FOREST FIRE CAUSES, IMPACTS AND MANAGEMENT: A COMPREHENSIVE REVIEW

Abstract

Forest fire has been a recurring natural phenomenon throughout the history of our earth. However, in recent time, the intensity and frequency of forest fire have increased because of natural and artificial factors. To maintain ecological balance, protecting habitat of wildlife and property of human being and their lives it is necessary to understand the causes, impacts and effective management practices of forest fire. There are multiple impacts of forest fire, affecting air quality, water resources, carbon sequestration and biodiversity etc. It disrupts the various ecological phenomenons in forest ecosystem which causes irreversible change in flora and fauna and threatening species to extinction. Additionally, particulate matter and smoke released during forest fire have extensive impact on air quality, damage respiratory system and cause cardiovascular diseases in population of both local and distant regions. Forest fire also releases considerable amount of carbon dioxide, cause climate change and accelerate global warming. Successful management of forest fire needs a holistic approach including preparedness, prevention, suppression and post fire recovery strategy. Awareness about prevention of forest fire, campaigns related to forest fire and early warning systems play significant role in reducing fire incidents. Moreover, forest thinning and controlled burning are important tools to reduce fuel loads and mitigate the risk of forest fire. Advancement in technology with time has increased the capability for firefighting by using aerial resources, remote sensing and predictive modeling. Post-fire recovery involves rehabilitating affected ecosystems, implementing reforestation programs, and monitoring ecosystem resilience and

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succession over time. Collaborative efforts between governments, non-governmental organizations, scientists, and local communities are indispensable for successful restoration initiatives.

Keywords: Forest Fire, Biodiversity, Fire Status, Fire Ecology, Habitat, Post-fire Management, Risk Mitigation and Impacts

I. INTRODUCTION

Forest is an integral part of human environment since long time back. It constitutes the complex and natural resource of great importance dominated by trees. It is nature's supreme reward to human being and plays a very crucial role in its life. It acts as home for all living being of nature and also protects them, including pre-historic man, it provides food, fodder, fuel, wood and great variety of other produces. Forest also plays significant role in social, economic and religious activities of human being to improve their living standard in variety of ways both material and psychological since ancient time (Satendra and Kaushik, 2014). As we all know that forest provides habitat to all the living being it is an important factor for increase or decrease in biodiversity of world. There are many forest ecosystems with more biodiversity than other ecosystems. Thus, forest cover also acts as one of the indicators of Sustainable Development Goal 15 "Life on land". Forest covers 30.8 percent of total global land area i.e., 4.06 billion hectares or about 0.5 ha per person, but forest is not distributed uniformly in the globe. Five countries (The Russian Federation, Brazil, Canada, The United States of America and China) are dominating in world's forest cover with share of more than half of the world's forest cover and ten countries have two-thirds (66 %) of forest cover (Figure 1). In three decades (from 1990 to 2020), forest area decreased from 32.5 % to 30.8 % with net loss of 178 million hectares of forest area. Still, net forest loss rate reduced by around 40 % from 1990 to 2000 and 2010 to 2020 (from 7.84 million hectares per year to 4.74 million hectares per year). Main reason behind these losses of forest area is agriculture expansion, while increment in forest area is primarily due to the afforestation, reforestation and expansion of forest through natural regeneration on abandoned land (FAO, 2020). Forest fire is also one of the reasons behind decrease in the forest area of world.
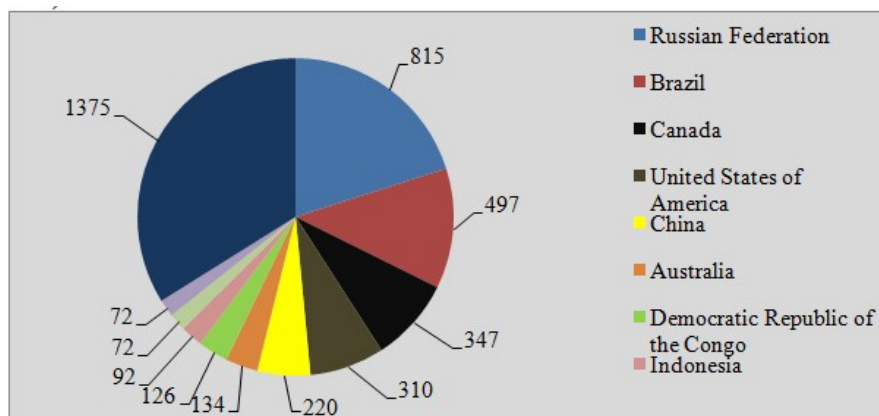
Figure 1: Global distribution of forest showing the ten countries with the largest forest area, 2020 (million hectares of world's forest)

