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Incidence of Forest Fire in India and Its Effect on Terrestrial Ecosystem Dynamics, Nutrient and Microbial Status of Soil

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Abstract Forest fire is very common in all the ecosystems and plays an important role in ecosystem dynamics, biodiversity, soil and microbes. The impact of fire on established trees of *Shorea robusta* and *Tectona grandis* has no longer effects and they recovers just on the onset of favourable climatic condition but the status of new recruits are adversely affected. Other important forest species viz. *Terminalia chebula, T. bellirica* and *T. tomentosa* which are having commercial and medicinal values gives poor yield after fire incidence and due to frequent fire in these area species of *Lantana camara*, *L. indica*, *Eupatorium glandulosum*, *Parthenium hysterophorus*, *Cassia tora*, *C. occidentalis* have invaded. The most significant effects of fire is reported to oak and coniferous forest which takes long time to recover because these species catches high intensity crown fire due to high calorific values. The low intensity fire results in combustion of litter and soil organic matter, increases nutrients availability which supports regeneration of herbs and growth of post fire community. The higher intensity fire results into complete loss of soil organic matter and volatilization of nitrogen, phosphorus and potassium but very high temperature is required for complete burning of Mn, Mg, Cu and other micronutrients. The soil microorganisms are mostly sensitive towards high temperature and mostly affected. The incidence of forest fire decreases the actinomycetes, fungal population and arbuscular mycorrhizal fungi, while increases the bacterial richness. It is also reported that forest fire are set intensely by people for the collection of Mahua (*Madhuca latifolia*) flower, Sal seed and Tendu (*Diospyros melanoxylon*) leave, so the involvement of local people in policy making and conservation and management of forest after fire will be more beneficial. The present review deals the impact of forest fire on species dynamics, biodiversity, soil nutrient and microbial status to manage a fire as a tool of forest management and control of nutrient, insect and disease.

Keywords Forest Fire, Biodiversity, Soil physicochemical properties, Microbial population

1. Introduction

Forest fire is mostly an anthropogenic phenomenon which burns valuable flora and fauna and sometimes also involves villages and structures. Every year, the world faces extreme wild fires, which affect million hectares of forest leading to effects on biodiversity, ecosystem functioning and landscape stability. Evidence of fire found first time in the Carboniferous age in 400 million year ago forming fossilized coal deposits [1]. Forest fires occur in three principal forms as Surface fire, Crown fire and Ground fire depending on their means of spread and their position to the ground. Surface fires burn surface litter, other loose debris on the forest floor, and small vegetation. Crown fires advance through the tops of trees or shrubs more or less independently of the surface fire and are the fastest spreading of all forest fires. Ground fires consume the organic material beneath the surface litter of the forest floor. Though the causes of fires may be both natural and anthropogenic [2] but however, mostly the fires are deliberately set by forest dwellers and farmers for their own direct benefits like for the collection of non wood forest products and cattle feed etc. But now a day, the fire is being used as a tool in forest protection and management in different part of the World [3, 4]. Fire helps in the distribution and maintains the structure and function of fire-prone communities [5-8]. Fire alone does not destroyed a landscape and vegetations but fire and hoof, fire and axe, fire and plough, fire and sword, all magnify the effects by altering the timing of the fire, its intensity, the fuels on which it feeds, or the biological potential for exploiting the aftermath of a burn [9]. Spatial and temporal variation in severity within a fire can have long-lasting impacts on the structure and species composition of post-fire communities and the potential for future disturbances [10]. In addition, Fire has long been integral part of the forest environment and has played an important role in shaping the flora and fauna. A fire may be

