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UNVEILING THE DEVASTATING REPERCUSSIONS OF FOREST FIRES AND THEIR ECOLOGICAL IMPACT IN *UTTARAKHAND*, INDIA: AN IN-DEPTH REVIEW

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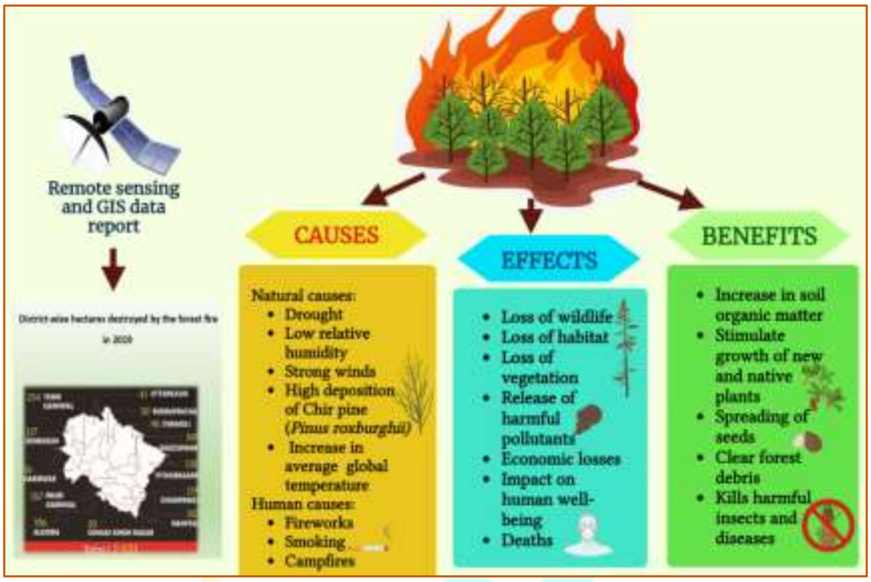
Abstract
Uttarakhand, India, boasts a forest cover of 45.4%, as per the Indian State of Forest Report 2021, yet faces susceptibility to change due to human and environmental factors, notably forest fires, implicated in forest degradation. Biotic factors, such as accumulated *Pinus roxburghii* and Chir pine needles, heighten flammability. Chir pine forests are fire-prone due to rapid foliage ignition. Recent instances of forest fires in Uttarakhand can be attributed to extreme dryness from inadequate rainfall, exacerbated by factors including two years of drought, temperature rise, low humidity, and strong winds. In March 2016, 1,218 fire events were reported, intensifying to over 427 fire points by April 24th, causing human casualties, widespread devastation, and loss of nearly 1900 hectares of forest. Over three years, Uttarakhand has seen a more than fourfold increase in affected area, surpassing 2,000 hectares this year. Employing remote sensing and GIS, our study assessed climate and forest fire data across Uttarakhand and Himachal Pradesh, revealing significant fire events in Pauri Garhwal (22.4%), Tehri Garhwal (8.5%), and Nainital (16.4%), among others. Effective forest and land management policies are crucial to mitigate escalating global forest fire risks, recognizing the role of fire in certain ecosystems. Prescribed fires, deliberately controlled, can aid ecosystem renewal, addressing the challenge of forest degradation and promoting overall ecological health.
Keywords: Forest fire; Biodiversity; Ecological Impact; Flora fauna; *Uttarakhand*.

Graphical Abstract



1. Introduction

Forest fires, known as wildfires when originating in rural landscapes such as woodlands, grasslands, or steppes, constitute a formidable environmental challenge. They can be triggered by both natural events, such as lightning strikes, and human activities, including campfires, smoking, and improper waste disposal. Rapidly spreading and profoundly destructive, forest fires pose a grave threat to ecosystems, habitats, and species, often resulting in the irreversible loss of biodiversity and substantial land destruction. To counter their devastating impact, strategies encompassing the removal of flammable debris, curbing activities during dry periods, and controlled burns are employed. Firefighters employ various tactics to control and extinguish flames, involving the creation of firebreaks and the utilization of fire-resistant substances like water and chemicals. According to the 2020 report by the FAO, the world's forests span an area of approximately 4.06 billion hectares, covering roughly 31% of the global landmass. In India, forests occupy 1.8% of the total forested expanse. However, these crucial ecosystems face numerous challenges, notably forest fires, which have emerged as a significant threat, adversely affecting forest health and productivity.

Jhariya and Raj (2014) have noted an alarming increase in forest fires, leading to widespread damage to ecosystems, neighboring communities, and economies. This trend is corroborated by the European Commission's Joint Research Centre (JRC), which reported 1,113,464 acres of land burned across 39 countries in a single year. Notably, Turkey, Algeria, and Italy were the most adversely impacted nations in 2021, with forest fire incidents far surpassing historical averages. Such intensified wildfire occurrences signal the escalating consequences of a changing climate, characterized by heightened temperatures and reduced humidity. These conditions create a vicious cycle, where increased aridity and the accumulation of dry vegetation fuel the proliferation of fires, which, in turn, contribute to further warming. In the face of this rapid environmental transformation, the imperative to update data, conduct comprehensive investigations, and elevate public awareness of the necessity to prevent and manage forest fires becomes paramount.

Indeed, wildfires have become emblematic of the wider implications of climate change, perpetuating a cycle of warming and environmental degradation. The combustion of vegetation emits carbon dioxide, driving global temperature elevation. Moreover, wildfires release carbon and other greenhouse gases, including nitrous oxide and methane, exacerbating climate fluctuations. In striking contrast to historical norms, data from 2020 portrays California's unprecedented fire-related emissions, which were three times higher than the previous two decades' average. On the most catastrophic days, emissions soared four to eight times above normal levels, underscoring the compounding impact of these fires. SP Sati, an esteemed geologist and environmental scientist, attributes another driver of increased forest fires to the year-round migration of people to previously remote areas. Over the span of just two decades, the expansion of roads in *Uttarakhand*, India, from 8,000 to 45,000 kilometers has facilitated greater human access to rural landscapes, consequently elevating the likelihood of human-initiated fires.

Nestled between latitudes 28.44° and 31.28° north and longitudes 77.35° and 81.01° east, *Uttarakhand* is characterized by its mountainous terrain and varied ecosystems. The state's importance is underscored by its geopolitical sensitivity due to international borders. With its diverse range of flora and fauna, alpine trees, tropical rainforests, and crucial water sources, *Uttarakhand* stands as an ecological treasure. However, its susceptibility to environmental vulnerabilities, earthquakes, and landslides underscores the urgency of sustainable management.

The investigation of forest fires in *Uttarakhand* emerges as an imperative undertaking. Analyzing fire behavior and progression facilitates the development of effective strategies for containment and mitigation. Protecting infrastructure and property, as well as preserving ecosystems, hinges on understanding the complex interplay of fires and their impacts. Furthermore, forest fires' substantial contribution to greenhouse gas emissions necessitates thorough research to inform comprehensive climate change strategies.

As forest fires assume various forms based on their origins, behaviors, and fuel sources, tailored strategies are requisite for control and extinguishment. Surface fires, which consume dried vegetation and ground cover, are most common. Electrical discharges from lightning strikes or intentional back blazes set by firefighters can initiate these fires. Effective response demands adaptability to the diverse nature of these fires.

In the context of forest fires' escalating threat, sustained investigation remains pivotal. It not only informs strategies for fire management but also enriches our comprehension of the intricate relationship between fire, environment, and human activity. By safeguarding these invaluable ecosystems, we ensure a sustainable future for both present and forthcoming generations.

Materials and methods

The present review manuscript is the result of a rigorous and systematic approach that draws upon a diverse array of authoritative scholarly sources, as well as datasets obtained from the Forest Survey of India and prior research endeavours. This methodology ensures a robust foundation for the composition's insights and conclusions.

Literature Synthesis: A comprehensive literature review was conducted to identify and incorporate relevant research studies, articles, and publications related to forest fires, their ecological impacts, and management strategies. This entailed a meticulous examination of academic databases, peer-reviewed journals, and reputable reports.

