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Fire in the Tropical Biota

Ecosystem Processes and Global
Challenges

With 116 Figures



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4 Fire in the Pine-Grassland Biomes of Tropical and Subtropical Asia

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4.1 Introduction

The genus *Pinus* is one of the most widely distributed genera of trees in the extra-tropical northern hemisphere (Critchfield and Little 1966; Mirov 1967). In the evolutionary history of its approximately 105 species two main centers of speciation are recognized. These are in southeastern Eurasia and southern North America, from where *Pinus* extends into the tropics. The range of extension of the pines in tropical South Asia has been described by Critchfield and Little (1966), Kowal (1966), Cooling (1968), and Stein (1978). Schweinfurth (1988) has compiled additional information and references on the distribution of pines in South East Asia provided by vegetation maps of the Himalayas, China, Cambodia, Viet Nam, Sumatra, and Thailand.

In tropical South Asia the biogeographical range of the genus *Pinus* is confined to the zone of lower montane rain forest and dry sites with a slight to distinct seasonal climate. In the perhumid equatorial rain forest biome of the lowlands of South East Asia the pines do not occur naturally. However, palynological data give evidence of *Pinus* occurrence in Northern Borneo up till the Pliocene (Muller 1972), thus reflecting the different climatic conditions at that time.

In a brief and general survey on the occurrence of conifers in tropical forests of Asia, Whitmore (1984) stated that the range of pines has been extended by anthropogenic and natural disturbances. The pines are pioneers (seral species) that easily colonize landslide sites and abandoned cultivation lands. Furthermore, pines are strongly adapted to and favored by fire. Both the flammability of the pine fuels and the various adaptive traits of pines to fire characterize most pine forest communities as a fire climax.

In tropical and subtropical Asia, most of the lands bearing pine forests are under increasing human pressure. Slash-and-burn cultivation extending into higher altitudes and steeper slopes, excessive fuelwood cutting, and grazing practices have brought an increasing frequency of man-caused fires into the mid-elevation forests. In many places the "fire-hardened" pine forests become more and more degraded because of shorter fire-return intervals and secondary

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Fig. 1. The regular influence of fire over centuries has created open, park-like stands of *Pinus kesiya* in the Central Cordillera of Luzón. The young stand in the background is reforested and protected from fire

effects of fire. Nowhere else can the ambiguous role of fire be better recognized than in the tropical pine forest biomes.

This chapter aims to highlight this dual role of fire in ecosystem processes of pine forests and associated vegetation in South Asia. Main emphasis is laid on the pine forests and grasslands of Northern Luzón, The Philippines (Fig. 1). Additional information on the fire ecology of pine forest communities in mainland South Asia and in Central America is found in this Volume (Stott et al.; Koonce and González-Cabán). The use and the impact of fire in pine plantations is covered by the contribution of De Ronde et al. (this Vol.).

4.2 Adaptive Traits of Tropical Pines to Fire

Forests and other wildlands, e.g., the various types of tree, brush, and grass savannas, which are regularly influenced by natural or anthropogenic short- to medium-return interval fires can be considered as a fire climax. In a fire climax the dominating tree species and associated vegetation are characterized by either fire tolerance or fire dependence (effects of fire selection). Furthermore, fire-dependent plant communities burn more readily than nonfire-dependent

communities because natural selection has favored development characteristics that make them more flammable (Mutch 1970).

The elimination of regular fire influence from these plant communities would allow the gradual development of seral stages finally leading to a nonfire climax. In the course of a seral development toward a nonfire climax, the distribution pattern and biomass load of fire-tolerant/dependent plants vs. fire-susceptible plants and the flammability of the plant community change considerably.

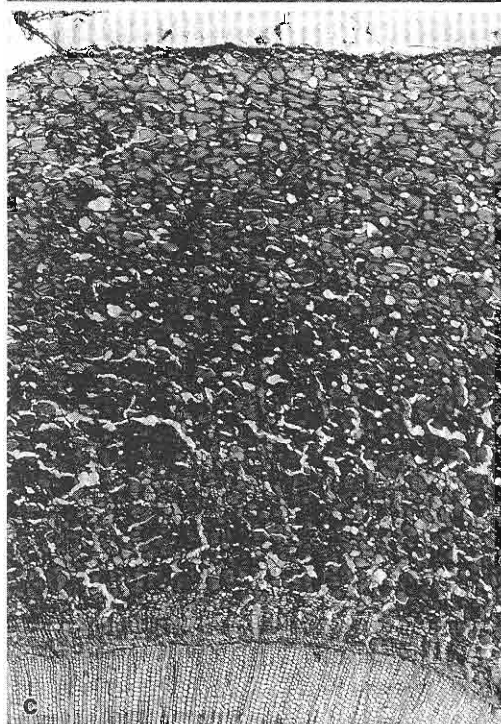
The main pine species forming fire climax communities in the tropical and subtropical climate zone of Asia and within its immediate area of influence (e.g., along the southern slopes of the Himalayas) are *Pinus kesiya* Royle ex Gordon, *Pinus merkusii* Jungh. and de Vriese, and *Pinus roxburghii* Sarg. These species have developed adaptive traits to fire which are described below.

