, India, Phase I*. Odisha: Ambika Prasad Research Foundation.
- Aggarwal, G. and Dwivedi, S. (2022). Forest fire risk mitigation and management. *Disaster Dev.* **11**(2): 183–197.
- Akburak, S., Son, Y., Makineci, E. and Çakir, M. (2018). Impacts of low-intensity prescribed fire on microbial and chemical soil properties in a Quercus frainetto forest. *J. For. Res.* **29**(3): 687–696.
- Alcañiz, M., Outeiro, L., Francos, M. and Úbeda, X. (2018). Effects of prescribed fires on soil properties: A review. *Sci. Total Environ.* **613**: 944–957.
- Alcañiz, M., Outeiro, L., Francos, M., Farguell, J. and Úbeda, X. (2016). Longterm dynamics of soil chemical properties after a prescribed fire in a Mediterranean forest (Montgrí Massif, Catalonia, Spain). *Sci. Total Environ.* **572**: 1329–1335.
- Alcasena, F., Ager, A., Le Page, Y., Bessa, P., Loureiro, C. and Oliveira, T. (2021). Assessing Wildfire Exposure to Communities and Protected Areas in Portugal. *Fire* **4**(4): 82. <https://doi.org/10.3390/fire4040082>.
- Archibald, S., Lehmann, C. E. R., Gómez-Dans, J. L. and Bradstock, R. A. (2013). Defining pyromes and global syndromes of fire regimes. *Proc. Natl. Acad. Sci. USA* **110**(16): 6442–6447.
- Azizi, G., Tavili, A. and Faramarzi, M. (2006). Effects of fire on plant diversity and vegetation structure in semi-arid rangelands of Iran. *J. Arid. Environ.* **67**(1): 150–164.
- Baltacı, U. and Yıldırım, F. (2020). Effect of Slope on the Analysis of Forest Fire Risk. *Hacettepe J. Biol. Chem.* **48**(4): 373–379.
- Bari, L. F., Ahmed, I., Ahamed, R., Zihan, T. A., Sharmin, S., Pranto, A. H. and Islam, M. R. (2023). Potential Use of Artificial Intelligence (AI) in Disaster Risk and Emergency Health Management: A Critical Appraisal on Environmental Health. *Environ. Health Insights* **17**: 11786302231217808. <https://doi.org/10.1177/11786302231217808>.
- Bizzarri, A., Paladini, M., Frassinelli, N., Marchi, E., Zampieri, R.M., Giovannelli, A. and Cocozza, C. (2025). Deciphering the Fate of Burned Trees After a Forest Fire: A Systematic Review Focused on Conifers. *Biology*. **14**(10):1372. <https://doi.org/10.3390/biology14101372>
- Bousfield, C. G., Morton, O., Lindenmayer, D. B., Pellegrini, A. F. A., Hethcoat, M. G. and Edwards, D. P. (2025). Global risk of wildfire across timber production systems. *Nat. Commun.* **16**(1): 4204. <https://doi.org/10.1038/s41467-025-59272-6>.
- Byrne, B., Liu, J., Bowman, K. W., Pascolini-Campbell, M., Chatterjee, A., Pandey, S., Miyazaki, K., van der Werf, G. R., Wunch, D., Wennberg, P. O., Roehl, C. M. and Sinha, S. Carbon emissions from the 2023 Canadian wildfires. *Nature* **633**(8031): 835–839.
- Calkin, D. E., Cohen, J. D., Finney, M. A., Thompson, M. P. (2014). How risk management can prevent future wildfire disasters in the wildland-urban interface. *Proc. Natl. Acad. Sci. USA* **111**(2): 746–751. <https://doi.org/10.1073/pnas.1315088111>.
- Carta, F., Zidda, C., Putzu, M., Loru, D., Anedda, M. and Giusto, D. (2023). Advancements in Forest Fire Prevention: A Comprehensive Survey. *Sensors* **23**(14): 6635. <https://doi.org/10.3390/s23146635>.
- Chandra, S. and Bhardwaj, D. R. (2015). Impact of forest fire on plant diversity: A review. *Research J. Agric. For. Sci.* **3**(9): 1–3.