Data Compilation and Analysis: Datasets retrieved from the Forest Survey of India were rigorously analysed to discern patterns and trends in fire incidents across different regions of *Uttarakhand*. Particular attention was devoted to the noteworthy fire events in 2016, allowing for a detailed exploration of their characteristics, causes, and consequences.

Integration of Forest Department Records: Insights and records sourced from the forest department were methodically compiled and curated. This involved extracting pertinent information related to fire occurrences, their geographical distribution, and the resultant ecological and socio-economic impacts. The collated data were then synthesized to form a coherent narrative that serves to enlighten a broader audience.

Engagement and Awareness Building: A core objective of this endeavour is to engage a wider audience and foster awareness regarding the critical necessity of proactive measures in safeguarding *Uttarakhand* precious forests and their diverse biodiversity. To achieve this, the compilation of information has been thoughtfully structured to resonate with various stakeholders, including policymakers, researchers, and the general public.

Through a meticulous integration of diverse sources and rigorous data analysis, this review manuscript contributes to a holistic understanding of forest fire dynamics in *Uttarakhand*. It lays a solid foundation for informed decision-making and collaborative efforts aimed at preserving the ecological balance and wealth of biodiversity within these invaluable forest ecosystems.

Fire Dynamics and Ecological Implications in *Uttarakhand* and India

Between 2003 and 2012, the global annual average of forest land consumed by fires stood at 1.7%. South America bore the brunt of this phenomenon, witnessing the highest yearly incidence of forest land burning. In India, an average of 35 million hectares of forest area succumbed to fires each year. Recognizing the historical context of fires becomes paramount for policymakers and forestry departments. Analyzing the period from 2005 to 2015, it becomes evident that states such as Mizoram, Orissa, Andhra Pradesh, Assam, Madhya Pradesh, Chhattisgarh, Manipur, and Maharashtra experienced the highest percentage of forest fire occurrences. In a significant development, the Government of India declared a state of emergency in Mizoram for the first time. The years 1911, 1921, 1930, 1931, 1939, 1945, 1953, 1954, 1957, 1958, 1959, 1961, 1964, 1966, 1968, 1970, 1972, and 1995 emerged as those with the most rampant forest fires in the state. Among Uttarakhand's districts, Pauri Garhwal and

Nainital took the lead in forest fire occurrences between 2005 and 2016, trailed by Tehri Garhwal, Almora, and Chamoli.

The global average of forest land consumed by fire per year between 2003 and 2012 was 1.7%. South America endured the greatest average yearly amount of forest land burning. Fires affected an average of 35 million hectares of forest area in India each year. It is essential that policymakers and forestry divisions take fire history into consideration. During the timeframe of 2005 to 2015, the states of Mizoram, Orissa, Andhra Pradesh, Assam, Madhya Pradesh, Chhattisgarh, Manipur, and Maharashtra had the highest percentage of forest fire occurrences. For the first time, the Government of India has declared a state of emergency in Mizoram. The years with the most forest fires in the state were 1911, 1921, 1930, 1931, 1939, 1945, 1953, 1954, 1957, 1958, 1959, 1961, 1964, 1966, 1968, 1970, 1972, and 1995. The districts of Pauri Garhwal and Nainital in *Uttarakhand* saw the greatest number of forest fires between 2005 and 2016, followed by Tehri Garhwal, Almora, and Chamoli.

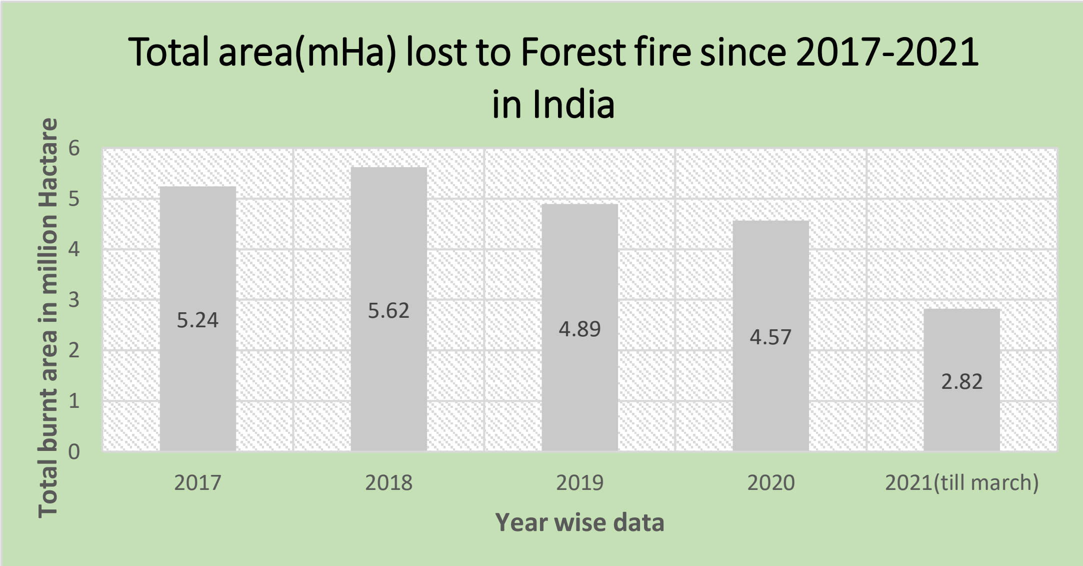


Fig 1- Data of forest fire in India from 2017- 2021 (source- FSI forest large monitoring system)

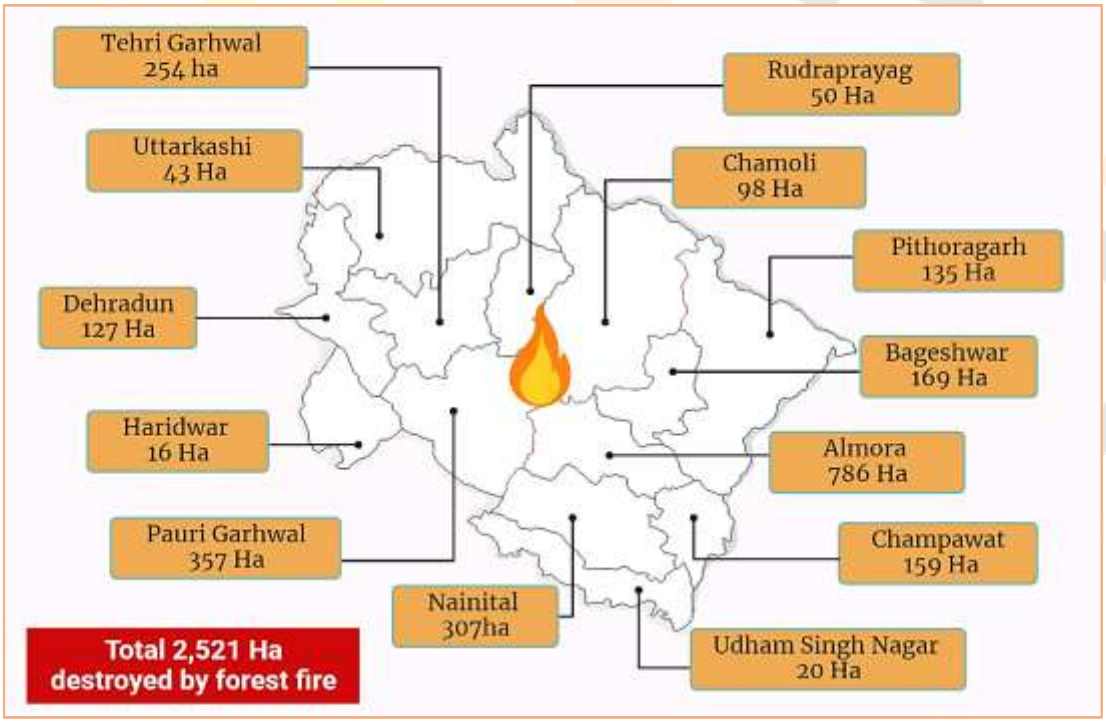


Fig. 2- Second Worst in 16 Years, Fires Destroy 2,521 Ha Forest Cover in *Uttarakhand* (forest dept. data as on June 3 2016)

Every year, the occurrence of approximately 4500 forest fires ravages Uttarakhand, scorching more than 0.6 million hectares of its forested expanse **(Babu, 2019)**. Certain plant species have developed adaptive traits, such as thick bark, enabling them to withstand the intensity of these fires **(Khan and Tripathi, 1989)**. Recognizing this, the exploration and comprehension of forest fire impacts on plant species diversity within ecosystems became a pertinent objective. Changes in land use over the last century have mssarkedly influenced global patterns of burned areas. Paradoxically, fire suppression strategies in midlatitude temperate zones might inadvertently foster more catastrophic fires in the long term. Concurrently, heightened utilization of fire to clear tropical vegetation has led to an escalation in wildfire frequency **(Littell *et al*., 2009; Cochrane, 2003)**.

