Typical surface fire in a dry dipterocarp forest, Thailand.
Photo: GFMC (K. Wanthongchai)

The role and history of fire in tropical landscapes

Johann Georg Goldammer

"Fire management solutions and decision making must be based on historic and contemporary scientific-technical evidence."

Introduction

Globally, most landscape fires occur in the tropics and subtropics, where natural, lightning-caused fires have favoured the evolution of characteristic plant communities in sustainable fire ecosystems. Indigenous communities developed traditional burning practices for land management, especially in fire-adapted and fire-dependent tropical savannas and deciduous forests. Traditional small-scale slash-and-burn agriculture is still practised in fire-sensitive ecosystems such as equatorial rainforests, peatlands and wetlands.

Fire is also increasingly used for large-scale conversion to agro-industrial plantations and grazing land, and this, as well as maintenance burning of newly created open landscapes — such as recurrent use of fire in cattle pastures or for removal of agricultural residues — is a major source of uncontrolled wildfires. These often spread to surrounding land, including fire-sensitive forests and protected areas, leading to severe degradation of ecosystems and loss of forest cover.

The characteristics, impacts and severity of fires vary, depending on land use, intensity of utilization and associated degradation. For example, secondary vegetation on degraded tropical forest lands, such as the vast areas of *Imperata* grasslands (*Imperata cylindrica* in Southeast Asia and *Imperata brasiliensis* in South America) that are highly flammable and where frequent — often annual — wildfires occur. In conjunction with increasingly extended droughts due to climate change, these landscapes suffer excessive burning, degradation and loss of vegetation cover.

Intensive agricultural and grazing systems result in the fragmentation of tropical and subtropical landscapes. Rural communities and individual farmers and pastoralists have a high interest in protecting their land, villages and other assets against the adverse effects of wildfires, and where the safe use of fire and wildfire prevention measures often results in a significant decrease in the number of wildfires and area burned. In regions where rural populations and especially youth are urbanizing, there is underutilized or abandoned land subject to plant encroachment and ecological succession, where invasion of flammable secondary and seasonally vegetation leads to increasing wildfire hazard and risk.

While landscapes and fire regimes — the typical occurrence of fire in an ecosystem as characterized by seasonality, return intervals, behaviour and severity — vary over regions and time, there are historical constants. Fires have affected the vegetation of the planet for more than 400 million years, long before the advent of humans. Besides the direct effects of fire on ecosystems, fire-generated emissions are part of global biogeochemical cycles and have always influenced the chemistry of the atmosphere. In the 1980s, interactions between fire, tropical forests, savanna, climate and climate change arose as a major focus of interdisciplinary research (Goldammer 1990; Crutzen and Goldammer 1993; Goldammer 2013); see Figure 1.