India has a forest cover of 7,13,789 km^2 with 21.71 % of total geographical area of country. Forest cove has three categories i.e., Very dense forest (99,7,79 km^2 or 3.04 %), moderately dense forest (3,06,890 km^2 or 9.33 %) and open forest (3,07,120 km^2 or 9.34 %) as showed in figure 2. Very dense forest and moderately dense forest comprise more than half (57%) of the total forest cover of the country (FSI, 2021).
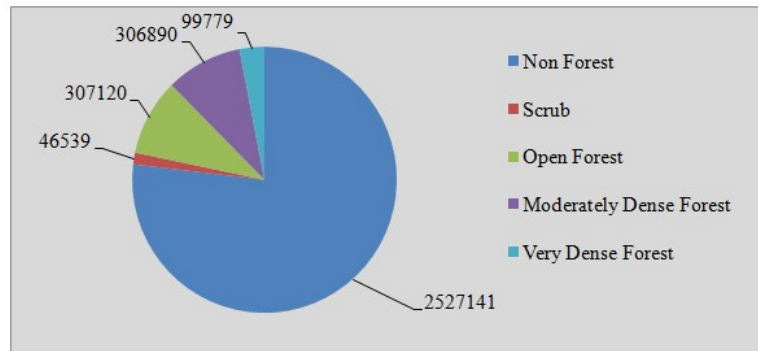
Figure 2: Pie-chart showing forest cover of India (in sq km)

Forest faces many problems that have adverse impact on health and vitality of forest which makes forest unable to provide full range of ecosystem services and their products, forest fire is also one them, acts as a major environmental disaster that has serious adverse effect on ecosystem services, biodiversity and human society. It causes injury, lose and degradetion to forest (Babu et al. 2016; Wang et al. 2021). Forest fire can originate from manmade or natural sources such as rockslide, volcanic eruption and lightening. Anthropogenic fire can be intentional or unintentional (Patil et al. 2008; Kim et al. 2019; Wang et al. 2021). Forest fire also serves as a natural filter which helps in ecological succession (Parashar and Biswas, 2003; Satendra and Kaushik, 2014; Aponte et al. 2016). However, forest fire causes some irreversible changes to landscape and its ecosystem when it is too frequent (Cha et al. 2020). Forest fire affected around 98 million ha of forest in 2015, it was mainly in tropical region, where 4 % of total forest area in burned by forest fire in that year. In Africa and South America, 2/3 of the total forest area was affected by forest fire (FAO, 2020). With increase in the population, the frequency and consequent harms due to forest fire are increasing every day. The effect of the forest fire is diverse on the flora and fauna. Forest fire not only damages forest tree but also affects the site quality with adverse effects on soil, wild animals, microclimate and forest regeneration of that site etc. It extensively damages the regenaration and growing stock and makes area more vulnerable to soil erosion and deterioration (Satendra and Kaushik, 2014). Physical features, forest types and weather conditions are the factors that affect the extent and intensity of forest fire (Kunwar and Khaling, 2006). Unluckily, in recent time forest fire became very frequent and intensity of forest fire is also increasing day by day which is increasing the damage to human society, economic and environment (Parashar and Biswas 2003). Alexander (1993) reported that forest fire damages more trees by burning than any other natural disaster such as frost, drought, insect, pest and parasite etc. Under such circumstance, an efficient and effective fire risk mitigation and management system is needed to control, manage and mitigate forest fire to eliminate the ecological, economical and social difficulties arising due to the impact of forest fire (Sudhakar et al. 2014).