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either beneficial or detrimental to individuals of a particular species but the effect of a single fire is not as environmentally significant as a change to the fire regime [11]. Fire may also play a role in recycling nutrients from the ground-layer vegetation and litter to the over-storey trees, thereby counteracting the infertile substrates and arrested decay [12]. Areas under larger burned patches have higher cover of tree seedlings and shrubs, greater densities of opportunistic species but have lower species richness [13]. Hence, fire is used as a management tool to administer a wide range of ecosystem worldwide. Climatic abnormalities are going to make forest ecosystem more susceptible and increase the risk of burning. Increased dry spells could also place dry and moist deciduous forests at increased risk from forest fires. There is growing scientific evidence that climate change will increase the number and size of wildfires globally [14]. Therefore from the last century, great efforts and vast resources have been applied to understanding and managing fire in forest [15]. Forest fires are expected to increase in some areas with climate change, urbanization and population pressure. Although some forest areas such as the Amazon, Mediterranean and temperate United State are predicted to be much drier and therefore more vulnerable to fire, other areas, such as tropical Africa, may be wetter and less vulnerable to fire [16]. Climate variability is expected to increase across the globe [17] and this will lead to increase in temperature along with prolonged droughts and less rainfall will make the forests more vulnerable to forest fires.

2. Extent of Forest Fire in India

The social, economic and ecological cost of fires is often overwhelmed. According to United Nations study, the total forest area of the World in 1900 was nearly 7000 M ha and by 1975, it was reduced to 2890 M ha [18] due to overexploitation, fire and grazing. The forest fires were reported in many countries of Asia, Africa, Europe, North America, South America and Australia during the years 1997 and 1998 have been linked to a drier climate attributed to events such as ENSO (E1 Nino Southern Oscillation) [19]. According to Forest Survey of India, the forest cover in India is 69.78 M ha, constituting 21.23 % area, represents 2.54% very dense, 9.70% moderate dense and 8.99% as open forest [20]. In India forest fire is a major cause of forest degradation and particularly in tropical deciduous forests it is a recurrent phenomenon due to higher levels of water stress during summer. It is also estimated that the proportion of fire prone forest area is 33% in some Indian States to over 90% in others [21] and about 3.73 million ha of forests are annually affected [22-24].

Inventories conducted by the Forest Survey of India show that on average 55% of forest area in India is affected by fire and 78 percent by grazing. Subsequently, little regeneration occurs in 72 percent of forested areas [22]. The annual losses from forest fires in India for the entire country have been estimated Rs. 440 crores. This estimate does not include the loss suffered in the form of biodiversity, nutrient, soil moisture and other intangible attributes. India witnessed the most severe forest fires in during the summer of 1995 in the hills of Uttaranchal and Himachal Pradesh in North West Himalaya in which 677,700 ha was affected with timber loss of around Rs. 17.50 crores. A study made by the Forest Survey of India reveals that 51% of the forest area in Assam and Gujarat, 93% in Arunachal Pradesh, 67% in Bihar, 69% in Himachal Pradesh, 46% in Jammu & Kashmir, 45% in Karnataka, 76% in Madhya Pradesh, 94% in Meghalaya and Orissa, 87% in Nagaland, 58% in Uttar Pradesh and 33% in West Bengal is subject to repeated annual fires [25].

3. Effect of Forest Fire on Ecosystem and Biodiversity

Fire determines the floristic composition of an area by selecting species, which will continue to occupy a site. A species can be removed if fire occurs too often, too early, or late in its life cycle. For instance, a non-sprouting species may be lost if fire occurs before seed has been produced, or if fire occurs after the species has died and seed pool is unavailable [26]. Two strategies typically characterize the response of different species to fire frequencies; those that sprout can withstand repeated fires while those that produce seed are favored by infrequent fire [27]. Numerous studies have attempted to define the temperature required to kill vascular plant tissue. A temperature of 60^{o}C has been considered as a lethal temperature required killing shoot tissues of land plants. Plant species surviving fires known as Pyrophytes coppice and have responses resulting into offspring from seed. The ability of an individual plant to sprout following a fire is dependent on the location of its dormant buds, the subsurface distribution of reproductive structures and the depths below the surface from which new shoots can develop. These morphological characteristics, combined with fire severity, typically determine the number of growing points that are able to survive a fire. Fire is linked to plant invasions. Gaps created by high-intensity fires are particularly susceptible to invasion by exotic species for example of *Imperata cylindrica* quickly recovers after fire and may respond with an increase in cover. Invasive species depletes the biodiversity of an area through allelopathic path ways. The extent of the damage depends upon the frequency and intensity of fires, the type of forests, availability of fuel and local climatic factors. Forest Fire in Sal (*Shorea robusta*) and Teak (*Tectona grandis*) forests takes the form of ground fires and though they have a higher frequency, they mostly affect the regeneration and the ground flora which normally recovers during the monsoons. *Terminalia chebula, T. bellirica*, *T. tomentosa* which is having highly commercial value is facing severe problem due to forest fire leaving behind poor stocking. Species like *Lantana camara, Eupatorium glandulosum*, *Parthenium hysterophorus*, *Cassia tora*, *C. occidentalis* etc. have invaded several of the significant sites of forest biodiversity conservation. However, in oak forests, the fire takes the form of a canopy fire and the whole oak tree catches fire and burns for several days, as its calorific value is high. Subsequently, the middle storey vegetation such as dwarf bamboo, *Viburnum* sp, *Edgeworthia* species aggressively colonizes the burnt area and prevents the climax species. The oak and coniferous forest affected by the major forest fire which occurred during the 1970s in West Sikkim is yet to recover fully.