In the contemporary context, fire represents a significant disturbance to global plant cover, influencing ecosystems that are either adapted to, tolerate, rely on, or are vulnerable to natural or human-induced fires. The assessment of fire risk is commonly referred to as fire danger **(Chuvieco *et al*., 2009)**. The likelihood of a fire occurrence is influenced by two key agents: natural factors, often involving lightning strikes, and human-related causes. Human activity, whether direct or indirect, amplifies the risk of fire ignition in such scenarios **(Martinez *et al*., 2009)**. Remarkably, around 90% of forest fires are ignited by human activities, in contrast to only 8% stemming from natural sources. **(Chuvieco *et al*. 2008)** noted that over 30% of the Earth's terrestrial surface is prone to significant fire incidents. A precise assessment of the global extent impacted by diverse fire regimes remains a challenge, currently lacking comprehensive quantification. In India, nearly half of the country's forested areas are susceptible to fires. Man-made fires, recurrent in nature, play a pivotal role in the Chir-pine *(Pinus roxburghii)* and oak *(Quercus leucotrichophora)* forest zone of the Central Himalayas, notably in Uttarakhand. The Indian government is actively engaged in endeavors to mitigate fire occurrences within the region **(Singh and Singh, 1992; Semwal and Mehta, 1996)**.

Emergence and Escalation of Forest Fires in India

Forest fires stand as a predominant catalyst for extensive forest degradation across India. The nation often grapples with terrestrial fires, witnessing an annual impact on over 35 million acres of woodland. The Indian Forest Survey on Forest Fire indicates that approximately 50 percent of forest areas are prone to fire events. However, this statistic does not equate to an annual conflagration affecting half of the country's land. Instead, major wildfires, strong blazes, recurrent forest fires, and sporadic fires correspond to just 0.84 percent, 0.14 percent, 5.16 percent, and 43.06 percent of forested areas, respectively. In reality, a mere 6.17 percent of India's wooded expanses are susceptible to critical combustion on an annual basis. As per the World Resources Institute, forest fires are anticipated to impact around 3.73 million hectares of forest annually out of a total forested expanse of approximately 63 million hectares **(Satendra and Kaushik, 2014)**.

Official data on fire-related losses remains limited; nevertheless, it is believed that the percentage of forest regions susceptible to yearly fires varies from 33% in certain states to exceeding 90% in others. Notable fluctuations in fire occurrence have been documented in India over the years. For instance, in 2005, 8,645 forest fires were recorded, followed by 20,567 in 2005-2006, 16,779 in 2006-2007, 17,264 in 2007-2008, 26,180 in 2008-2009, and 30,892 in 2009-2010. The incidence then reduced to 13,898 in 2010-2011, followed by 29,362 in 2012, 18,451 in 2013, 19,054 in 2014, and 15,937 in 2015 **(Jhariya and Raj, 2014)**. Forest Survey of India, which has been actively monitoring forest fires since 2004, indicates that severe fires predominantly afflict dry deciduous forests, with evergreen, semi-evergreen, and montane temperate forests displaying comparatively lower susceptibility. The India State of Forest Report (ISFR) 2021 indicates that the forest fire-prone area encompasses 7,13,789.03 square kilometers, equivalent to 35.46% of India's total forest cover **(ISFR 2021).**

While forest fires are recurrent and intrinsic to the state, their frequency and intensity are on the rise. The 'forest fire season,' spanning from winter to monsoon, is growing more intense, attributed in part to climate change and the ensuing reduced rainfall in the Himalayan region. In the period from October 1, 2020, to April 4, 2021, forest service data registered 989 fire occurrences in Uttarakhand, consuming 1,297.43 hectares of woodland. Notably, the same timeframe in 2019 witnessed only 39 fires in the state's forests, emphasizing the escalating trend. The Forest Survey of India identified Uttarakhand as the second state, following Madhya Pradesh, with the highest number of active fires on April 5, 2021, recording 71 fires compared to Madhya Pradesh's 93. The stark reduction in rainfall between January and March 2021—merely 10.9 millimeters as opposed to the usual 54.9 millimeters—translating to an 80% deficit, further exacerbated the fire risk. Additionally, rising temperatures in Uttarakhand and neighbouring Himalayan states have added to the challenging scenario. As of ISFR 2021, India's forest fire-prone area extends to 7,13,789.03 km², encompassing 35.46% of the nation's total forest cover **(ISFR 2021).**

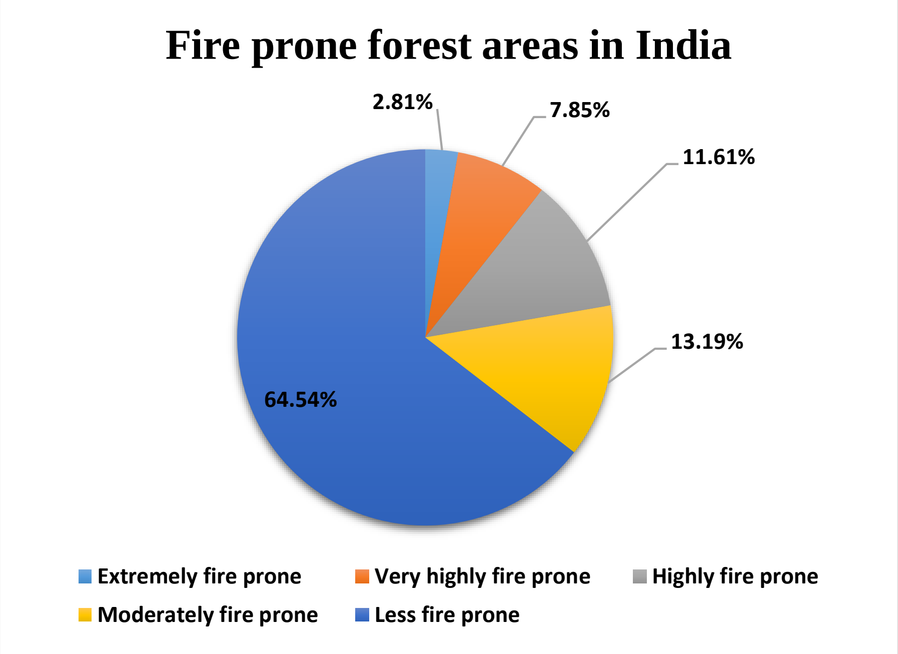


Fig. 3- Distribution of Fire-Prone Forest Areas in India as a Percentage of the Total Indian Forest Cover (Forest Survey Data 2020).

Vulnerability and Historical Incidences of Forest Fires in Uttarakhand

The Himalayan Mountain ranges, considered the youngest on Earth, stand as the most susceptible to the ravages of fire. Human-induced forest fires have a long-standing history in the Himalayan state of Uttarakhand. Notable episodes of significant infernos date back to 1911, 1921, 1930, 1931, 1939, 1945, 1953, 1954, 1957, 1958, 1959, 1961, 1964, 1966, 1968, 1970, 1972, and 1995. Among these, certain fires in 1921, 1930, and 1942 were attributed to groups opposing the forestry regulations imposed by the British colonial authority, advocating for regional autonomy.