II. FOREST FIRE IN WORLD

Fire is being used by people as a management tool from millennia to increase the agriculture and grazing land, make travelling easy, favour trees used by them for their livelihood and household and develop better condition for hunting. Fire helps in management of several ecological units, for example savannas, fire also helps in creating habitat of various

ages and stages of regeneration for wildlife when it is less frequent in temperate and boreal forest. In an ecological unit, more or less fire can change the composition of species, structure of habitat and biological diversity. Every disastrous fire is linked to severe danger situation depends on meteorological factors like low humidity, high temperature, lack of precipitation and high wind speed. Fires continue to have considerable effects across the world, cause loss to living being, habitat, ecosystem services, biological diversity, production and productivity; disturbance to livelihood of people; degradation and deterioration of biome. In recent time, destructive fire actions linked with drought and heat waves including those in the Amazon and in the Arctic in 2019; Portugal in 2003, 2005 and 2017; Greece in 2007 and 2018; Australia in 2009 and 2019/20; the Russian Federation in 2010; the United States of America in 2013, 2017, 2018 and 2019; Canada in 2016; Chile in 2017 and Indonesia in 2019 (FAO, 2020).

During the period of 2001 to 2018, fire burned 7.20 billion ha land (not limited to forest) at an average of more than 400 million ha per year (Artes et al. 2019). During 2013 to 2018, burned area was found less than the average long term average. Africa has more than two third of fire during the period of 2001 to 2018. Sub regions of Eastern and Southern Africa, Northern Africa and South America, Oceania (mainly Australia), Western and Central Africa have the largest burned areas globally, all have greater than 500 million ha during that period. Markedly, the average of both Eastern and Southern Africa and Western and Central Africa was found greater than 100 million ha per year in this period. In forest, the burned areas don't show loss and damage all the time, fire with cyclic burning also has ecological influence on grassland and savanna found in Northern Africa, South America, Western and Central Africa, Oceania (mainly Australia) and Eastern and Southern Africa. Based on the analysis done by FAO, during the time period of 2001 to 2019, Africa alone has 78 percent of burned areas in tree covered areas; Northern Africa has only 5 percent of that burned area. On average, tree covered area comprised for approximately 29 percent of total burned area by fires during 2001 to 2018, ranging from 23 percent to 34 percent. Central America with 47 percent has the largest tree covered area as a proportion of total burned area, followed by South and Southeast Asia with 44 percent (FAO, 2020).

Fire affected 98 million ha of forest (3 percent of global forest) in 2015, which was 26 percent of total burned area in that year. Mainly fire occurred in tropics, where 4 percent of forest area gets affected (Artes et al. 2019). Among researchers and fire management communities, it is considered that wild land faces progressively more difficult fire weather situations, longer fire seasons and large fire influenced by climate change. Estimation for Europe signifies an increase of 120 to 270 percent above the average during 2000 to 2010 by 2090 in annual burned area (Robinne et al. 2018).

Table 1: Proportion of tree-covered burned area in total wildfire area, by region or sub region, 2001–2018

Region/sub region	Share of tree-covered burned area in total wildfire (%)
Eastern and Southern Africa	35
Northern Africa	16
Western and Central Africa	39
East Asia	8

South and Southeast Asia	44
Western and Central Asia	0
Europe	25
Caribbean	19
Central America	47
North America	31
South America	30
Oceania	2
World	29

Source: FAO, 2020

Table 2: Country-reported burned area, by ecological domain, 2015

Ecological domain	Forest area affected by fire in 2015 (1000 ha)	% of forest area
Tropical	72860	4
Subtropical	9760	2
Temperate	9390	1
Boreal	6030	1
Total	98040	3

Source: FAO, 2020

III. FOREST FIRE IN INDIA

Severe forest fires occur in India, mostly in dry deciduous forest, montane temperate, evergreen and semi evergreen forests in India are less prone to forest fire in comparison to dry deciduous forest (FSI, 2015). It has been estimated that more than 36 percent of India's forest cover is prone to frequent forest fire. Around 4 percent of India's forest cover is found to be extremely fire prone, while 6 percent of the forest cover is very high prone to fire (FSI, 2019). Generally forest fire season in India is called from November to June; most of the forest fires in India are caused by man-made factors. The National Action Plan on Forest Fire helps in reducing the chances for the occurrence of forest fire by informing, enabling and empowering forest fringe communities, and also incentivizing them to work in tandem with state forest departments. During the forest fire season 2019 -2020 and 2020-2021, number hotspots for fire detected by MODIS sensor were 22,447 & 52,785 and by SNPP-VIIRS were 1,24,473 & 3,45,989 respectively. In India, during the forest fire season of 2020-2021 Odisha has maximum (51,968) number of fire detections followed by Madhya Pradesh (47,795) and Chhattisgarh (38,106); among districts, maximum (10,577) number of forest fire detections were found for Gadchiroli in Maharashtra followed by Kandhamal in Odisha (6,156) and Bijapur in Chhattisgarh (5,499). Around 10.66 percent of forest cover of India is under very high to extremely prone zone for forest fire. North Eastern region of India falls under very high to extremely forest fire zone. In term of frequency and occurrence of forest fire Tripura, Manipur, Mizoram and Meghalaya have the highest probability (FSI, 2021).