Many believe that fires are bad but they are actually necessary to promote diversity [28, 29]. Forest species change in composition after fire, this may be good or bad depending on the utility of the stands that preceded and succeeded the fires [30]. The state of the ecosystem, namely the set of fire regimes that prevail in a landscape, pre-conditions the responses of biodiversity and ecosystem processes to any particular fire. Awareness of this fundamental principle and the concept of fire regimes is a mandatory pre-requisite for decision-making and evaluation of ecological effects of any fire, for example, a high intensity fire in a mature forest will not be a disaster provided that some part of the habitat provides corridor for free movement of animals [31]. In the case of Tehri-Garhwal Himalayas, field data analysis suggest that low intensity surface ground fire were less detrimental to forests of *Shorea robusta, Tectona grandis, Pinus roxburghii* trees but herbs and shrubs were most suffered. Some trees suffered fire scars which were vulnerable spots for infestation by insects and pests. It was also observed that it is not fire alone responsible for degradation of area but it's the combination of fire and grazing; because grazing is quite ubiquitous in Upper Himalaya especially goat, sheep rearing which are browsing animal causing more damage to regeneration [32]. In Uttaranchal *Shorea robusta* was the successful survival after fire but *Cassia fistula* suffered to certain extent as compared with unburnt site. Among the shrubs Z*izipus species* has taken advantage of fire as it can survive xerophytic conditions after fire and can grow well. Some of the species, which were totally exterminated, were *Vitex negundo, Hypericum species*. Thus, fire has decreased floral diversity of burnt area to a considerable extent. Therefore, fire tolerant species, such as Douglas fir and Ponderosa pine, as well as species that are able to re-sprout and develop quickly tend to become important components of the post-fire community.

3.1. Effect on Soil

Fire effects on soil may have strong influences on the composition and structure of post-fire forests [33]. Forest fires occur in almost all types of ecosystem, some of these ecosystems are extremely sensitive to fire, but without subsequent ignition of wildfires, they can recover [34]. In tropics recently, demographic and land use changes have made fire a matter of serious concern [35]. Many studies have addressed the influence of fire on soil properties. The role of forest fire on forest soil is very complex and less studied in comparison to its aboveground effect [36]. These effects directly depend on fire intensity and the duration of combustion. Depending on the fire severity, these changes in soil properties may be beneficial or deleterious to entire ecosystem [37, 38]. Fire can influence a variety of soil physical and chemical properties including the loss of structure and soil organic matter, reduced porosity, and increased pH [39, 40]. Change in soil properties after fire produces varying responses in the water, vegetation dynamics and fauna of ecosystems. The wide range of effects is due to the inherent pre-burn variability in these resources, fire behaviour characteristics, season of burning, and pre-fire and post-fire environmental conditions such as timing, amount, and duration of rainfall [41]. These changes can also result in various indirect impacts including increased water repellency, which results in decreased infiltration and increased runoff that often results in increased erosion [42].