- Chen, G., Guo, Y., Yue, X., Tong, S., Gasparrini, A., Bell, M. L., Armstrong, B., Schwartz, J., Jaakkola, J. J. K., Zanobetti, A., Lavigne, E., Nascimento Saldiva, P. H., Kan, H., Royé, D., Milojevic, A., Overcenco, A., Urban, A., Schneider, A., Entezari, A., ... Li, S. (2021). Mortality risk attributable to wildfire-related PM2.5 pollution: A global time series study in 749 locations. *Lancet Planet. Health* **5**(9): e579–e587. [https://doi.org/10.1016/S2542-5196\(21\)00200-X](https://doi.org/10.1016/S2542-5196(21)00200-X)
- Chitale, V. S. and Behera, M. D. (2019). How will forest fires impact the distribution of tree species in the Indian Himalaya? *Biodiv. Conserv.* **28**: 2259–2273.
- Clarke, H., Nolan, R. H., De Dios, V. R., Bradstock, R., Griebel, A., Khanal, S. and Boer, M. M. (2022).

- Forest fire threatens global carbon sinks and population centres under rising atmospheric water demand. *Nat. Commun.* **13**(1):7161. <https://doi.org/10.1038/s41467-022-34966-3>
- Clement, S., Garmestani, A., Beckwith, J. A. and Cannon, P. J. (2024). To burn or not to burn: Governance of wildfires in Australia. *Ecol. Soc.* **29**(1): 8. <https://doi.org/10.5751/ES-13789-290108>.
- Cochrane, M. A. (2003). Fire science for rainforests. *Nature* **421**(6926): 913–919.
- Creighton, M. L. and Rómulo, S. (2002). Early post-fire succession in a *Nothofagus glauca* forest in the Coastal Cordillera of south-central Chile. *Int. J. Wildland Fire* **11**(2): 115–125.
- Curt, T. and Frejaville, T. (2017). Wildfire policy in Mediterranean France: How far is it efficient and sustainable? *Risk Anal.* **38**(3): 472–488. <https://doi.org/10.1111/risa.12855>.
- CWFPMC. (2024). *Canadian Wildland Fire Prevention and Mitigation Strategy*. Ottawa: Canadian Council of Forest Ministers, Minister of Natural Resources.
- Doerr, S. H. and Santín, C. (2016). Global trends in wildfire and its impacts: Perceptions versus realities in a changing world. *Philos. Trans. R. Soc. B Biol. Sci.* **371**(1696): 20150345. <https://doi.org/10.1098/rstb.2015.0345>.
- Dove, N. C., Saford, H. D., Bohlman, G. N., Estes, B. L. and Hart, S. C. (2020). High severity wildfire leads to multi-decadal impacts on soil biogeochemistry in mixed-conifer forests. *Ecol. Appl.* **30**(4): e02072. <https://doi.org/10.1002/eap.2072>.
- Engstrom, R. T. (2010). First-Order Fire Effects on Animals: Review and Recommendations. *Fire Ecol.* **6**: 115–130.
- Fatih, S., Bülent, S., Abdullah, E. A. and Nuri, B. (2014). Evaluation of Forest Fire Risk with GIS. *Pol. J. Environ. Stud.* **23**(1): 187–194.
- Fernández-García, V., Marcos, E., Fernández-Guisuraga, J. M., Taboada, A., Suárez-Seoane, S. and Calvo, L. (2019). Impact of burn severity on soil properties in a *Pinus pinaster* ecosystem immediately after fire. *Int. J. Wildland Fire* **28**(5): 354–364.
- FFIMM. (2023). *Forest Fire Impacts Mitigation Management*. Cuttack: Ambika Prasad Research Foundation.
- Forest Fire Management Group. (2014). *National Bushfire Management Policy Statement for Forests and Rangelands*. Canberra: Council of Australian Governments.
- Fredericksen, N. and Fredericksen, T. (2002). Terrestrial wildlife responses to logging and fire in a Bolivian tropical humid forest. *Biodivers. Conserv.* **11**: 27–38.
- FSI (Forest Survey of India). (2022). *Forest Fire Monitoring and Assessment*. New Delhi: Ministry of Environment, Forest and Climate Change, Government of India.
- Fusco, E. J., Finn, J. T., Balch, J. K., Nagy, R. C. and Bradley, B.A. (2019). Invasive grasses increase fire occurrence and frequency across US ecoregions. *Proc. Natl. Acad. Sci. USA* **116**(47): 23594–23599.
- Gajendiran, K., Kandasamy, S. and Narayanan, M. (2024). Influences of wildfire on the forest ecosystem and climate change: A comprehensive study. *Environmental research.* **240**(2): 117537. <https://doi.org/10.1016/j.envres.2023.117537>
- Gazzard, R., McMorrow, J. and Aylen, J. (2016). Wildfire policy and management in England. *Philos. Trans. R. Soc. B: Biol. Sci.* **371**(1696): 20150341. <https://doi.org/10.1098/rstb.2015.0341>.