India is known as one of the major zone of biodiversity in world, has abundant diversified and unique flora and funna, including various environmental benefits and services

Indian forest is very rich economically too. There are 1.7 million ha of productive conifer forest in India with some important timber species such as deodar, teak, chir pine, blue pine, spruce, sal and fir. Growing stock estimation of these forest is more than 200 million cubic meters, which has a monitory value of greater than ₹ 40,000 to 60,000 million (Bahuguna, 1999; Anonymous, 2018). Indian forest ecosystems fulfill 30 percent of the fodders and 40 percent of the energy needs for India, where 18 percent cattle population and 17 percent human population of the world lives. In India, forest provides 280 million tons fodder, 270 million tons fuel wood, 12 million cubic meters valuable timber and a large number of Non Timber Forest Products annually (Satendra and Kaushik, 2014). With increasing the population of the country the difficulties for survival of this world class land ecosystem is also increasing with raising the interference of human activities in the natural land ecosystem which extremely escalates the forest fire activities. Forest fire is a factor that adversely affects the forest, which occurs occasionally and damages timber, habitat of wild animal and other properties of land ecosystem. These ecosystems are under severe risk because of persistent occurrence of forest fire, leads to damage, degradation and deterioration of forest, soil lose and reduction in productivity of forest (Anonymous, 2018).

Forest fire has three components i.e. oxygen, heat and fuel. Fire cannot take place in absence of any one of these three components. These three components are not distributed uniformly throughout the forest of country so occurrence of forest fire is also not uniform. It depends upon the climatic condition, type of vegetation, vulnerability of tree, other natural and artificial factors; fire condition is very different for each forest area. Himalayan region of India with coniferous trees such as fir, deodar, spruce, chir pine and blue pine etc. is highly prone to forest fire. More density of rainfall in forest of Eastern Himalayas makes it less susceptible to forest fire in comparison to that in Western Himalayas. In Himalayan mountains, with increase in extend of chir forest, the intensity and frequency of forest fire has increased drastically. In Uttarakhand, 3,75,000 ha of forest area has been burned by forest fire in 1995. Approximately 34,24,857 hectares (63.91 %) of forest land in Uttarakhand is susceptible to forest fire. Vast forest fire events occur frequently in Ganga-Yamuna watershed also, huge fire occurred in this region during 1999, which has destruction over area larger than 80,000 ha of forest land by turning it into ash (Satendra and Kaushik, 2014).

IV. CAUSES OF FOREST FIRE

There are three essential elements (fuel, air and ignition source) for the occurrence of forest fire. Combination of these three elements is also known as fire triangle. Presence of these three elements in susceptible area is the main cause behind the occurrence of fire (Vasudeva, 2018). The causes of forest fire may be natural or anthropogenic (Henderson et al. 2005). In weather, temperature and wind are important factors as high temperature approach toward easier ignition and wind helps in promotion of fire by spreading it to a large extend and causes to break all the barriers like river, firebreaks and ditch etc. Presence of felling residual like dry leaves, dry twigs and broken branches on forest floor act as fuel load for fire, which is one of the factors for occurrence of fire (Attri et al. 2020). In hilly region, topography also adds a new element to the environment of fire. Aspect and altitude both affect the temperature, rainfall and humidity etc. and thus impact the development of environment for fire. Southern and south western aspect is hotter so more fire risk is available at these sites in comparison to northern and north western sites. With increase in altitude, temperature decreases so fire risk also decreases at high altitude. Slop plays a important role