3.2. Impact of Fire on Physical Properties of Soil

Important physical characteristics in soil that are affected by soil heating include Soil colour, texture, pH, bulk density, and water holding capacity. Soil colour and texture are most noticeable altered in severely burned soil under concentrated fuel in comparison to nearby slightly or moderately burned soil [43]. At higher temperature reddening of soil matrix occurs. Redder hue appears in the burned soils is apparently because of Iron oxides transformation and complete removal of organic matter [43, 40]. While in low to moderate fire ground is covered by a layer of black or grey ash [40]. Reddening at high temperature (600^{o}C) did not occur until after 45 minutes of exposure, soil became yellower as values and chromes decreased with short-term heating at 300 or 600^{o}C [44]. Surface patches of reddened soil indicate the place where soil was severely burned and are detectible by a characteristic increase in magnetization compared to surrounding soil. Hence, the long term pattern of forest fire intensities over a landscape may be detectable as the spatially heterogeneous accumulation of thermally produced iron oxides in soils [45]. In severely burned soil underlying layer is blackened with the thickness of 1-15 cm [43]. The composition of soil texture viz. sand, silt, and clay have high temperature thresholds and are not usually affected by fire unless they are subjected to high temperatures at the mineral soil surface. The most sensitive textural fraction is clay, which begins changing at soil temperatures of about 400^{o}C when clay hydration and clay lattice structure begin to collapse. At temperatures of 700 to 800^{o}C the complete destruction of internal clay structure may occur [43, 46]. Ulery and Graham [43] reported that after fire soil layers had significantly less clay content than unburned soils. Soil pH is generally increased after forest fire [47-49]. However significant increase occurs only at higher temperature (450-500^{o}C) [40]. The presence of ash may increase soil pH due to high pH of ash [50, 51]. Bulk density is related to porosity and is the mass of dry soil per unit volume, which is the pores volume in a soil sample divided by the bulk volume of the sample. Bulk density of forest soils increase significantly as a result of forest fire [40, 52]. Bulk density increases because of collapse of aggregates and clogging of voids by the ash and dispersed clay minerals, as a consequence, soil porosity and permeability decreases [40]. Bulk density increases with ash depth [53].

3.3. Impact of Fire on Chemical Properties of Soil

The most intuitive change soil experience during burning is loss of organic matter [40]. The organic horizon is critical component of ecosystem sustainability in that it provides a protective soil cover that mitigates erosion, aids in regulating soil temperature, provides habitat and substrates for soil biota and can be major source of readily mineral nutrients [37]. It plays an important role in soil cation exchange capacity (CEC) and retention of ions [54]. The effect of fire on organic matter is highly variable from total destruction of soil organic matter to partially scorching depending on fire severity, dryness of the surface organic matter and fire type [37, 55]. soil type and nature of the burned materials. Low-intensity prescribed fire usually results in little change in soil carbon, but intense prescribed fire or wildfire can result in a huge loss of soil carbon [56]. Whereas increasing the fire frequency results in an increase in carbon in the fine fractions of the soil and an increase in organic carbon in soil, while soil texture, on the other hand, controls the magnitude of the increases in both the abundance of organic carbon [57]. Charcoal is formed after forest fire in the forest floor. Charcoal can promote rapid loss of forest humus and belowground carbon during the first decade after its formation, because charred plant material causes accelerated breakdown of simple carbohydrates [58]. Fernandez et al., [59] suggested that in low intensity fire, lipids are least affected group whereas 90% of water soluble cellulose, hemicelluloses and lignin are destroyed. The nutrients are most likely to affect site productivity and vegetation dynamics and therefore of most interest to forest managers and ecologists. Due to the incidences of fire, the nutrient elements may be lost to the atmosphere, deposited as ash, or remain in incompletely burned vegetation [49]. Research suggests that after forest fire soil nutrient decreases but their plant available forms increases [60]. Burned soils have lower nitrogen than unburned soils, higher calcium, and nearly unchanged potassium, magnesium, and phosphorus stocks [61]. The immediate effect of fire on soil nutrients is in terms of its loss through volatilization due to of high temperature [37, 40]. During high intensity fire, temperature reaches to 675^{o}C where as in moderate and low intensity fire temperature reaches to 400^{o}C and 250^{o}C respectively [37]. Nitrogen volatilization during prescribed fire is the dominant mechanism of Nitrogen loss from these systems [62]. At the 500^{o}C, half of the Nitrogen in organic matter can be volatilized [37, 63]. Fire may affect soil nutrient status by direct addition of nutrients and by indirectly altering the soil environment [64]. Nutrients in small live twigs or dead plant material are probably either lost by volatilization during fire or released in a highly soluble form and deposited on the soil surface. These highly soluble plant nutrients on the soil surface may be used for plant growth or easily lost by erosion [65]. This nutrient enhancement is largely restricted to the surface soil, only soluble N appeared to increase in the subsurface soil (5-10 cm) [64]. The most significant short-term effects of the forest fire are the increases in the soil solution concentrations and leaching of mineral forms of N, S, and P [66]. However, the total amount of nitrogen decreases [67]. Mg, Ca and Mn are relatively less sensitive in comparison to nitrogen because of high threshold temperature of 1107^{o}C, 1484^{o}C, and 1962^{o}C respectively [39]. Phosphorus, Potassium and Sulfur is partially affected in high intensity fire [65]. The behaviour of Fe, Mn, Cu, Zn, B, and Mo, with respect to fire is not well known because specific studies are lacking [40]. The influence of fire on micronutrient availability is useful to understand its effect on the post-fire recovery of soils and plants [68]. Studies are suggesting that micronutrients also experience reduction in the amount after forest fire. Marafa and Chau [69] has reported reduction in the amount of Mn (14%), Fe (12%) and Zn (4%) after fire. Garcia-Marco and Gonzalez-Prieto [68] has also studied short- and medium- term effects of fire on soil micronutrient availability and found increasing availability that of Mn and Zn and decreasing that of Fe and Co, they found no effect on Cu availability.