- Ghazoul, J., Burivalova, Z., Garcia-Ulloa, J. and King, L. A. (2015). Conceptualizing Forest degradation. *Trends Ecol. Evol.* **30**(10): 622–632.
- Global Forest Resources Assessment (GFRA). (2020). Food and Agriculture Organization of the United Nations, Rome, Italy. <https://doi.org/10.4060/ca8753en>
- Heino, M., Kumm, M., Makkonen, M., Mulligan, M., Verburg, P. H., Jalava, M., and Räsänen, T. A. (2015). Forest Loss in Protected Areas and Intact Forest Landscapes: A Global Analysis. *PLoS ONE* **10**(10): e0138918. <https://doi.org/10.1371/journal.pone.0138918>.
- Heydari, M., Rostamy, A., Najaf, F. and Dey, D. C. (2017). Effect of fire severity on physical and biochemical soil properties in Zagros oak (*Quercus brantii* Lindl.) forests in Iran. *J. For. Res.* **28**(1): 95–104.
- ISFR. (2015). *India State of Forest Report*. Dehradun: Forest Survey of India, Ministry of Environment. Forest & Climate Change.
- ISFR. (2019). *India State of Forest Report*. Dehradun: Forest Survey of India, Ministry of Environment. Forest & Climate Change.
- ISFR. (2021). *India State of Forest Report*. Dehradun: Forest Survey of India, Ministry of Environment. Forest & Climate Change.
- ISFR. (2023). *India State of Forest Report*. Dehradun: Forest Survey of India, Ministry of Environment. Forest & Climate Change.
- Jain, A., Ravan, S. A., Singh, R. K., Das, K. K. and Roy, P. S. (1996). Forest fire risk modeling using remote sensing and geographic information systems. *Curr. Sci.* **70**(10): 928–933.
- Jhariya, M. K. and Raj, A. (2014). Effects of wildfires on flora, fauna and physico-chemical properties of soil: An overview. *J. Appl. Nat. Sci.* **6**(2): 887–897.
- Jhariya, M. K. and Raj, A. (2014). Human Welfare from Biodiversity. *Agrobios Newsl.* **12**(9): 89–91.
- Jhariya, M. K. and Singh, L. (2021). Effect of fire severity on soil properties in a seasonally dry forest ecosystem of Central India. *Int. J. Environ. Sci. Technol.* **18**: 3967–3978.
- Johnston, F. H., Henderson, S. B., Chen, Y., Randerson J. T., Marlier, M., Defries, R. S., Kinney, P., Bowman, D. M. and Brauer, M. (2012). Estimated global mortality attributable to smoke from landscape fires. *Environ. Health Perspect.* **120**(5): 695–701.
- Kauffman, J. B., Cummings, D. L. and Ward, D. E. (1994). Relationships of fire, biomass and nutrient dynamics along a vegetation gradient in the Brazilian cerrado. *J. Ecol.* **82**(3): 519–531.
- Kirschner, J. A., Ascoli, D., Moore, P., Clark, J., Calvani, S. and Boustras, G. (2024). Governance drivers hinder and support a paradigm shift in wildfire risk management in Italy. *Reg. Environ. Chang.* **24**: 24. <https://doi.org/10.1007/s10113-023-02174-4>.
- Koundouri, P. and Tsani, S. (2022). Assessing Policy Preferences for Preventing and Managing Wildfire Risk: Evidence from Greece. *SSRN*

- Electron. J.* <https://doi.org/10.2139/ssrn.4587462>.
- Kramp, B. A., Patton, D. R. and Brady, W. W. (1983). *The Effects of Fire on Wildlife Habitat and Species*. RUN WILD: Wildlife/Habitat Relationships. Albuquerque: United States Department of Agriculture—Forest Service, Southwestern Region.
- Krishna, P. H. and Reddy, C. S. (2012). Assessment of increasing threat of forest fires in Rajasthan, India using multi-temporal remote sensing data (2005–2010). *Curr. Sci.* **102**(9): 1288–1297.
- Kumar, S. N., Kumar, S. and Biswal, S. K. (2023). Community, Forest Fire and Conservation: Keys of Wildlife Management. *Indian For.* **149**(5): 487–496.
- Lawes, M. J., Murphy, B. P., Fisher, A., Woinarski, J. C. Z., Edwards, A. C. and Russell-Smith, J. (2015). Small Mammals Decline with Increasing Fire Extent in Northern Australia: Evidence from Long-Term Monitoring in Kakadu National Park. *Int. J. Wildland Fire* **24**(5): 712–722. <https://doi.org/10.1071/WF14163>.