in spreading behavior of fire, it spreads faster when moves form uphill side to downhill side and vice versa (Satendra and Kaushik, 2014; Martin et al., 2016; FSI, 2017; Attri et al. 2020) Human activities are the main reason behind the occurrence of most of the forest fire; globally 95 % of forest fires are take place because of anthropogenic activities (Attri et al. 2020), in which most of the forest fires are due to land use pattern such as conversion of pastureland and plantation into agriculture land. Shifting cultivation and permanent conversion are two very common practices for conversion of forest land to agriculture (Satendra and Kaushik, 2014). Forest fires also link with social and economical factors. Collection of non timber forest products like tendu leaves, sal seeds, mahua, other edible and non-edible products are also come under the cause to initiate fire in forest area in many developing countries. Forest fire also gets initiated due to the carelessness of grazers, tourists and local people etc. during their visit inside the forest area. Bonfire, cooking food, throwing burning bidi or cigarette and camp inside or near the forest area are some example that causes fire due to carelessness of people. Sometime forestry personnel are also responsible for massive fire when they put fire for control burning without precaution may leads to a huge devastation. (Jhariya and Raj, 2014; Satendra and Kaushik, 2014; Juarez-Orozco et al. 2017; Vasudeva, 2018; Attri et al. 2020). In some tribal communities, during the celebration of ritual customs forest is ignited by the communities, this ignited forest fire can reach in the adjacent forest area and leads to devastation. Some developmental activities like construction of road and residence inside the forest work as ignition source by providing access to the forest and increase the fire incidents in that forest area. Globally, with increase in grazing by livestock forest fire is also increasing (Satendra and Kaushik, 2014; Vasudeva, 2018). Regional estimates of human induced forest fire are as follows: Balkan countries- 59 %, North America- 80 %, South America- 85 %, South Asia- 90 % and Mediterranean- 95% (FAO, 2006).

Forest fire, caused by natural reason i.e. rise in temperature, friction of rolling stones, volcanic explosion, lightening and Rubbing of dry bamboo clumps etc., are very rare, accounts only 5 % of the forest fire reported area (Attri et al. 2020). Sometimes these types of fires occur due to the population of bacteria which release enough energy during the breathing process cause fire, it is known as 'ghost fire' (Vasudeva, 2018). Forest fire may occur due to the lightening during the thunderstorms can burn trees. On the other hand, such fires may get extinguish by rain in most of the cases without much loses to that area. For initiation of forest fire high temperature, low rainfall and low humidity (dryness) are favorable conditions. Forest fires due to lightening reported throughout the history from India, Finland, Australia, Eastern and Southern Africa and Southeastern and Central United States. (Kaushik, 2004; Jhariya and Raj, 2014; Satendra and Kaushik, 2014; Juarez-Orozco et al. 2017; Attri et al. 2020). During dry season, sparks may take place due to the friction by rolling of stones in the mountain region may induce forest fire. When forest has large amount of flammable material on its floor there is more chance for this type of incidence. Sometimes a little spark is also enough for the initiation of fire. In February 2001, such fire has taken lives of 4 ladies in Rudraprayag, Uttarakhand (Satendra and Kaushik, 2014).

During the period from 2006 to 2010, forest fires cause was recognized in Mediterranean countries and recorded for 71 percent of the fire incidents, out of these, 55.8 percent of the events are due to the intentional activities of human being, 33.5 percent are due to carelessness, 6.1 percent are due to accident and 4.7 percent are due to natural causes (Camia et al. 2010). Globally, it is proven that human factors are related to fire pertinacity

and seasonality, while frequency of fire occurrence is link with variability of human activities for specific climate and vegetation type of region (Chuvieco and Justice, 2010; Le Page et al. 2010). Good quality knowledge on causes of forest fire is necessary for management and mitigation of forest fires risk. It assists in designing the prevention policies for specific area, which adapt the cultural, socio-economic and environmental condition of that area. Definitely, when fire causes are known, it becomes easy to eliminate or reduce the number of fires (Ganteaume et al. 2013).

V. IMPACTS OF FOREST FIRE

Forest fires affect the human lives, natural habitat, ecosystem services and biological diversity and also contribute to global warming. Impacts of forest fire on natural environment and ecosystem are emissions of high carbon, release of almost 100 million tons of smoke aerosols into the atmosphere (Hao and Liu, 1994; Fearnside, 2000), biodiversity loss (Brown and Davis, 1959), increment in surface albedo and water runoff (Darmawan et al. 2001) and change in atmospheric chemistry, emissions of large amounts of trace gases and aerosol particles and black carbon (Dwyer et al. 1998) due to the burning of biomass. Forest fire not only affects the biodiversity but also degrades the soil properties such as structure, fertility, porosity, productivity and hydraulic conductivity (Neary et al. 1999). There are ecological and socio-economic impacts of forest fire such as biodiversity loss, global warming, loss of fodder, fuel wood and non-timber forest products, loss of natural regeneration, loss of wildlife habitat, increase in soil erosion and damage to natural water sources. It is estimated that the tangible annual loss caused by the forest fire in India is Rs. 440 crores (US$ 100 million approximately) (Attri et al. 2020).