3.4. Impact of Fire on Microbial Properties of Soil

Soil micro-organisms have numerous functional roles in forest ecosystems, including serving as sources and sinks of key nutrients and catalysts of nutrient transformations, acting as engineers and maintainers of soil structure and forming mutual relationships with roots that improve plant fitness [70]. Forest fire can significantly alter microbes that affect large-scale processes such as nutrient cycling [37]. Fire affects biological organisms either directly or indirectly. Direct effects cause short-term changes due to direct exposure of particular organism where enough heat is transferred into the organism's immediate surroundings to raise the temperature sufficiently to either kill or severely injure the organism. Infact, peak temperature often exceeds those required for killing most living being [37]. The immediate effect of fire on soil microorganism is a reduction of their biomass Indirect effects usually cause long-term changes in the environment that can involve competition for habitat, food supply and other more changes that affect the re-establishment and succession animals.

Effect on Bacteria:- The bacterial population also affected due to forest fire which generally increases in the bacterial population after fire events [71]. Although there are only few studies conducted on soil bacteria after forest fire suggesting that Bacterial community structure is significantly changed. Community structure of soil bacteria in post-fire non-climax forest several years after fire reported more heterogeneous compared with that in unburned climax forest [72]. Aerobic heterotrophic bacteria, including the acidophilic and sporulating ones, were stimulated by fire while cyanobacteria, was clearly depressed. In the long term, the positive effect of fire on bacteria was nullified except on the sporulating ones reached the unburned soil values, cyanobacteria also increased. Vazquez et al. [73] reported that the soil incubation improved the beneficial and diminished the negative fire effect on the micro biota, whereas Jaatinen et al. [74] found that there is no significant effect of forest fire on methane oxidizing bacteria. They suggested that fire increased CH_4 oxidation rates, but the increased pH after the fire and ash probably do not cause any alterations in methane oxidizing bacteria. The increase in the population of bacteria after burning is due to the enhanced availability of N and K [71]. The favourable microclimatic conditions viz., moisture content, temperature, litter decomposition might have accounted for maximum bacterial action during post-rainy season. Similarly, Neal et al. [75] Balagobalan et al. [76] has reported seasonal variations in bacterial population after burning. Similarly among bacteria, *Bacillus* species are most dominant in all depths after rainy season in burnt sites because of the endospore forming capacity the genus, might have tolerated higher temperature and thus proliferated heavily after fire.