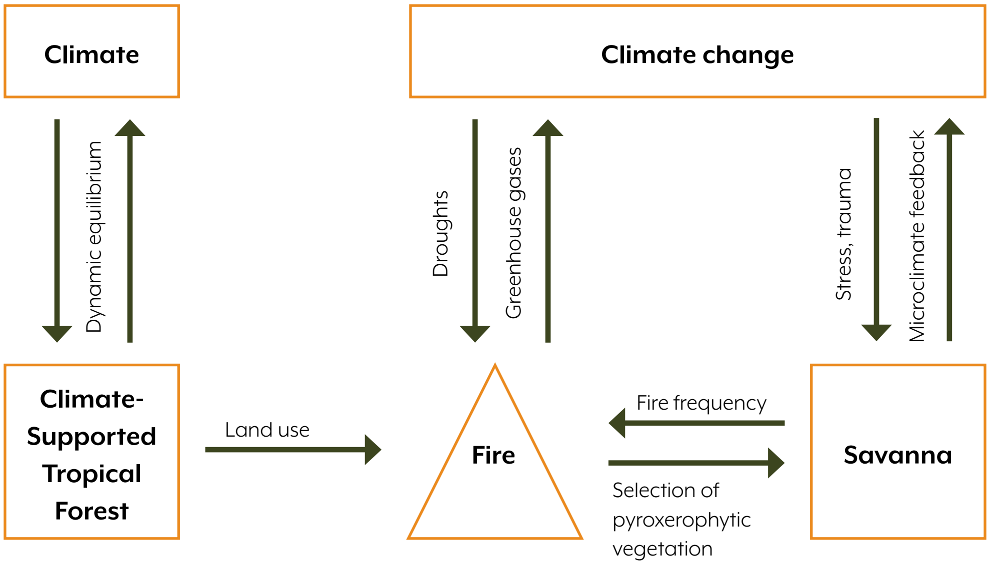


Figure 1. Interactions between fire, tropical vegetation and climate, developed at the first global forum on the role of fire in the tropics and its global implications. Source: Goldammer (1990)

History of fire in the tropics

Charcoal fragments in coal seams (fusain) provide evidence of fire in ancient forests from the Carboniferous Period. Radiometric age determination of charcoal found in Amazon rainforests reveals prehistoric natural or early-human-caused fires in the Holocene (ca. 3500–6000 years BP). In Southeast Asia, charcoal samples from lowland rainforests in eastern Borneo were dated to the peak of the last Pleistocene glaciation, ca. 18,000 years BP (Goldammer and Seibert 1990).

During the Pleistocene, the role and influence of fire on vegetation may have changed in accordance with climatic fluctuations. During interglacial periods, the prevailing warmer and more humid climate created conditions that were unfavourable for fire. During glacial epochs that occurred for some 80% of the last two million years, the tropical climate was cooler, more arid and seasonal than at present. This caused rainforests to retreat into refugia, surrounded by savanna-type vegetation that was likely to have been strongly influenced by fire. Such fire "corridors" between refugia may have contributed significantly to the genetic isolation of present-day rainforest "islands."

In Africa, early humans used fire for at least 1.5 million years, and this spread globally, becoming a dominant factor that especially influenced tropical vegetation, as shown by pollen analysis. In seasonally dry regions adjoining humid equatorial rainforests, fires were set for hunting, to improve grazing, and to keep land open for security (improved visibility) and accessibility. Neolithic fires played a role in opening closed forest ecosystems and savannization, and the reasons for and methods of fire use have changed little since then. Today, however, unprecedented human population pressure, consequences of climate change, and changing fire regimes mean that the influence of fire is now a critical element in the development of tropical vegetation and a predominant driver of degradation and destruction.

Tropical fire regimes

Fire regimes in tropical forests and derived vegetation are characterized and distinguished by fire frequency, seasonality and behaviour (intensity/severity). Tropical and subtropical fire regimes (Figure 2) are determined by ecological and anthropogenic (socio-cultural) gradients. Lightning is also an important cause of natural fires, which influenced savanna-type vegetation in pre-settlement periods, and are observed in deciduous and semi-deciduous forests and occasionally in rainforests.

However, with increasing human activities, the contribution of natural ignition to overall tropical fire occurrence is becoming less significant, compared to