Fire also affects physical properties of soil like structure, porosity, infiltration, texture, wettability and water holding capacity (Jhariya and Raj, 2014). Burning may cause to loss of soil organic matter which have harmful impact on soil physical properties. Soil organic matter consists of sand, silt and clay particles aggregately, so loss of soil organic matter degrades the structure of soil. By changing the structure of soil, soil bulk density can get increase and reduction in soil porosity through losing the macrospores (>0.6 mm diameter). Forest fire causes to the death of soil invertebrates which help in making the soil porous that's why soil porosity decreases. Severe fire (> 400 °C) can also permanently affects the soil texture by changing the size of soil particles form clay to sand which makes soil texture coarse and erodible. Severe burning forces hydrophobic substances of upper layer for downward movement through the soil profile that encourages the formation of water repellent layer of soil. These water repellent layers can contribute to the runoff and erosion by blocking the infiltration of water into soil. Usually soil has less soil organic matter, when it burns repeatedly soil becomes denser, harder and less permeable than unburned soil (Attri et al. 2020).

Forest fires affect the microclimate of the region by reducing the soil moisture and increasing the evaporation from soil (Flannigan et al. 2006). Visibility also gets affected up to 14000 feet when smoke of the fire is dense (Jhariya and Raj, 2014; FSI, 2017; Hirschberger, 2016). In current situation when the preservation and conservation of endemic species of biodiversity is priority some exotic species became a threat to the local species of biodiversity (Mathew, 1965; Srivastava, 2000). In India, *Eupatorium glandulosum, Cytisus scoparius* and

Acacia mearnsii turn out to be a threat to the native valued flora and fauna of Western Ghats.

Forest fire is also responsible for dispersion of such species, which facilitates the germination of above mentioned weeds and leads to depletion in undergrowth of native flora and fauna (Gupta et al. 2014). Native dwarf bamboo has thick growth in open space and valley in hilly region that burns easily during the dry season. After the fire it grows vigorously and resulted in fast colonization and rapid invasion of the space that get burn during the forest fire. Now fire – dwarf bamboo is an annual rotation (Mao and Gogoi, 2010). Firstly forest fires affect the undergrowth such as grass and herbs species. Micro flora and fauna of the top soil and litter affected simultaneously. This has impact on decomposition of organic matter and soil fertility and makes the soil vulnerable to erosion, reduces water holding capacity. After that impact of fire reaches to the shrubs and when fire becomes destructive it affects the tree also. Regeneration gets affected by death of young and new seedlings leads to delay in establishment of new crop. Fungal diseases may take place because of damage to tissues of trees and cause rot which lead to decrease the market value of timber (Vasudeva, 2018). Forest fire generates gases like nitric oxide, nitrous oxide, carbon monoxide (CO), hydrocarbons and methane and also aerosol particles which considered as important factor of climate change and global warming (Agree, 1994). Forest fires also destroy the sink which absorbs the carbon dioxide for atmosphere and also decreases the air quality (Westerling et al. 2006).

Presence of fine particulate matter in forest fire causes cardiovascular and respiratory diseases. CO, comes under health hazard, has much concentration nearby forest fire area. When it is inhaled, it absorbs into stream of blood through lungs and reduces the supply of oxygen to some vital organs of body. Burning of biomass is also releases the methyl bromide which is one of the dynamic ozone depleting substances. Wild animals' instant reaction to forest fire depends on fire season, size, intensity, uniformity, severity and rate of speed. Responses cause injury, immigration and mortality of wild animals. Young animals are more susceptible to mortality and injury than mature ones due to the limited mobility. Animals which live on ground are most affected. Generally understory fire affects habitat and wild animals less severely. Crown fire improves the habitat quality for species which prefer light cover and reduces it for species which requires dense crown. Forest fire also affects the socio-economic condition of the area. After fire forest area dominated by weeds like eupatorium, parthenium and lantana, that replace the species which have socio-economic importance, this leads to reduction in productivity of forest. Repetition of forest fire cause elimination of fire susceptible species and fire hardy species remain. Forest fire also has some beneficial impacts; it helps in creating favorable condition for regeneration by thinning out the litter layer, it also play a significant role in release of locked nutrients and chemicals which results in increment in productivity of forest ecosystem. But adverse effects of forest fire overshadow the beneficial effects (Vasudeva, 2018).