Effect on Fungi: The fungal population follows reducing trend in the burnt area in comparison to the unburnt areas. Since fungal spores are the main propagules for reproduction of fungi, elimination of spores during fire have reduced the total fungal population in soils. Renbuss et al. [77] reported that fungal population growth was very slow in the burnt soil. Wright and Tarraunt [78] observed decrease in soil fungal population after burning. The fungal population was found to increase from the summer to winter season in ascending order which might be due to the return of favourable climatic conditions in the subsequent seasons and finally the population level of unburnt and burnt areas became equal in number as the season changed. Sankaran [79] observed a general decrease in fungal population after fire because of unfavourable conditions.

Effect on Actinomycetes: The actinomycetes population is reported a lower population in burnt areas than unburnt areas due to the burning of spores. It is perceived that the heat generated in the soil during the burning, might have inhibited the spore formation and also eliminated aerial spores. Accordingly, Renbuss et al. [77] and Saravanan et al. [71] has reported slower rate of recolonization of actinomycetes in the burnt soil. In summer season immediately after fire, the actinomycetes population was found to be low due to adverse environmental condition and then the population increased during winter season due to the return of favourable environment [80]. Fungal and actinomycetes population got reduced heavily after fire. Unlike bacterial endospores, spores of these two organisms could not tolerate higher temperature. Hence, the population reduced drastically after fire due to poor reproductive propagules.

Effect on Mycorrhiza: Mycorrhizal fungi maintain overall forest health. They play a crucial role in nutrient uptake, extended root life and protection against root pathogens. Stendell et al. [81] studied that the total ectomycorrhizal biomass in the unburned plots did not differ for any core layer, while in the burnt site, the destruction of the litter organic layer resulted in an eight-fold reduction in total ectomycorrhizal biomass. Forest fire can affect arbuscular mycorrhizal (AM) fungi by changing the soil conditions and by directly altering AM proliferation. Rashid et al. [82] suggested that compared with a nearby control area, the burnt site had a similar number of total spores but a lower number of viable AM fungal propagules.

4. Major Causes of Forest Fire in India

Most of the forest fires in India are deliberately set by small-scale farmers or landless rural people. In the north eastern parts of India, the practice of slash and burn shifting cultivation is the leading cause of forest destruction. The most heavily affected areas are Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland and Tripura. Nationally, an estimated 4.35 million ha are affected by fire as part of shifting cultivation. This is especially significant in that with the growth of population and consequent decrease in the land and person ratio, not only are more areas subjected to shifting cultivation, but also the fallow period for regeneration has been reduced from the initial 30 years to two years. Another of the most important causes of forest fires is related to the need for fodder for grazing animals. Although 12.5 million ha of land is officially classified as permanent pasture or grazing land, most of this area is virtually devoid of grass. Therefore, most of the grazing requirement is met from forest area by setting fires to produce new flushes of grass in the dry season. In central India such as Chhattisgarh and in Madhya Pradesh, the production of tendu leaves (*Diospyros melanoxylon*) is another major cause of forest fire. Tendu leaves are used to make a cigarette known as Bidi. Their collection and sale is an important secondary source of income for tribal dominated areas. Collectors of tendu leaves set fires in the summer months to promote a better flush of leaves. The problem is compounded by the fact that tendu areas are leased for the collection of leaves on an annual basis, the purchasers are therefore reluctant to make long-term investments in crop improvement. The most economical and quick alternative is to set tendu areas on fire; these fires all too often then extend to other forest areas owing to negligence and carelessness. Another non-wood forest product that contributes to forest fire is the mahua flower (*Madhuca indica*), collected by local people in north-central India to produce a popular beverage, or boiled with sal seeds (*Shorea robusta*) as a seasonal grain substitute. Mahua pickers burn the dry leaves under the trees to get a clean patch of floor to facilitate flower collection. While the intention is only to clear a small patch beneath a single tree, these fires often spread out of control. Since the collection of Mahua flowers is done during the summer months, the hot dry weather aggravates the situation.