The devastating pinnacle of forest fires in Uttarakhand was reached during 2002, 2003, 2004, 2005, 2008, 2009, 2010, 2012, and 2016, transforming the occurrence into an annual ordeal. The spectre of forest fires looms over 34,24,857 hectares of Uttarakhand's forested terrain, encompassing a staggering 63.91 percent of the state's total forest area. Noteworthy examples of the havoc forest fires can wreak were witnessed during the summers of 1995 and 1999 in the Himalayan highlands. These fires, predominantly scorching pine woods on the slopes of the sub-Himalayan region, cast ominous clouds of smoke, severely hampering visibility **(Satendra and Kaushik, 2014).** In 2016, a staggering 12,000 hectares of forest cover were consumed across the country in tens of thousands of individual fire incidents. These fires echoed the patterns of the past, enveloping the mountains in dense smoke and diminishing visibility to a mere 200 meters **(Satendra and Kaushik, 2014).**

The Ecological Significance and Complex Dynamics of Wildfires

Wildfires wield a substantial impact on ecosystems worldwide, constituting an integral part of numerous natural habitats. They play a pivotal role in ecosystem functioning and support the survival of species that have evolved in tandem with fire (Fig. 3). While the notion of wildfires may evoke images of destruction, it is essential to recognize the multifaceted benefits they bring, particularly in ecosystems adapted to their presence **(Keeley and Pausas, 2019)**.

Wildfires, often a part of natural processes, serve as catalysts for various advantageous ecological outcomes. Certain plants, for instance, require periodic fires to trigger seed dispersal and regeneration. This environmental shift fosters species renewal and spurs growth. Notably, fireweed relies on fire disturbance to initiate flowering and rejuvenate fire-affected plants. The demise of vegetation paves the way for fresh life, establishing new habitats rich in resources and low in competitors **(Keeley *et al.*, 2012)**. Furthermore, wildfires can purge pathogens, parasites, and excess organic matter, providing access to sunlight-nourished nutrients for plant growth **(Pausas and Keeley, 2014)**. Controlled low-intensity fires serve to clear undergrowth, thwarting the spread of future destructive fires. In the aftermath of wildfires, new grasslands emerge, proving beneficial for grazing animals **(Koltz *et al.*, 2018; Pausas and Parr, 2018)**.

A salient advantage of wildfires is their role in preserving biodiversity and genetic diversity, which yield manifold benefits for humans. Fire-prone regions often boast rich plant diversity and robust root systems. These plants store buds and carbohydrates underground, offering sustenance for humans. Some have even been cultivated for gardening and horticulture purposes. Beyond flora, wildfires function as a natural defense mechanism against diseases and pests, safeguarding animals, forests, livestock, and humans. Suppressing wildfires can augment the risk and spread of infectious diseases. For instance, Stone's sheep (Ovis Dalli stonei) in British Columbia exhibited significantly lower lungworm loads when granted access to recently burned areas compared to counterparts with no such access **(Seip and Bunnell, 1985)**. Regular surface fires reduce the peril of more destructive conflagrations, which pose threats to both the environment and human-populated forest zones.

Yet, the suppression of wildfires, spurred by successful fire control programs like those in 20th-century US pine forests, has inadvertently escalated hazardous fuel accumulation in forest understory. The absence of natural fire occurrences disrupted vital ecosystem processes, potentially contributing to extensive tree mortality during the Sierra Nevada Mountains' devastating drought of 2012-2014 **(Walker *et al*., 2018)**. Amid a warming planet, numerous plant species face the challenge of relocating to more suitable habitats. Swift migration might be unrealistic for long-lived plants due to competition with established species. Wildfires, by generating gaps, facilitate faster species replacement and foster the selection of individuals best adapted to new conditions. These gaps promote adaptation to drier environments by favoring genotypes attuned to the evolving landscape (**Wang *et al*., 2019).**

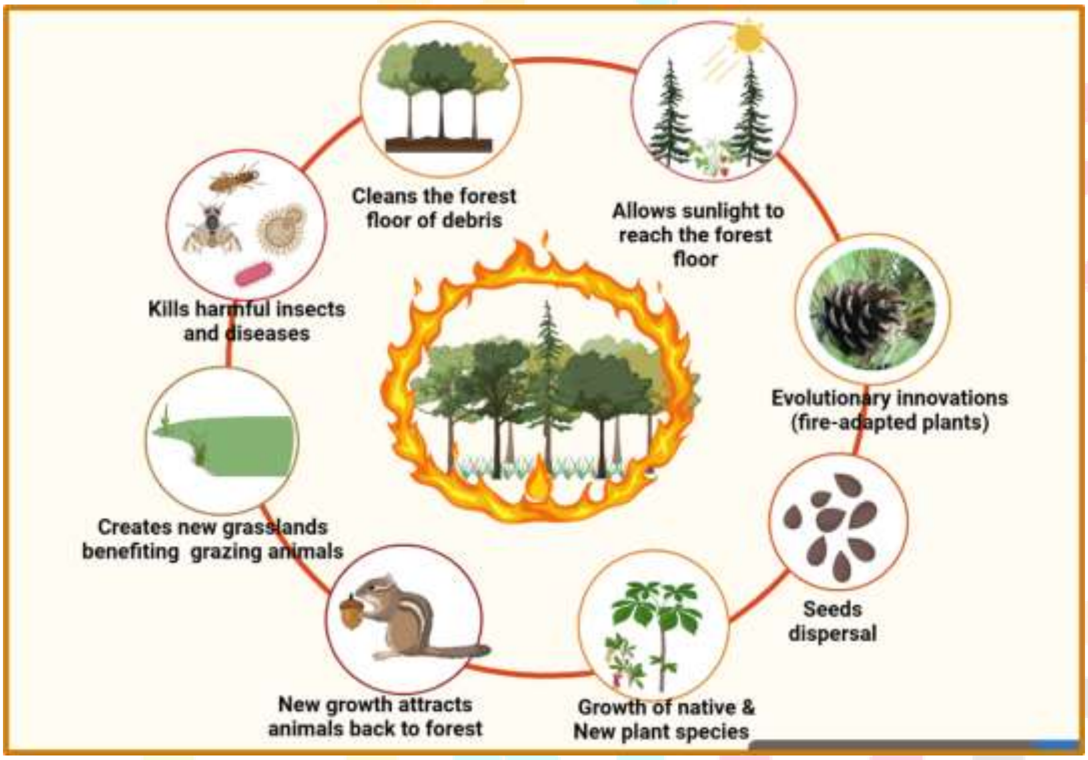


Fig. 4- Ecological Benefits Unveiled: Positive Impacts of Forest Fires

Fire emerges as a catalyst for a multitude of ecological functions, bestowing a range of benefits upon ecosystems. Wildfires play a pivotal role in generating open spaces within ecosystems, fostering an environment conducive to a diverse array of plants and creatures that thrive in light-filled habitats **(Parr, 2014; Keeley *et al*., 2012; Andersen, 2019)**. The intense heat and oxygen generated by fire are responsible for creating gaps in vegetation. This release of energy serves as a dynamic force that can be harnessed to fuel fires in regions teeming with biodiversity. As fire interacts with the atmosphere, it not only spurs the growth of vegetation gaps but also unleashes a potential that can invigorate and sustain the intricate web of life within these ecosystems.

Impacts of Forest Fire Frequency on Floristic Diversity in *Uttarakhand* and Western Himalayan Forests

Due to the prevailing humid conditions, ample moisture in combustible materials, and abundant rainfall, forest fires are not a customary occurrence in most undisturbed,