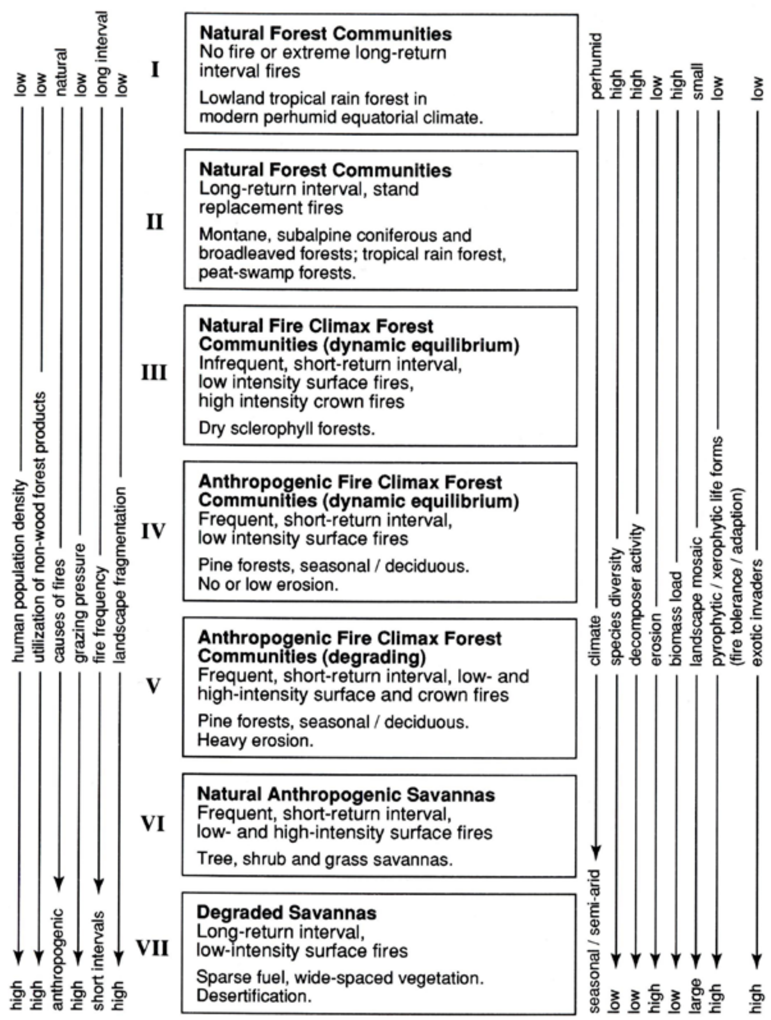


Figure 2. Types of tropical/subtropical fire regimes, related to ecological and anthropogenic gradients. Note: there are exemptions to this generalized scheme, such as higher species diversity in certain fire climax communities.
Source: Goldammer (1993)

Effects of a forest-conversion fire after clearing a lowland dipterocarp forest in East Kalimantan, Indonesia. Photo: GFMC

human-caused ignitions or fires purposely set for the following main reasons (see also Goldammer and de Ronde 2004).

- the most convenient and inexpensive tool for converting forest and other native vegetation (including wetlands and peatlands) to other land uses; e.g., agriculture, plantations and pasture, or exploiting other natural resources (open-cast mining);
- traditional slash-and-burn agriculture;
- grazing land and pasture management; i.e., fires set by hunters and herders, mainly in savannas and open forests, and by managers of industrial livestock enterprises;
- harvest of non-timber forest products; i.e., the use of fire to facilitate harvesting or improve yields of plants, fruits, etc., predominantly in deciduous and semi-deciduous forests;
- fires that start at the interface of residential areas;
- traditional fire uses such as religious, ethnic and folk practices; and
- targeted or collateral consequences of conflicts over land-use rights or territorial sovereignty.

The following sections discuss the role and history of fire in five generic forest types: equatorial rainforests, seasonal forests, tropical highland and subtropical lowland pine forests, savannas and open woodlands and planted forests.

Fire in equatorial rainforests

These are fire-sensitive ecosystems, where the main issue is the use of fire for forest clearing:

- slash-and-burn agriculture, where small forest areas are temporarily converted to agricultural use before being allowed to return to forest vegetation after a relatively short period; and
- conversion to plantations, cropland and pastures (or other non-forestry land uses), where large forest areas are permanently changed.

Clearing and burning always follow the same pattern. Trees are felled at the end of the wet season, and to improve burning efficiency, vegetation is left for some weeks to dry out. In undisturbed rainforests, the efficiency of the first burning varies and may not exceed 10–-30% of aboveground biomass, as only a small amount of the biomass in the tree trunks is consumed. The remainder is treated by a second fire or is left at the site to decompose.

Slash-and-burn farming provided a sustainable system for indigenous forest inhabitants, and the patchy impacts had limited effects on the overall tropical forest biome. Today, it is still practised in many topical regions, but is becoming increasingly destructive because of population pressures, which lead to larger cleared areas and shorter fallow (forest recovery) periods. In addition, large areas of primary and secondary rainforest are increasingly being converted for plantations, agriculture and grazing land in many regions of the tropics (Page et al. 2013; Cochrane 2013).