- Mallik, A. U. (2003). Conifer regeneration problems in boreal and temperate forests with ericaceous understory: Role of disturbance, seedbed limitation, and keystone species change. *Crit. Rev. Plant Sci.* **22**(3–4), 341–366.
- Maren, S. and Thilo, H. (2025). Allometric estimation models for aboveground and belowground biomass of pre-fire and post-fire vegetation in Scots pine forests. *For. Int. J. For. Res.* **98** (1): 84–97.
- Meraj, G., Hashimoto, S., Dasgupta, R. and Mitra, B. K. (2025). Ecological Risk Assessment and Management of Forest Fires in Tamil Nadu, India: A MaxEnt Model-Based Approach for Strategic Resource Allocation and Fire Mitigation. *Risk Anal.* <https://doi.org/10.1111/risa.70098>.
- MoEF (Ministry of Environment and Forests). (1988). *National Forest Policy, 1988*. New Delhi: Government of India.
- MoEFCC (Ministry of Environment, Forest and Climate Change). (2018). *Forest Fire Prevention and Management Scheme*. New Delhi: Government of India.
- Moore, R. A., Bomar, C., Kobziar, L. N. and Christner, B. C. (2021). Wildland fire as an atmospheric source of viable microbial aerosols and biological ice nucleating particles. *ISME J.* **15**(2): 461–472.
- MRFF (2021). *Monitoring of Regeneration in Forest Flora in Bonai Forest Division, Odisha, India*. Sundargarh: Bonai Forest Division, Odisha, India; Cuttack: Ambika Prasad Research Foundation, India.
- Murphy, P. G. and Lugo, A. E. (1986). Ecology of tropical dry forest. *Annu. Rev. Ecol. Syst.* **17**(1): 67–88.
- Nasi, R., Dennis, R., Meijaard, E., Applegate, G. and Moore, P. (2002). Forest fire and biological diversity. *Unasylva* **53**(209): 36–40.
- Neeraja, U. V., Rajendrakumar, S., Saneesh, C. S., Dyda, V. and Knight, T. M. (2021). Fire alters diversity, composition, and structure of dry tropical forests in the Eastern Ghats. *Ecol. Evol.* **11**(11): 6593–6603. <https://doi.org/10.1002/ece3.7514>.
- Neyişçi, T. (1999). The role of fire in Turkish pine (*Pinus brutia* Ten.) ecosystems. In Proceedings of the International Symposium on Fire Economics, Planning, and Policy: Bottom Lines, San Diego, CA, 5–9 April. USDA Forest Service, General Technical Report PSW-GTR-173.
- Nieman, W. A., Van Wilgen, B. W. and Leslie, A. J. (2021). A review of fire management practices in African savanna-protected areas. *Koedoe* **63**(1): a1655. <https://doi.org/10.4102/koedoe.v63i1.1655>.
- Novacek, M. J. and Cleland, E. E. (2001). The current biodiversity extinction event: Scenarios for mitigation and recovery. *Proceeding Natl. Acad. Sci. USA* **98**(10): 5466–5470. <https://doi.org/10.1073/pnas.091093698>.
- Pandey, P., Huidobro, G., Lopes, L. F., Ganteaume, A., Ascoli, D., Colaco, C., Xanthopoulos, G., Giannaros, T. M., Gazzard, R., Boustras, G. and Steelman, T. (2023). A global outlook on increasing wildfire risk: Current policy situation and future pathways. *Trees For. People* **14**: 100431. <https://doi.org/10.1016/j.tfp.2023.100431>.
- Pausas, J. G. and Keeley, J. E. (2009). A burning story: The role of fire in the history of life. *Bioscience* **59**(7): 593–601.
- Pellegrini, A. F., Ahlström, A., Hobbie, S. E., Reich, P. B., Nieradzick, L. P., Staver, A. C., Scharenbroch, B. C., Jumpponen, A., Anderegg, W. R., Randerson, J. T. and Jackson, R. B. (2018). Fire frequency drives decadal changes in soil carbon and nitrogen and ecosystem productivity. *Nature* **553**(7687): 194–198.
- Rafaqat, W., Sanchez, P., Botnen, D. and Fernandez-Anez, N. (2025). Analysing historical events and current management strategies of wildfires in Norway. *Sci. Rep.* **15**(1): 24905. <https://doi.org/10.1038/s41598-025-08760-2>.
- Rahimi, S., Sharifi, Z. and Mastro Lonardo, G. (2020). Comparative study of the effects of wildfire and cultivation on topsoil properties in the Zagros Forest, Iran. *Eurasian Soil Sci.* **53**(11): 1655–1668.