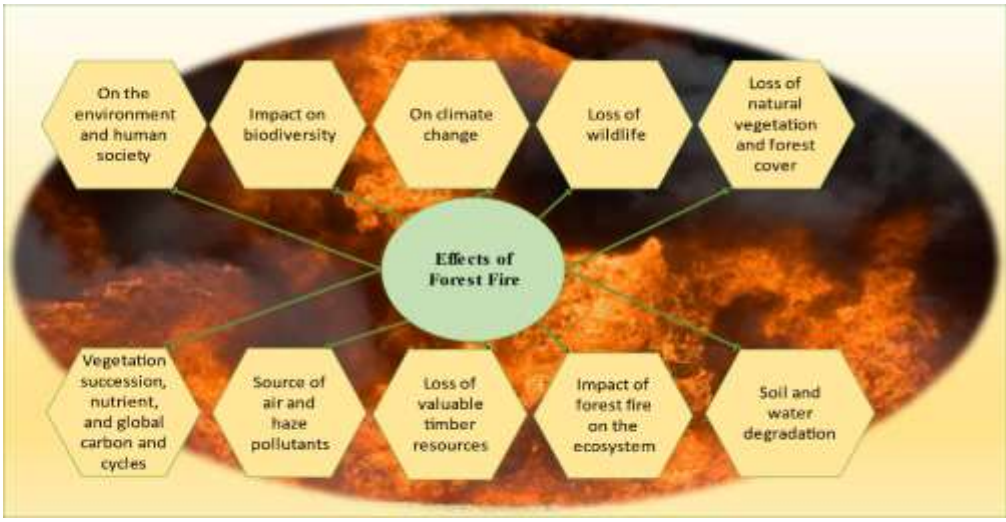


Fig. 5- Impacts of Forest Fire on Various Ecological Facets of the Ecosystem

towering, closed-canopy rainforests. However, during periods of extreme drought, such as those witnessed recently, these forests can become more vulnerable to the ravages of flames. Unlike fire-adapted ecosystems, these rainforests lack the adaptations that shield them from fire, leaving seedlings, saplings, vines, and young trees susceptible to destruction as they lack protective thick bark **(Woods, 1989)**. The impacts of destructive fires on plant diversity within these ecosystems have been profound. A comprehensive study conducted by **(Bargali *et al*., 2022)**, focusing on 16,206 fire incidents in *Uttarakhand* between 2011 and 2020, revealed significant insights. Among the observed fire spots, the highest frequency recorded was 34. Remarkably, the majority of fire locations (13,619) displayed low or no fire frequency, covering a vast 84.04% of the state's total area. Conversely, a mere 129 fire spots exhibited high fire frequency, accounting for a mere 0.79% of the state's expanse.

The study demonstrated that plant populations have an inherent ability to respond to disturbances like wildfires. This was reflected in the varying levels of species diversity across different fire frequency categories. Notably, areas with low fire frequency exhibited higher diversity, while an increase in fire frequency correlated with reduced variety and the dominance of specific species. Such outcomes were attributed to the constrained regrowth of certain species. Intriguingly, tree species exhibited a more diverse presence at low and moderate fire frequencies compared to areas with no fire frequency, while high fire frequencies exhibited the lowest diversity. This suggests that mild fires do not adversely impact tree density.

Further analysis unveiled that a low frequency of fire might have positive implications for the rejuvenation of herb and shrub species within forests. This study indicated that species regeneration tends to flourish in response to moderate or light disturbances. However, as fire frequency escalates, a reduction in plant species diversity became apparent. Particularly notable was the significant decline in sapling density within moderate and high fire frequency categories, with an approximate 30% decrease observed. This decrease in tree density could be attributed to the effects of fire.

Additionally, the research illuminated that both low and moderate fire frequencies yielded favourable results for shrub and tree densities. Conversely, an intensified fire frequency had a detrimental impact on herb density. Sustaining species diversity and quantity necessitates the effective regeneration of species within each habitat. This study serves as a foundation for future investigations to delve deeper into the repercussions of forest fires on plant structures within the western Himalayan region, enriching our understanding of the intricate interactions between wildfires and the delicate ecosystems they influence.

Impact of Fire on Forest Fauna & Loss of Habitat Territories and Shelter

Fire, when occurring as an unnatural disturbance, can have adverse effects on both invertebrates and vertebrates within forest ecosystems. The extinction of crucial species like pollinators, vertebrates, and decomposers can significantly impede the forest's recovery process. The 1998 fires in the Russian Federation serve as an illustrative example, revealing the severe impact on animals and fish. Following the fires, squirrel and weasel mortality rates ranged from 70 to 80 percent, boar mortality was between 15 to 25 percent, and rodent mortality reached 90 percent **(Goldammer and Shvidenko, 2001)**. Small mammals such as tarsiers, bats, and lemurs, along with cavity-dwelling birds, face detrimental consequences as their habitats, comprised of standing cavity trees and fallen logs, are decimated by wildfires. The displacement of these creatures from their habitats can disrupt local ecosystems and even lead to species extinction due to the absence of suitable relocation options **(Kinnaird and O'Brien, 1998).** In Russia's 1998 wildfires, the elevated water temperatures in lakes and rivers caused by the fires impacted aquatic environments, resulting in the death of salmon. This environmental catastrophe underscored the significance of maintaining diverse populations in fire-affected areas **(Shvidenko and Goldammer, 2001).**

Loss of food

The extinction of fruit trees leads to a notable decline in bird and mammal species that rely on fruit as a primary food source. This impact is particularly evident in tropical forests such as East Kalimantan, Indonesia. The aftermath of the 1982-1983 fires in Kutai National Park saw a significant reduction in fruit-eating birds like hornbills, while insectivorous species, notably woodpeckers, became more prevalent. The aftermath of fires in burned forests results in the scarcity of small animals, birds, and reptiles. The decrease in small rodent populations can disrupt the food chain for small predators. Furthermore, fires disrupt leaf litter and the arthropod populations residing within it, reducing the food supply for omnivores and carnivores and increasing the transmission of diseases to both wildlife and humans **(Kinnaird and O'Brien, 1998)**.

Fire Regimes in Natural Ecosystems and Adaptations of Plant Species

Tropical forests that face exposure to fires during the dry season have developed distinct adaptations that enhance their survival amidst blazes. These adaptations include the development of thicker bark, the ability to regenerate from fire scars, the capacity to resprout, and the presence of fire-adapted seeds.

Fig 6- Some Fire-Adapted Plant Species (Uttrakhand Pauri disst 2022.)

In such conditions, fire-resistant species thrive, often outcompeting those that are better suited for undisturbed environments. For instance, the Jack pine *(Pinus banksiana)* features serotinous cones that remain sealed until a fire occurs. These cones release their viable seeds onto the newly cleared ash bed as their scales open during the fire. Similarly, the Mountain ash *(Eucalyptus regnans)* requires fire for its growth.

These adaptations enable vegetation to regenerate either from the stem or the rootstock, flourishing under full sunlight **(Trabaud and Lepart, 1980).** The survival of forests depends on fire in certain ecosystems, such as the oak *(Quercus suber)* forests. In boreal forests, fire stands as the primary driver of ecological disturbance, with fire return intervals ranging from 40 to 300 years depending on the climate. Notably, certain habitats with Jackpine in central Canada experience remarkably short fire intervals of around 40 years **(Van Wagner, 1978)**. While many evergreen conifers and deciduous trees with thin bark and dry leaves succumb rapidly to low-intensity fires, some North American pine species exhibit thicker bark, elevated crown bases, and taller statures, enabling them to withstand multiple fire events. Historical records suggest that around 1% of Sweden's forested area burned annually before systematic fire suppression measures were implemented during the late nineteenth century **(Johnson, 1992)**. Some damp and moist forest regions experience infrequent fires, sometimes spanning hundreds of years without a blaze. The ecological transformation induced by fire generates a diverse range of age classes and vegetation types. Some species can only thrive in these post-fire conditions, facilitating the dispersion of essential seeds for the repopulation of scorched areas **(Ohlson *et al*., 1997).** Surface fires, occurring approximately every eighty to one hundred years, play a critical role in northern woodlands, sparsely-covered taiga, and forest tundra. These fires, particularly on permanently frozen ground, function as a natural mechanism, preventing the transition of forests to shrub land or grassland and maintaining ecosystem stability **(Shvidenko and Goldammer, 2001)**.

Effect of High-Intensity Fires on Soil and Vegetation Dynamics

High-intensity wildfires can have profound effects on both soil properties and vegetation dynamics. The intensity of a fire can lead to the destruction of almost all organic matter in the soil, resulting in significant alterations in its physicochemical and biological characteristics. Research by **(Bhandari *et al*, 2000)** demonstrated that organic carbon and nitrogen levels in burned soils were initially lower compared to unburned soils. However, post-fire, there was a steady increase in organic carbon and nitrogen levels, indicating short-term changes in soil physicochemical attributes.