Targeted fire use in rainforests often results in wildfires that escape control. The impact of drought and fire on Borneo and the Amazon rainforests since the 1980s show that undisturbed vegetation may become flammable. Cases of rainforest fires associated with droughts were reported in Borneo in the 1800s and 1900s, and during the 1982–83 drought, numerous fires spread beyond forest conversion and shifting agriculture areas, affecting approximately 5 million ha in East Kalimantan, Indonesia, and the Malaysian provinces of Sabah and Sarawak (Goldammer and Seibert 1990). The 1997–98 fires in Southeast Asia resulted in a total burned area of 5 million ha in East Kalimantan, including 2.6 million ha of forest that burned with varying degrees of damage (Heil and Goldammer 2001; and Siegert et al. 2001).

Forest regeneration after fire shows no coherent pattern. Although dipterocarp forests tend to be highly fire-sensitive, there is regeneration potential where burning is moderate. However, recurring fires in rainforests lead to degradation over time by successively reducing forest cover and species diversity, and finally, with the invasion of pyrophytic grasses. Large tracts of former tropical lowland rainforests are now degraded *Imperata* grasslands, maintained by fires with a short return interval.

Fire in seasonal forests

The occurrence of seasonal dry periods in the tropics increases with distance from the equatorial zone. Rainforests gradually transition to open, semi-deciduous and deciduous monsoon, moist and dry forests. Between

Fire-induced destruction of a lowland tropical rainforest in East Kalimantan, Indonesia.

(a) Pristine dipterocarp rainforest (1980); (b) surface fire following selective logging (1982); (c) post-fire stage with some trees still standing (1985); (d) post-fire stage after more trees have died and undergrowth now dominated by pioneer species, highly flammable in extremely dry years (1995); (e) after a second, high-intensity fire (1998); and (f) final stage of savannization, and invasion by *Imperata cylindrica* (1998, on a frequently burned site nearby). Source: Goldammer et al. (1996) and Goldammer (1999). Photos: GFMC

Left: Typical pure stands of fire-resistant sal (*Shorea robusta*); and right: teak (*Tectona grandis*) in northern India that result from fires occurring every 1 to 3 years, eliminating competing tree species. Photos: GFMC

more closed deciduous forests and grass savannas, a broad range of ecotones are found. As varied terminology is used to describe non-evergreen forests and transitions to savannas, the prevailing fuel type is more appropriate for distinguishing diverse formations (Goldammer 1991, 1993).

The term "forest" is used where trees and woody matter dominate the fuel mix. The main fire-related characteristics of forests are seasonally available flammable fuels (grass-herb layers and shed leaves), which allow the understorey (grass and shrub layers) and overstorey (tree layer) to survive and even take advantage of the regular influence of fire. Adaptive traits include thick bark, ability to heal (fire scars), resprouting capability (coppicing, epicormic sprouts, dormant buds, and lignotubers), and seed characteristics (serotiny, or seed release after fire, dispersal, dormancy, etc.) (Stott et al. 1990; Goldammer 1993). These features are characteristic elements of a fire ecosystem.

Deciduous trees shed their leaves during the dry season, creating an annual source of surface fuel. In addition, the layer of drying and dried grass, together with the shrub layer, add to the available fuel, which generally ranges between 5 and 10 tonnes/ha. Herders, hunters and collectors of non-timber forest products usually set fires to burn the forest floor to remove dead plant material, stimulate grass growth, and facilitate or improve the harvest of forest products. Fires usually develop as moderately intense surface fires and can spread over large areas. The canopy layer is generally not affected, although isolated crowns may burn earlier in the dry season before leaves are shed. In some cases, fires may occur in the same area several times per year; e.g., an early dry season fire that consumes the grass layer, and a subsequent fire that burns shed leaf litter.

The ecological impacts of annual fires on deciduous and semi-deciduous forests are significant. Fire strongly favours fire-tolerant tree species, which replace other species that would grow in an undisturbed environment. For example, many monsoon forests in continental Southeast Asia would return to evergreen rainforest if human-caused fires were eliminated. This effect has also been observed in Australia when aboriginal fire practices and fire regimes were controlled, and rainforest vegetation started to replace fire-prone tree-grass savannas.