VI. FOREST FIRE MANAGEMENT

Forest fire management deals with the activities concerned for safety of people, property and forest areas from fire (Martell, 2001). In India, 55 % of forest area comes under prone to fire which has socio-economic and ecological effect on forest so mitigation and management of fire is important in countries like India (Gubbi, 2003). Effects of tropical wildfire on environment shows high carbon emission from fire (Hao et al., 1996; Fearnside,

2000), emission of huge quantity of trace gases and aerosol particles (Crutzen and Andreae, 1990), release of black carbon (Dwyer et al. 1998) and large quantity of smoke aerosol into atmosphere in the process of biomass burning. Theses aerosols have a significant role in radiation balance in the atmosphere of earth (Kaufman et al. 1998). There is also concern about the biodiversity loss, impacts on atmospheric chemistry, increase in water runoff, soil erosion and surface albedo as a result of biomass burning (Attri et al. 2020).

There are some steps for forest fire management-

1. **Prevention:** In the British period, during the summer season "Forest Fire Line" is created by removing the forest litter along the boundary of forest to prevent the occurrence of fire. This fire line acts as a tool to prevent the spread of fire from one compartment to another. The forest litter that was collected in the process of fire line making was burnt separately (Attri et al. 2020). In India, JFM (Joint Forest Management) committees play a vital role in the prevention of occurrence of forest fire. It was established at village level primarily to increase the involvement of local people in protection and conservation of forest (Khanna, 1998). There are 36,165 JFM committees in the country at present which cover 10.24 million hectares of area. Protection of forest from fire is also one of the responsibilities of these committees (Bahuguna and Singh 2002; Joseph et al. 2009).

2. **Detection:** Forest fire management also includes early fire detection as soon as possible after occurrence of incidence. Early fire detection in essential to minimize the damage to forest and reduce the losses. Generally, early warning system, fire watch tower and regular patrolling are used for detection of forest fire. Density of fire watch tower is more in protected areas as compared to area without protection. Patrolling activities are increased during fire seasons. Local people are also involved in ground based detection of forest fire; their involvement mainly depends on ability of local forest personnel to engage people as informers. (Anonymous, 2022). These methods become ineffective due to constraints in accessibility in forest of remote area. Satellite remote sensing is used for detection of fire, assessment of damage and reduction in fire risk in less cost and less time (Attri et al. 2020). A number of remote sensing systems including National Oceanic and Aeronautic Administration - Advanced Very High Resolution Radiometer (NOAA-AVHRR), Geostationary Operational Environmental Satellite (GOES), Environment Satellite (ENVISAT), Moderate resolution Imaging Spectroradiometer (MODIS), Defense Meteorological Satellite Program-Operational Line scan System (DMSP-OLS) and Meteosat Second Generation Spinning Enhanced Visible and Infra-red Imager (MSG-SEVIRI) are used in detection of forest fire, monitoring of active forest fire, assessment of damage and planning for mitigation of fire (Szpakowski et al. 2019)

3. **Suppression:** Early in the twentieth century, fire suppression was comparatively ineffective, but as the century went on, it became more and more effective and varied temporally and spatially. In regions with easy access, where fire could be spotted early and resources deployed rapidly to extinguish them, fire suppression was instantly effective. Prior to the advent of the fire lookout system, which made early fire detection easier, and the smoke leaping program, which made access easier, suppression measures did not have much of an impact on fire behavior in more remote areas. As a result, in the second half of the twentieth century fire control practices in many remote areas underwent major change (Keeley, 2008). The following are a few of the suppression

mechanisms: In addition to the conventional method of putting out forest fires such as bush beating, numerous State Forest Departments (SFDs) are purchasing firefighting equipment. They also involve Joint Forest Management Committees (JFMCs), Eco-Development Committees (EDCs) and Biodiversity Management Committees (BMCs), and each state has its own best practices for managing forest fires and working plans, which are being put into practice by the government. Additionally, whenever a situation spirals out of hand, local residents must be contacted, district administration must be involved, and in urgent cases, the State Disaster Response Force or National Disaster Response Force must be sent (Anonymous, 2022).

4. **Post-fire Management:** After extinguishing fires, the Forest Fire Prevention and Management (FFPM) process continues with two key activities: (1) post-fire data gathering and the evaluation of forest fire impacts; and (2) restoration and rehabilitation.