The impact of fire on the vegetation that follows can be multifaceted. The alteration of soil properties and the removal of dead plant material create opportunities for a diverse range of species to establish and flourish. In particular, the burning of the forest canopy, typically composed of shrubs, can stimulate ground-level plant growth due to increased sunlight and warmth. This transition can foster a greater richness in species diversity **(Bhandari *et al*., 1997)**. Moreover, biodiversity studies in the *Uttarakhand* Himalaya have revealed that both burnt and unburnt pine forests demonstrate greater biodiversity of herbaceous plants compared to other types of forests **(Semwal, 1990; Rawat, 1990; Mehta and Semwal, 1996; Bhandari *et al*., 1999)**.

Following a high-intensity fire, subsequent heavy rainfall can significantly impact the biomass and productivity of the affected area. In the aftermath of a crown fire, characterized by its intensity, a shift in environmental conditions occurs. The prompt release of nutrients stored in the biomass, stimulation of seed and bud dormancy, and enhanced growth of herbaceous plants are observed due to the interaction between fire and subsequent rainfall **(Semwal, 1990; Semwal and Mehta, 1996).** This process maximizes the seasonal sustenance of grazing grounds associated with pine trees, thereby illustrating the complex interplay between fire, soil, and vegetation dynamics.

Economic Impacts of Wildfires and Invasive Plants in Arid and Semi-Arid Environments

Examining the economic repercussions of wildfires in arid and semi-arid environments reveals a multifaceted landscape of effects, wherein the intersection of wildfires and invasive plant species plays a crucial role. While ranching stands as a pivotal economic activity in rural regions, the influence of wildfires extends beyond this domain, affecting sectors such as farming, fishing, and tourism. A case study delved into the economic aftermath of extensive wildfires encompassing 648,000 hectares across five counties in northern Nevada. The assessment disaggregated costs into four categories: lost animal-unit months of forage, fence maintenance, infrastructure expenses, and firefighting outlays. Moreover, the study accounted for structural losses, livestock casualties, and rehabilitation expenditures. This case underscores the diverse dimensions of economic consequences that emerge from wildfires.

Invasive plant species compound these economic challenges, imposing an additional burden on economies. Research points to an annual cost exceeding $13 million attributed to invasive weeds. However, the allocation of this cost across factors like wildlife loss, erosion escalation, road upkeep, landscape degradation, and human life impact remains unquantified, as does the economic influence on regions like California. Notably, the economic ramifications of most invasive species in rangelands and wildlands receive scant scrutiny. While certain agricultural costs, including grazing value reduction, are estimated, broader economic and social outlays are often omitted.

Exploration into the economic impact of specific invasive plants remains limited. For instance, the economic repercussions of leafy spurge (*Euphorbia esula L.*) and salt cedar (*Tamarix spp.*) have yet to be fully addressed. Moreover, research on both woody and non-woody plants remains sparse, with few comprehensive economic analyses even for potentially influential species like buffelgrass and cheatgrass.

As a case in point, **(Eiswerth *et al*, 2005)** estimated that non-native plants in Nevada could incur economic impacts ranging from $6 million to $12 million annually. These findings also projected the adverse influence of invasive plants on wildlife-related activities, with estimated yearly costs ranging between $ million and $ million.

Understanding the nexus between major wildfires and urban environments requires a nuanced perspective. While natural disasters often trigger increased expenditures in firefighting and government funding during and after wildfire events, communities' perceptions of risk and disaster outcomes remain complex. Dr. Jodeler suggests that tangible evidence of a wildfire's potential impact is pivotal for driving public awareness. Instances like the deliberately set Utah fire frequently lead to public ire directed at authorities.

In the context of economic recovery, wildfires act as both natural and human-caused disasters. A town's ability to rebound hinges on its pre-existing socio-economic and infrastructural foundations. The interplay of wildfire, invasive species, and economic repercussions thus necessitates a holistic approach to mitigate adverse effects and foster resilient communities.

Addressing the Persistent Threat of Forest Fires in India

Forest fires remain a relentless natural menace, exerting their impact on the lives of a staggering 275 million people, constituting 22% of the population based on the 2011 census. Effectively countering this hazard necessitates the allocation of enhanced resources. An extensive study by the Council on Energy, Environment, and Water has unveiled a disconcerting tenfold surge in forest fire occurrences in India over the last two decades. Remarkably, this increase has transpired amidst a mere 1.12% expansion in the overall forest cover (TFC). In this endeavour, a comprehensive assessment tailored to local climatic conditions stands poised to yield substantial benefits **(Mohanty and Mittal, 2022).**

Leveraging Fire Detection Systems: A Technological Approach

To proactively tackle forest fires, India employs advanced fire detection systems. These systems heavily rely on cutting-edge technologies such as the Moderate Resolution Imaging Spectroradiometer (MODIS) instrument and the Visible Infrared Imaging Radiometer Suite (VIIRS) for satellite-based hotspot surveillance **(World Bank, 2018)**. The advent of the Forest Fire Alert System 3.0 in 2019 stands as a testament to collaborative ventures between NASA- ISRO (National Aeronautics and Space Administration- Indian Space Research Organization) and ISRO- FSI (Indian Space Research Organization-Forest Survey of India) (Forest Survey of India, 2011a).

Strategic Initiatives for Mitigation and Management

In a bid to curtail the menace of forest fires, India introduced the National Action Plan on Forest Fires (NAPFF) in 2018. This multifaceted plan aims to minimize the occurrence of forest fires by fostering awareness, empowering forest fringe communities, and fostering collaboration with State Forest Departments. Key objectives of the NAPFF encompass equipping forest personnel and institutions with enhanced capabilities to combat fires swiftly and ensuring prompt recovery post-fire incidents.

At the heart of forest fire prevention and management lies the Forest Fire Prevention and Management Scheme (FPM). This unique centrally funded initiative caters specifically to assisting states in addressing forest fire challenges. The financial allocation under the FPM adheres to a well-defined centre-state cost-sharing formula. This translates to a ratio of 90:10 for central and state funding in the Northeast and Western Himalayan regions, while maintaining a 60:40 distributions for all other states. These funding provisions underscore India's commitment to collaborative and strategic efforts in managing and mitigating forest fires.

Conclusion: Managing Forest Fires for a Sustainable Future

This research delves into the critical issue of forest fires in the Indian Subcontinent, revealing the profound ecological damage inflicted on plant and animal life, alongside the release of harmful pollutants stemming from these fires. According to a Forest Survey of India Report, an alarming 50% of India's forests are susceptible to fire, with 6% of them facing the risk of severe destruction. The dominant cause of these fires lies in human activity, stemming from negligence or deliberate actions. Typically occurring between February and May, these incidents predominantly coincide with the dry season. Among the diverse forest types, Tropical Deciduous forests are the most susceptible to fire **(Reddy *et al*., 2020; Reddy *et al*., 2017; GFMC 2002)**.

The devastating 2016 forest fire has highlighted a spectrum of critical concerns demanding immediate attention: (i) An urgent need to comprehend the root causes of such catastrophic forest fires; (ii) The Forest Department's inadequacies in mounting effective responses, even in the face of the El Nino phenomenon and post-monsoon droughts; (iii) The scarcity of financial resources, infrastructure, and manpower to execute proactive measures; (iv) Overreliance on technology without a holistic approach to fire extinguishment; (v) Ambiguities in assessing the extent of the damage.

Notably, vegetation such as agricultural crops and the forests bordering these fields are equally susceptible to ignition, escalating the overall vulnerability. While forest fires may not wreak immediate havoc, their gradual and persistent impact over time can precipitate the extinction of species, disruption of genetic diversity, and the unravelling of intricate food chains, ultimately destabilizing the ecosystem's health. Mitigating these threats necessitates the preservation of our invaluable forests, which lie at the core of our sustenance. While contemporary remote sensing technologies offer promising safeguards against fires, it remains imperative to heighten vigilance and foster public awareness to avert ignition.