5. Prescribed Fire for Forest Management

Overly simplified fire prevention propaganda which gave recognition only to the destructive effects of fire [83] led also to a school of thought that all fire on wild-lands was bad and that even accepted uses of fire must be tolerated only as a matter of choosing the lesser of two evils. How can fire help forests? The answer depends on the nature of the ecosystem, the weather, and the amount of fuel available [83, 84, 85] but in general, controlled fires can:

1) Reduce the build-up of fuel, and thus the intensity of future burns.
2) Recycle nutrients bound up in litter.
3) Reduce competition, allowing existing trees to grow larger. To control the encroachment or development of undesirable plants and encourage desirable food plants such as legumes for both forage and soil improvements, or shrubs.
4) Leave snags that provide nesting spots for woodpeckers and other birds.
5) To remove unpalatable growth remaining from previous seasons.
6) To stimulate growth during seasons when there is little green grazing.
7) To control or destroy insect and disease.
8) To aid in the better distribution of animals on a range or management unit, including bird habitat.
9) To stimulate seed production or opening of cones and prepare seedbeds for seeding, either naturally or artificially.
10) To establish fire breaks in a system of protection from wildfire.
11) To provide training for fire fighters and fire researchers.
12) To induce good growth of Tendu leaves (*Diospyros melanoxylon*).

For successful use of fire as a management tool in sustainable forestry practices it is must to carry out fire-prevention measures in frequent fire prone areas as integrated element of forestry in accordance with scientific norms, improve airborne forest fire monitoring and ground-based fire detection and patrolling. It is obvious due to difficult terrain, inaccessibility, lack of technical staff regular patrolling of the fire prone area is not possible; this can be overcome by suitable silvicultural measures employing rehabilitation of burnt sites with broad leaved evergreen trees. For successful rehabilitation of burnt sites utilize to the full extent the regeneration potential from unburned forest fragments. The post fire work may be as follows:

1. Establish plantations only in accessible sites by using fast-growing species in order to speed up carbon sequestration.
2. Concentrate and prioritize planning and implementation of forest cultures in protection forests in water catchment regions and unburned forest fragments with a high protective value for habitat rehabilitation of rare and the most valuable wildlife animal species.
3. Livestock grazing breaks up potential fuel and establishes trails through the forest that can be used as fire breaks, but there is need of controlled grazing below carrying capacity of ecosystem.
4. The use of GIS technology for forest fire simulation allows the integration of all the data on a single platform simplifying the modeling and analysis of potential forest fires.
5. The use of Remote Sensing technology for forest fire detection and evaluation of the intensity and losses.

6. Prevention and Control Measures of Forest fire in India

Fire can be extinguished by removing any one of the elements of the fire. Consider a natural gas flame, such as from a stovetop burner. The fire can be extinguished by any of the following:

- Turning off the gas supply, which removes the fuel source;
- Covering the flame completely, which smothers the flame as the combustion both uses the available oxidizer (the oxygen in the air) and displaces it from the area around the flame with CO_2.
- Application of water which removes heat from the fire faster than the fire can produce it. Similarly, blowing hard on a flame will displace the heat of the currently burning gas from its fuel source, to the same end.
- Application of a retardant chemical such as Halon to the flame, which retards the chemical reaction itself until the rate of combustion is too slow to maintain the chain reaction.

The Fire Fighting Strategy to fire management is following:-

i. Early detection and management extended to higher altitudes, including community participation in management of fire.
ii. Restocking forests, immediately after the area is burnt with nursery seedlings. Therefore nurseries have to be set up of Sal, Oak, and Conifer with adequate saplings available for future requirements.
iii. Considering that climate change is occurring, research needs to be carried out to identify forest tree species that would adapt itself at different altitudes.

A forest fire management policy has been developed in State for the first time to enable the government to focus on fire prevention aspects and to coordinate efforts with various agencies. The policy integrates modern fire fighting approaches with community based fire fighting strategies and is devised to preserve the unique biodiversity of the forests of the State especially those of the lower altitudes and plane area. The policy provides for zoning of the forests on the basis of their vulnerability, so that different treatments can be opted out to the different zones. Hence, there is a great need to explore options for early detection of forest fires and Remote Sensing may also play vital role in the creation of a model which may act as an alarm for quick counter action.