Tropical deciduous forests largely constitute a "fire climax"; i.e., their composition and dynamics are predominantly shaped by fire. However, they are not necessarily ecologically stable, as the long-term impacts of frequent fires lead to considerable site degradation. For instance, erosion tends to be significant due to depletion of the protective litter layer by fire just before the onset of monsoon rains. In India, fire adaptations and the fire dependency of economically important trees such as sal (*Shorea robusta*) and teak (*Tectona grandis*) have been the focus of discussions regarding fire control policy since the colonial period.

Fire in tropical highland and subtropical lowland pine forests

Of the more than 100 species of pines, some extend into the tropics, but none occur naturally in tropical Africa or in the whole of the southern hemisphere (except Sumatra). Tropical pines are largely confined to lower montane rainforest zones, usually on dry sites with a seasonal climate. Most are pioneers and tend to occupy disturbed sites such as landslides, abandoned lands and burned sites. In the subtropics, pines are also found in lowlands.

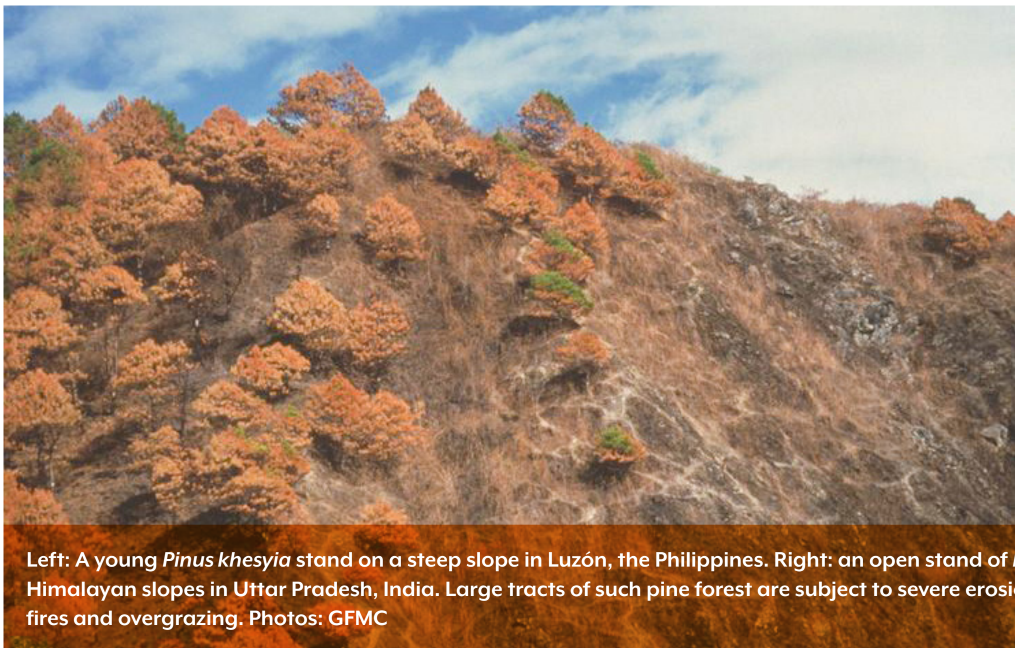
Most tropical pines show distinct adaptations to fire, with thick bark, taproots, some sprouting post-fire, and highly flammable litter. Tropical fire-climax pine forests, largely the result of a long history of regular burning, are found throughout Central America, at mid-elevations of the southern Himalayas, and in submontane elevations throughout much of Southeast Asia. As in tropical deciduous forests, fires are generally started by herders, hunters and collectors, but they also spread from the careless use of fire in farmland. The increased frequency of human-caused fires has led to an overall increase of fire-adapted pines and pure pine stands outside their natural area of occurrence in a non-fire environment. In tropical montane zones, fire also leads to an increase in altitudinal distribution, expanding mid-elevation pine forest belts into lowland rainforests and higher-altitude broadleaved forests.