Concurrently, a robust data repository chronicling ongoing forest fires is crucial for assessing damages and devising comprehensive recovery strategies. To mitigate the ramifications of forest fires, the cultivation of fire-resistant trees such as Banj, Oak, Myrica, Alder, and Rhododendron is recommended for Chir Pine forests. Transforming forest humus into bio-bricks and vermicomposting presents innovative solutions. Cutting-edge fire detection systems like radio acoustic sound systems and Doppler radar should be integrated, while bolstering collaboration between the forest department and local communities is pivotal. Instituting a fire forecasting and alert system is essential, along with establishing a dedicated firefighting division within the forest department. By incentivizing local participation and incorporating their indigenous knowledge, harnessing forest resources becomes a viable avenue.
As we navigate the intricate landscape of forest fires and degradation, it is imperative to recognize the significance of effective Uttarakhand forestry resource management. Utilizing satellite-based remote sensing, we can monitor and map vegetation resources across scales and timeframes. By employing Geographic Information Systems (GIS) and remote sensing techniques, we can organize data sets for informed decision-making. Satellite imagery proves instrumental in charting forest fires and assessing ecological impact, enhancing our ability to devise and implement comprehensive green area management plans. It's essential to acknowledge that we might not completely prevent forest fires, but we hold the capability to adeptly manage them through a holistic and collaborative approach.

References

1) 1Andersen, A. N. (2019). Responses of ant communities to disturbance: Five principles for understanding the disturbance dynamics of a globally dominant faunal group. *Journal of Animal Ecology*, *88*(3), 350-362.
2) Babu, K. S. (2019). Developing Forest Fire Danger index using geo spatial techniques. *International Institute of Information Technology, Hyderabad*.
3) Babu, K. S. (2019). Developing Forest Fire Danger index using geo spatial techniques. *International Institute of Information Technology, Hyderabad*.
4) Babu, K. S. (2019). Developing Forest Fire Danger index using geospatial techniques. *International Institute of Information Technology, Hyderabad*.
5) Bahuguna, V. K., & Upadhay, A. (2002). Forest fires in India: policy initiatives for community participation. *International Forestry Review*, *4*(2), 122-127.
6) Bahuguna, V. K., & Upadhay, A. (2002). Forest fires in India: policy initiatives for community participation. *International Forestry Review*, *4*(2), 122-127.
7) Bargali, H., Gupta, S., Malik, D. S., & Matta, G. (2017). Estimation of fire frequency in Nainital District of Utarakhand state by using satellite images. *Journal of Remote Sensing & GIS*, *6*(4), 1-5.
8) Bargali, H., Kumar, A., & Singh, P. (2022). Plant studies in *Uttarakhand*, Western Himalaya: A comprehensive review. *Trees, Forests and People*, 100203.
9) Bargali, H., Mathela, M., Sharma, R., Sharma, M., Yaming, D., & Kumar, A. (2021). Plant studies in Himachal Pradesh, Western Himalaya: a systematic review. *Journal of Mountain Science*, *18*(7), 1856-1873.
10) Bargali, H., Mathela, M., Sharma, R., Sharma, M., Yaming, D., & Kumar, A. (2021). Plant studies in Himachal Pradesh, Western Himalaya: a systematic review. *Journal of Mountain Science*, *18*(7), 1856-1873.
11) Bargali, H., Singh, P., & Bhatt, D. (2020). Role of chir pine (pinus roxburghii sarg.) in the forest fire of *Uttarakhand* Himalaya. *ENVIS BULLETIN HIMALAYAN ECOLOGY*, *28*, 82.
12) Bargali, H., Singh, P., & Bhatt, D. (2020). Role of chir pine (pinus roxburghii sarg.) in the forest fire of *Uttarakhand* Himalaya. *ENVIS BULLETIN HIMALAYAN ECOLOGY*, *28*, 82.
13) Bourlière, F. (1993). Johnson, EA—Fire and Vegetation Dynamics: Studies from the North American Boreal Forest. Cambridge University Press. Cambridge Studies in Ecology. Cambridge UK, 1992. *Revue d'Écologie (La Terre et La Vie)*, *48*(1), 90-91.
14) Bargali, H., Calderon, L. P. P., Sundriyal, R. C., & Bhatt, D. (2022). Impact of forest fire frequency on floristic diversity in the forests of *Uttarakhand*, western Himalaya. *Trees, Forests and People*, *9*, 100300.
15) Capellesso, E. S., Cequinel, A., Marques, R., Sausen, T. L., Bayer, C., & Marques, M. C. M. (2021). Co-benefits in biodiversity conservation and carbon stock during forest regeneration in a preserved tropical landscape. *Forest Ecology and Management*, *492*, 119222.

16) Centre, J. R. (2022, March 21). *EU 2021 wildfire season was the second worst on record, finds New Commission Report*. EU Science Hub. Retrieved February 21, 2023, from https://joint-research-centre.ec.europa.eu/jrc-news/eu-2021-wildfire-season-was-second-worst-record-finds-new-commission-report-2022-03-21_en
17) Chuvieco, E., Giglio, L., & Justice, C. (2008). Global characterization of fire activity: toward defining fire regimes from Earth observation data. *Global change biology*, *14*(7), 1488-1502.
18) Chuvieco, E., González, I., Verdú, F., Aguado, I., & Yebra, M. (2009). Prediction of fire occurrence from live fuel moisture content measurements in a Mediterranean ecosystem. *International Journal of Wildland Fire*, *18*(4), 430-441.
19) Cochrane, M. A. (2003). Fire science for rainforests. *Nature*, *421*(6926), 913-919.
20) Dasari, P., Reddy, G. K. J., & Gudipalli, A. (2020). Forest fire detection using wireless sensor networks. *International Journal on Smart Sensing and Intelligent Systems*, *13*(1), 1-8.
21) de Groot, W. J., Goldammer, J. G., Keenan, T., Brady, M. A., Lynham, T. J., Justice, C. O., ... & O'Loughlin, K. (2006). Developing a global early warning system for wildland fire. *Forest Ecology and Management*, *234*(1), S10.
22) Duncan, C. A., Jachetta, J. J., Brown, M. L., Carrithers, V. F., Clark, J. K., DiTOMASO, J. M., ... & Rice, P. M. (2004). Assessing the economic, environmental, and societal losses from invasive plants on rangeland and wildlands. *Weed Technology*, 1411-1416.
23) Eiswerth, M. E., Darden, T. D., Johnson, W. S., Agapoff, J., & Harris, T. R. (2005). Input–output modeling, outdoor recreation, and the economic impacts of weeds. *Weed Science*, *53*(1), 130-137.
24) Fenner, P. (2008). Effects of invasive plants on public land management of pinyon-juniper woodlands in Arizona. *Ecology, Management, and Restoration of Piñon-Juniper and Ponderosa Pine Ecosystems*, 113.
25) Goldammer, J. G. (2002, October). Forest fire problems in South East Europe and adjoining regions: challenges and solutions in the 21st Century. In *International Scientific Conference "Fire and Emergency Safety* (Vol. 31).
26) Humpenöder, F., Popp, A., Dietrich, J. P., Klein, D., Lotze-Campen, H., Bonsch, M., ... & Müller, C. (2014). Investigating afforestation and bioenergy CCS as climate change mitigation strategies. *Environmental Research Letters*, *9*(6), 064029.
27) Jhariya, M. K., & Raj, A. (2014). Effects of wildfires on flora, fauna and physicochemical properties of soil-An overview. *Journal of Applied and Natural Science*, *6*(2), 887-897.
28) Joshi, G., & Negi, G. C. (2011). Quantification and valuation of forest ecosystem services in the western Himalayan region of India. *International Journal of Biodiversity Science, Ecosystem Services & Management*, *7*(1), 2-11.
29) Keeley, J. E., & Pausas, J. G. (2019). Distinguishing disturbance from perturbations in fire-prone ecosystems. *International Journal of Wildland Fire*, *28*(4), 282-287.
30) Keeley, J. E., Bond, W. J., Bradstock, R. A., Pausas, J. G., & Rundel, P. W. (2011). *Fire in Mediterranean ecosystems: ecology, evolution, and management*. Cambridge University Press.
31) Khan, M. L., Rai, J. P. N., & Tripathi, R. S. (1987). Population structure of some tree species in disturbed and protected subtropical forests of north-east India. *ACTA OECOL(OECOL. APPL.)*., *8*(3), 247-255.
32) Kinnaird, M. F., & O'Brien, T. G. (1998). Ecological effects of wildfire on lowland rainforest in Sumatra. *Conservation Biology*, *12*(5), 954-956.
33) Kinnaird, M. F., & O'Brien, T. G. (1998). Ecological effects of wildfire on lowland rainforest in Sumatra. *Conservation Biology*, *12*(5), 954-956.
34) Koltz, A. M., Burkle, L. A., Pressler, Y., Dell, J. E., Vidal, M. C., Richards, L. A., & Murphy, S. M. (2018). Global change and the importance of fire for the ecology and evolution of insects. *Current opinion in insect science*, *29*, 110-116.
35) Kumagai, Y., Carroll, M. S., & Cohn, P. (2004). Coping with interface wildfire as a human event: lessons from the disaster/ hazards literature. *Journal of Forestry*, *102*(6), 28-32.
36) Kumar, A., Mitra, M., Adhikari, B. S., & Rawat, G. S. (2015). Depleting indigenous knowledge of medicinal plants in cold-arid region of Nanda Devi Biosphere Reserve, Western Himalaya. *Med Aromat Plants*, *4*(195), 2167-2178.
37) Kumar, S., Das Bairagi, G., & Kumar, A. (2015). Identifying triggers for forest fire and assessing fire susceptibility of forests in Indian western Himalaya using geospatial techniques. *Natural Hazards*, *78*, 203-217.