- Renbuss, M. A., Chilvers, G. A. and Pryar, L. D. (1973). Microbiology of an ash bed. *Proc. Linn. Soc.* **97**: 302–311.
- Saha, S. and Howe, H. F. (2003). Species composition and fire in a dry deciduous forest. *Ecology* **84**(12): 3118–3123.
- Scharenbroch, B. C., Nix, B., Jacobs, K. A. and Bowles, M. L. (2012). Two decades of low-severity prescribed fire increases soil nutrient availability in a Midwestern, USA oak (*Quercus*) forest. *Geoderma* **183**: 80–91.
- Sewak, R., Vashisth, M. and Gupta, L. (2021). Forest Fires in India: A Review. *J. Univ. Shanghai Sci. Technol.* **23**(7): 247–259.
- Shackelford, N., Standish, R. J., Ripple, W. and Starzomski, B. M. (2018). Threats to biodiversity from cumulative human impacts in one of North America's last wildlife frontiers. *Conserv. Biol. J. Soc. Conserv. Biol.* **32**(3): 672–684. <https://doi.org/10.1111/cobi.13036>.
- Sheuyange, A., Oba, G. and Weladji, R. B. (2005). Effects of anthropogenic fire history on savanna vegetation in northeastern Namibia. *J. Environ. Manag.* **75**(3): 189–198.

- Shvidenko, A. and Goldammer, J. G. (2001). Fire situation in Russia. *Int. For. Fire News* **24**: 41–59.
- Singh, S. (2022). Forest fire emissions: A contribution to global climate change. *Front. For. Glob. Change* **5**:925480. [https://doi: 10.3389/ffgc.2022.925480](https://doi.org/10.3389/ffgc.2022.925480)
- Smucker, K. M., Hutto, R. L. and Steele, B. M. (2005). Changes in Bird Abundance after Wildfire: Importance of Fire Severity and Time since Fire. *Ecol. Appl.* **15**: 1535–1549. <https://doi.org/10.1890/04-1353>.
- Srivastava, P. and Garg, A. (2013). Forest Fires in India: Regional and Temporal Analyses. *J. Trop. For. Sci.* **25**(2): 228–239.
- Syaufina, L., Ardiansyah, M. and Herlina, N. (2018). The effect of forest fire on plant diversity and ecosystem resilience in tropical forests. *Biodiversitas J. Biol. Divers.* **19**(6): 2232–2240.
- Synolakis, C. E. and Karagiannis, G. M. (2024). Wildfire risk management in the era of climate change. *PNAS Nexus* **3**(5): 151. <https://doi.org/10.1093/pnasnexus/pgae151>.
- Ulery, A. L. and Graham, R. C. (1993). Forest fire effects on soil color and texture. *Soil Sci. Soc. Am. J.* **57**(1): 135–140.
- Valzano, F. P., Grene, R. S. B. and Murphy, B. W. (1997). Direct effects of stubble burning on soil hydraulic and physical properties in a direct drill tillage system. *Soil Tillage Res.* **42**: 209–219.
- van Nieuwstadt, M. G. L., Sheil, D. and Kartawinata, K. (2001). The ecological consequences of logging in the burned forests of East Kalimantan, Indonesia. *Conserv. Biol.* **15**(4): 1183–1186. <https://doi.org/10.1046/j.1523-1739.2001.0150041183.x>.
- Weinhold, B. (2011). Fields and forests in flames: Vegetation smoke & human health. *Environ. Health Perspect.* **119**(9): a386–a393.
- Wells, W. G. (1981). Some effects of brushfires on erosion processes in coastal Southern California. Erosion and Sediment Transport in Pacific Rim Steep lands, Christchurch, New Zealand. *Int. Assoc. Hydrol. Sci. Christch. N. Z.* **132**: 305–342.
- Whelan, R. J., Rodgers, L., Dickman, C. R. and Sutherland, E. F. (2002). Critical Life Processes of Plants and Animals: Developing a Process-Based Understanding of Population Changes in Fire-Prone Landscapes. In *Flammable Australia: The Fire Regimes and Biodiversity of a Continent*. Cambridge: Cambridge University Press.
- Woods, P. (1989). Effects of logging, drought, and fire on structure and composition of tropical forests in Sabah, Malaysia. *Biotropica* **21**(4): 290–298.
- Zeng, Y., Koh, L. P. and Wilcove, D. S. (2022). Gains in biodiversity conservation and ecosystem services from the expansion of the planet's protected areas. *Sci. Adv.* **8**(22): eabl9885. <https://doi.org/10.1126/sciadv.abl9885>.