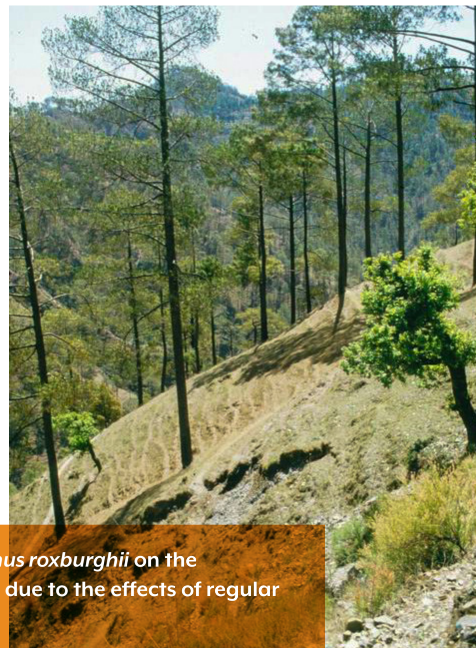
Subtropical fire-climax pine forests are also the result of a long history of natural and anthropogenic fires. In North America, the belt of southern pines stretches from the subtropical coastal area along the Gulf of Mexico into southern temperate forest regions. Pines that may dominate or form pure stands are in permanent competition with more fire-sensitive broadleaved trees. Pines gained a competitive advantage with regular natural lightning-caused fires, and with historic fires set by the pre-Columbian population and later by European colonists. This fire regime was disturbed, however, by the influential European dogma of fire exclusion, which was inappropriately imposed on North America in the late 1800s, and on many other areas in the world. In the 1970s, US public policies were further modified, this time aiming to re-establish natural and human-shaped fire regimes through the reintroduction of prescribed burning practices, and by allowing some wildfires to burn within fire management objectives.

In tropical and subtropical regions, fire-climax pine forests can support large human populations. If managed properly, fire creates highly productive forests that can provide sustained supplies of timber, fuelwood, resin and grazing. However, the increasing occurrence of wildfires — coupled with overgrazing and excessive logging — tends to destabilize submontane pine forests, resulting in forest depletion, erosion and subsequent flooding of downslope catchments.

Fire in savannas and open woodlands

The various types of natural savannas are shaped by their edaphic, climatic and orographic origins and by wildlife (grazing, browsing and trampling) and fire (Cole 1986). Alongside anthropogenic influences





Left: A young *Pinus khesyia* stand on a steep slope in Luzón, the Philippines. Right: an open stand of *Pinus roxburghii* on the Himalayan slopes in Uttar Pradesh, India. Large tracts of such pine forest are subject to severe erosion due to the effects of regular fires and overgrazing. Photos: GFMC

such as livestock grazing and harvesting of fuelwood and non-timber products, most tropical savannas are also affected by regularly occurring human-made fires (Figure 3). The interactions of wildlife, humans and fire throughout history are significant in the development of tropical savannas, and modern analyses have always regarded the role of fire as especially important.

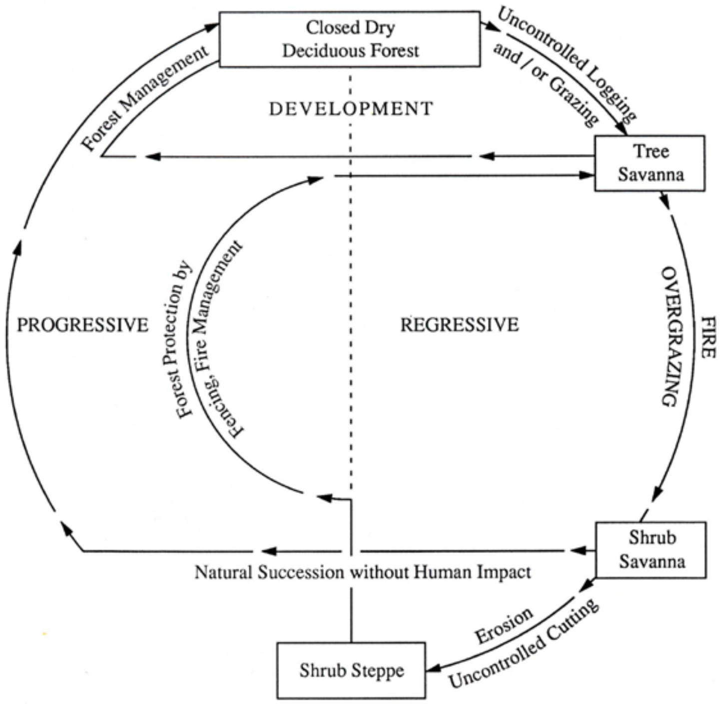


Figure 3. Generalized scheme of closed dry deciduous forest degradation and rehabilitation, as induced by uncontrolled fire and grazing (regressive) and protective measures (progressive). Adapted from Verma (1972)