38) Lavorel, S., Flannigan, M. D., Lambin, E. F., & Scholes, M. C. (2007). Vulnerability of land systems to fire: Interactions among humans, climate, the atmosphere, and ecosystems. *Mitigation and Adaptation Strategies for Global Change*, *12*, 33-53.
39) Littell, J. S., McKenzie, D., Peterson, D. L., & Westerling, A. L. (2009). Climate and wildfire area burned in western US eco provinces, 1916–2003. *Ecological Applications*, *19*(4), 1003-1021.
40) Maram, M. K., & Khan, M. L. (1998). Regeneration Status ofTrees inVarious Categories ofForests in Manipur. *Journal of Hill Research*, *11*(2), 178-182.
41) Måren, I. E., & Sharma, L. N. (2021). Seeing the wood for the trees: Carbon storage and conservation in temperate forests of the Himalayas. *Forest Ecology and Management*, *487*, 119010.
42) Martínez, J., Vega-Garcia, C., & Chuvieco, E. (2009). Human-caused wildfire risk rating for prevention planning in Spain. *Journal of environmental management*, *90*(2), 1241-1252.
43) Mohanty, A., & Mithal, V. Managing Forest Fires in a Changing Climate.
44) Negi, G. C. S. (2019). Forest fire in *Uttarakhand*: causes, consequences and remedial measures. *International Journal of Ecology and Environmental Sciences*, *45*(1), 31-37.
45) Negi, G. C. S. (2019). Forest fire in *Uttarakhand*: causes, consequences and remedial measures. *International Journal of Ecology and Environmental Sciences*, *45*(1), 31-37.
46) Negi, G. C. S., & Dhyani, P. P. (Eds.). (2012). *Glimpses of Forestry Research in the Indian Himalayan Region: Special Issue in the International Year of Forest-2011*. ENVIS Centre on Himalayan Ecology, GB Pant Institute of Himalayan Environment and Development.
47) Niklasson, M., Zin, E., Zielonka, T., Feijen, M., Korczyk, A. F., Churski, M., ... & Brzeziecki, B. (2010). A 350-year tree-ring fire record from Białowieża Primeval Forest, Poland: Implications for Central European lowland fire history. *Journal of Ecology*, *98*(6), 1319-1329.
48) Ohlson, M., Söderström, L., Hörnberg, G., Zackrisson, O., & Hermansson, J. (1997). Habitat qualities versus long-term continuity as determinants of biodiversity in boreal old-growth swamp forests. *Biological conservation*, *81*(3), 221-231.
49) Parr, C. L., Lehmann, C. E., Bond, W. J., Hoffmann, W. A., & Andersen, A. N. (2014). Tropical grassy biomes: misunderstood, neglected, and under threat. *Trends in ecology & evolution*, *29*(4), 205-213.
50) Pausas, J. G., & Keeley, J. E. (2014). Evolutionary ecology of resprouting and seeding in fire-prone ecosystems. *New Phytologist*, *204*(1), 55-65.
51) Pausas, J. G., & Parr, C. L. (2018). Towards an understanding of the evolutionary role of fire in animals. *Evolutionary Ecology*, *32*(2-3), 113-125.
52) Pimentel, D., Zuniga, R., & Morrison, D. (2005). Update on the environmental and economic costs associated with alien-invasive species in the United States. *Ecological economics*, *52*(3), 273-288.
53) Podur, J., Martell, D. L., & Csillag, F. (2003). Spatial patterns of lightning-caused forest fires in Ontario, 1976–1998. *Ecological modelling*, *164*(1), 1-20.
54) Reddy, C. S., Bird, N. G., Sreelakshmi, S., Manikandan, T. M., Asra, M., Krishna, P. H., ... & Diwakar, P. G. (2019). Identification and characterization of spatio-temporal hotspots of forest fires in South Asia. *Environmental monitoring and assessment*, *191*, 1-17.
55) Rogstad, A. (2008). Southern Arizona buffelgrass strategic plan: a regional guide for control, mitigation, and restoration. *Tucson, AZ: Buffelgrass working group*.
56) Satendra, K. A. (2014). Forest fire disaster management. *National Institute of Disaster Management, Ministry of Home Affairs, New Delhi*.
57) Seip, D. R., & Bunnell, F. L. (1985). Nutrition of Stone's sheep on burned and unburned ranges. *The Journal of wildlife management*, 397-405.
58) Semwal, R. L., & Mehta, J. P. (1996). Ecology of forest fires in chir pine (Pinus roxburghii Sarg.) forests of Garhwal Himalaya. *Current Science*, *70*(6), 426-427.
59) Semwal, R. L., & Mehta, J. P. (1996). Ecology of forest fires in chir pine (Pinus roxburghii Sarg.) forests of Garhwal Himalaya. *Current Science*, *70*(6), 426-427.
60) Shvidenko, A., & Goldammer, J. G. (2001). Fire situation in Russia. *International Forest Fire News*, *24*, 41-59.
61) h, J. S. (1992). Forests of Himalaya: Structure, functioning and impact of man. *CGyanodaya Prakashan*.
62) Singh, J. S., Rawat, Y. S., & Chaturvedi, O. P. (1984). Replacement of oak forest with pine in the Himalaya affects the nitrogen cycle. *Nature*, *311*(5981), 54-56.
63) Singh, R. D., Gumber, S., Tewari, P., & Singh, S. P. (2016). Nature of forest fires in *Uttarakhand*: frequency, size and seasonal patterns in relation to pre-monsoonal environment. *Current Science*, 398-403.

64) Singh, R. D., Gumber, S., Tewari, P., & Singh, S. P. (2016). Nature of forest fires in *Uttarakhand*: frequency, size and seasonal patterns in relation to pre-monsoonal environment. *Current Science*, 398-403.
65) Skre, O., Wielgolaski, F. E., & Moe, B. (1998). Biomass and chemical composition of common forest plants in response to fire in western Norway. *Journal of vegetation Science*, *9*(4), 501-510.
66) Stenseth, N. C., & Dunlop, E. S. (2009). Unnatural selection. *Nature*, *457*(7231), 803-804.
67) Trabaud, L., & Lepart, J. (1980). Diversity and stability in garrigue ecosystems after fire. *Vegetatio*, *43*, 49-57.
68) Wagner, C. V. (1978). Age-class distribution and the forest fire cycle. *Canadian Journal of Forest Research*, *8*(2), 220-227.
69) Wang, Y., Case, B., Lu, X., Ellison, A. M., Peñuelas, J., Zhu, H., ... & Camarero, J. J. (2019). Fire facilitates warming-induced upward shifts of alpine treelines by altering interspecific interactions. *Trees*, *33*, 1051-1061.
70) Woods, P. (1989). Effects of logging, drought, and fire on structure and composition of tropical forests in Sabah, Malaysia. *Biotropica*, 290-298.
71) Woods, P. (1989). Effects of logging, drought, and fire on structure and composition of tropical forests in Sabah, Malaysia. *Biotropica*, 290-298.
72) ***Capacity Building***
73) Woods, P. (1989). Effects of logging, drought, and fire on structure and composition of tropical forests in Sabah, Malaysia. *Biotropica*, 290-298