The Ministry of Environment and Forests, Government of India issued guidelines for prevention and control of forest fires to all states in June 2000. Some of those important guidelines or measures of prevention and control of forest-fires in India are –

1. Identification and mapping of all fire-prone area.
2. Compilation and analysis of data-base on the damage due to forest fire.
3. Installation of Forest Danger Rating Systems and Fire-Forecasting Systems.
4. Items of forest protection to be treated as a Plan Item in order to raise their profile and thereby increase their Budget Allocation.
5. All preventive measures are to be taken before the beginning of the fire season like summer season.
6. Recruitment of a Nodal Officer to coordinate with various agencies including the Government of India on issues of forest-fire.
7. A 'Crisis Management Group' should be constituted at the state headquarters, district headquarters, and at block levels to monitor the situations during fire period, coordinate various preventive and control measures, and arrange adequate enforcement of men and materials in case of any eventuality.
8. Communication network to be set up for quick flow of information and movement of materials and man-power to the fire site.
9. JFM Committees and Forest Protection Committees are to be actively involved in the prevention and control of forest fires. Other people living in and around forest areas and getting benefits from the forest should also be involved actively.
10. Regular training of Government Staff and communities as Fire –Fighters should be organized by the government.
11. Public awareness should be created against ill effects of forest fires- a Fire -Week should be celebrated to create mass awareness.
12. Legal Provisions for fire prevention and control should be implemented forcefully.

A Master Plan called as Forest Fire Control and Management has also implemented by GOI, blends of modern and Traditional methods and Technologies. These are –

i. Building up of a strong communication network of wireless system and satellite phone
ii. Arrangement of effective transportation
iii. Improved fire-resistant clothing
iv. Fire- finders
v. Fire Tender or Tractor- trolley mounted with water tanker
vi. Back pack pumps
vii. Fire fighting machines, helicopters, fire extinguishing materials, Fire- retardant sprays by helicopters etc. and other technological innovations

In the Constitution of India, the subject of forests is on the Concurrent List. It means that the Central Government and State Governments are both competent to legislate on the issue of forest fires etc. Issues relating to policy, planning, and finance are primarily the responsibly of the Government of India. On the other hand the field administration of forests is the responsibility of the different State Governments. Fire Prevention and Control Measures are therefore carried out by the State Departments of Forest. In India, forests are protected and managed through well prepared Forest-Working Plans, and Prevention and Control of Forest- fires has always been at the place of priority. Some of the important prescriptions included in the working plans are employing traditional practices of fire control like:

- Creation and maintenance of fire-lines, fire-tracks, controlled burning, engaging fire-watchers during fire seasons etc.
- Villagers inhabiting in and around forest areas are legally supposed to assist the forest department staff in extinguishing fires.

In conclusion, the forest fires is detrimental, causes enormous damage in several parts of the country depleting precious forest cover and destroying a rich variety of flora and fauna and beneficial microbes. The effect of forest fire on established trees of tropical forest viz. Sal and Teak species is less than subtropical and temperate forest species viz. Oak and Pine species due to their high calorific value. However the regenerations status of most of the species is affected adversely. After frequent fire incidences on the same area causes invasions of certain species viz. *Lantana, Xylia, Cleistenthus*, *Butea, Eupatorium glandulosum*, *Parthenium*, *Cassia tora*, *C. occidentalis* and subsequent degradation of dominant Sal and Teak forest. Due to fire macronutrients especially nitrogen becomes more available due to combustion of litter and organic matter which ultimately supports herbs but the status of micronutrients lost completely when the intensity of fire is extremely high. In this condition, nitrogen, phosphorus and potassium also burnt completely. The burning of organic matter increases pH in soil due to ash deposits on forest floor also results in loss of fungal spores, actinomycetes and mycorrhiza but the status of bacterial population is improved due to the enhanced availability of N and K and might have tolerated higher temperature and proliferated heavily after fire. A location specific research is essential to understand the dynamics of forest fire on the ecological, social and economical aspects because of the variability in climate, soil and forest in India. This will also be useful for the adoption of prescribed fire for the management of forest composition, control of disease and insect etc. as a tool. A holistic strategy must be followed including involvement of forest dwellers for the conservation and development of forest after fire events for faster and successful recovery of biomass and microbes.

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