Many tropical humid savannas are stable fire climax ecosystems, such as humid Guinean savannas in Côte d'Ivoire that are subject to regular fires. The extreme fire tolerance of palms (here: *Borassus aethiopum*) is a pantropical phenomenon. Photo: GFMC

Left: A typical fuel load of needles in a 9-year-old *Pinus ellliottii* plantation in Brazil, with a "ladder" of aerial fuels and a lack of understorey. Right: Surface fuel load in a 15-year-old *Pinus taeda* plantation after the third thinning. Photos: GFMC

Concerning fire ecology, the distinction between savannas and open forests can be based on potential fuel availability. In grass savannas, the grass layer is the exclusive or predominant fuel, whereas in open deciduous forests the predominant fuel is tree leaf litter and woody material from the tree layer. In open savanna woodlands (tree savannas), grass is also an important surface fuel.

Fuel availability varies with the various bioclimatic and phytogeographic savanna zones (Menaut et al. 1991). In the arid West African Sahel, aboveground biomass is 0.5–2.5 t/ha, increasing to 2–4 t/ha in the mesic Sudan zone, and up to 8 t/ha in the humid Guinea zone. Fire frequency largely depends on fuel continuity and density. Thus, savannas with relatively high and continuous loads of flammable grasses, such as those in the Guinea zone, are subject to shorter fire-return intervals than arid savannas. In addition, burning efficiency depends on the moisture content of dead and live organic matter, so fires in the early dry season generally consume less aboveground biomass than those at the end of the dry season.

Fires in planted forests

Forest plantations in the tropics are established for three main purposes: (i) to support the demands of local people for timber, fuelwood, non-timber forest products, etc., (ii) for landscape rehabilitation or environmental protection; e.g., greenbelts, shelterbelts, erosion control and sand stabilization; and (iii) to establish industrial monoculture plantations for timber, pulpwood or oilseeds, almost entirely with exotic species (commonly, pine and eucalyptus). Litter production in plantations of fast-growing species is extremely high, and with the exclusion of other forest uses leads to an accumulation of surface fuels (thick layers of needles/leaves, woody debris, shed bark) and aerial fuels (shed needles, leaves and twigs that are caught in branches).

Within their natural range, both pine and eucalyptus have developed forest formations that are largely shaped by natural and human-made fires. Regularly occurring fires suppress fire-sensitive vegetation and favour the formation of pure stands. Exclusion of fire from these fire-climax ecosystems generally leads to a build-up of fuels and an extreme wildfire hazard, where high-intensity fires are likely. Similarly, they were established as plantations without considering or introducing recurrent fire as a basic element to stabilize the biological disequilibrium in fuel dynamics. Consequently, many of these plantations are also highly susceptible to high-intensity fires.

The introduction of prescribed fire into tropical plantations, or the reintroduction of fire into fire ecosystems where fire-free management systems have been applied, remains a necessary but challenging field of practice and requires changes in fire management policy (Goldammer and de Ronde 2004).

Conclusions

Globally, the role of natural fire in ecosystems, and of cultural fire in land management, has been explored widely. This article provides an overview of the many roles and impacts and roles of fire in different environments in and around tropical forests, and while not exhaustive, it shows that fire management solutions and decision making must be based on historic and contemporary scientific and technical evidence.

There has been substantial progress in understanding the application of fire management approaches in which local communities act in their own interest to maximize the benefits from the appropriate use of fire and to avoid damage caused by wildfires. Unfortunately, only a few countries have put in place fire management policies and practices that address the underlying causes of the excessive and harmful application of fire where it is not appropriate.

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