- **Post-Fire Data Collection:** In order to create effective FFPM plans and procedures, post-fire data collection is a vital component of the fire management process. However, this step in the management process receives little attention and is frequently only completed to satisfy administrative demands. It is necessary to refocus post-fire data gathering and analysis on enhancing prevention. The gathering of information on fire incidents through field reporting and the use of remote sensing are both included in the post-fire data collection process. In this process, forest guards report at the location of incident and gather data though field survey. Once data is collected they sent it to range officer (RO), who creates a daily summary of fire events and present it to the divisional forest officer (DFO). The DFO reports to the conservator of forests (CF), then the principal chief conservator of forests (PCCF), who is in charge of either forest preservation or fire. Field staff shortages, challenging terrain, and a lack of communications infrastructure in more remote places all pose challenges to post-fire field reporting. Institutional disincentives may also drive field employees to underreport forest fires (Anonymous, 2018).

- **Restoration and Rehabilitation:** Forest officials were questioned about helping communities harmed by fires recover afterward. Officers responded that other government agencies, such as the revenue, welfare, and agricultural departments, might offer financial support. In the event of a disaster, communities may also get aid from nongovernmental organizations. Many police officers, however, said that no such instances of monetary damage to communities had ever happened in their region. Activities for ecological restoration and rehabilitation in forests devastated by fire are similarly few, according to the officers who were surveyed. The state of Uttarakhand stands out as an exception, as the forest administration is working to restore water retention and erosion control functions in regularly burned chir pine forests. The check dams made of chir pine needles have a dual function of eliminating combustible trash and preventing erosion in gullies. These measures' efficacy has not been evaluated (Anonymous, 2018). Ecosystem restoration encompasses a wide range of tactics, including as reintroduction plant species, creating commercial plantations or agroforestry systems, reducing barriers to succession such as fire, competition, erosion and unassisted recovery. The local restoration context such as topographic features, frequency, and severity of disturbance, potential obstacles and resource constraints such as available knowledge, technical capacity, and funding and desired

project outcomes should all be taken into consideration when choosing an appropriate strategy (FAO and WRI, 2019; Holl and Aide, 2011; Scheper et al. 2021). Goals for restoration can include restoring the structure, functionality, and species composition of an existing forest, as well as maximizing carbon sequestration and boosting biodiversity. Other restoration objectives include the creation of forested landscapes that provide additional socioeconomic functions (Holl, 2012; FAO, 2020; Scheper et al. 2021).

VII. CONCLUSION

Forest fire is one of the significant environmental issues with widespread causes, severe impacts, and crucial management strategies. Forest fires can be triggered by both natural and human-related factors. Natural causes include lightning strikes and volcanic eruptions, while human activities like campfires, discarded cigarettes, arson and machinery use can also lead to fire outbreaks. Climate change and prolonged droughts can exacerbate the risk of fires by creating favorable conditions for ignition and spread. Forest fires have far-reaching consequences on the environment, economy, and society. They result in the destruction of vast areas of forest cover, leading to habitat loss for wildlife and depletion of biodiversity. The release of greenhouse gases during fires contributes to climate change. Additionally, fires can have severe impacts on air quality, posing health risks to nearby communities. The loss of forests also affects water cycles and can lead to soil erosion and subsequent floods. Economically, wildfires cause damage to property and infrastructures, disrupt tourism and burden firefighting and recovery expenses. Effective forest fire management involves a combination of prevention, preparedness, suppression, and recovery efforts. Preventive measures include raising public awareness about fire safety, implementing fire bans during high-risk periods, and managing vegetation through controlled burns and forest thinning. Preparedness involves developing early warning systems, training firefighting personnel, and creating evacuation plans for at-risk communities. Suppression strategies consist of deploying firefighting crews, aircraft, and specialized equipment to extinguish fires. After a fire, rehabilitation and recovery efforts focus on reforestation, ecosystem restoration, and supporting affected communities. Understanding the causes, impacts, and effective management of forest fires is crucial in mitigating their destructive effects and safeguarding our environment and communities. Combining preventive measures with well-prepared firefighting efforts is essential to minimize the damage caused by these natural disasters. Collaborative efforts between governments, non-governmental organizations, scientists, and local communities are essential for successful restoration initiatives. Additionally, international cooperation and mutual aid agreements are vital for tackling large-scale wildfires that transcend national borders.

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