4.2.1 Character of Bark

Of all the protective mechanisms of the tree, the bark is the most important (Martin 1963; Brown and Davis 1973). The heat-insulating capacity of the bark layer depends on those characteristics which have influence on heat conduction (structure, density, moisture content, thickness). With most of the pine species, bark thickness is strongly related to age. Old trees of the Asian pines *P. kesiya*, *P. merkusii*, and *P. roxburghii* generally develop a thick bark in the lower part of the bole, thus making the tree resistant to low- to medium-intensity surface fires. Kowal (1966) found that the survival of *P. kesiya* in the Central Cordillera of Luzón (ca. 2200 m) after wildfire was practically assured when DBH was 6 cm (at the age of ca. 11 yrs) and more.

An altitudinal gradient of bark thickness and fire resistance of *P. roxburghii* (and *Shorea robusta* as well) in the Central Himalaya is described by Singh and Singh (1984, 1987). The findings show that relative density of thick-barked trees is highest in elevations up to ca. 1800 m where fire is frequent, and declines rapidly above ca. 1800 m, where the influence of frequent burning is negligible. In the elevations of ca. 2500 m and above, forests consist primarily of fire-susceptible evergreen broadleaf species among which *Pinus wallichiana* is mixed.

The ability of healing physical damage by fire (bole injury, fire scar) is another characteristic feature of tropical Asian pines. Surface fires driven by wind or running uphill create hotter and more persistent flames in the lee (or uphill) side of tree stems. If the living tissue of the downwind parts of the stem is killed, the affected bark sloughs off. The surviving cambium forms callus tissue at the edge of the killed area, and the lateral wood rings eventually meet and cover the dead scar. This phenomenon, which was first described in *P. roxburghii* in India (Champion 1919), is an excellent source of dating historical fires and reestablishing historical fire regimes of tropical and subtropical pine forests (Fig. 2).



4.2.3 Basal Sprouting

Basal sprouting of young pines after fire injury has been described for a limited number of North American and Central American pines (*P. echinata*, *P. taeda*, *P. rigida*, *P. oocarpa*) (Stone and Stone 1954; Little and Somes 1960; Phares and Crosby 1962; Venator 1977). The resprouting capability is a prerequisite adaptive trait of *P. merkusii* to survive in a grass stage as described by Stott et al. (this Vol.). The ability of *P. roxburghii* seedlings to coppice after fire injury or browsing was first reported by Troup (1916). Our investigations show that dormant buds of *P. roxburghii* are embedded in the thickened cortex of the stem base (Fig. 3d). Both the heat insulating and the sprouting capability of the cortex characterize this plant as highly specialized to cope with a fire environment.

4.2.4 Site and Fuel Characteristics

Needle litter fall and fuel accumulation has been described for *P. roxburghii* (Mehra et al. 1985; Chaturvedi 1983) and for various subtropical and tropical pine plantations (Goldammer 1983; De Ronde et al. this Vol.). The accumulation of needle litter layer in *P. roxburghii* forests is explained by the high C:N ratio found in the litter and soils of the pine forest sites (Singh and Singh 1984). Furthermore, the decomposers on litter with high C:N ratio immobilize available N from the soil solution. It was suggested by Singh et al. (1984) that this fact, in addition to the fire-promoting character of the needle layer, is the main strategy through which pine invades a disturbed oak area and is partially able to hold the site against possible reinvasion by N-demanding broadleaved species. The heavy logging and fuelwood cutting of oaks in the Himalayan mixed oak-pine forests reduces the N return through leaf litter fall and thus gives additional advantage to the low-N-demanding pine. Altogether these site and fuel characteristics lead to an increase of fire occurrence and gradual expansion of pure fire climax pine lands into sites formerly occupied by mixed broad-leaf-pine forests and pure broadleaf forests.

4.3 Origin and Extent of Fires

In the seasonal pine forests and mixed pine-broadleaf forest biomes of tropical Asia lightning-struck trees and lightning fires have been reported occasionally (e.g., Osmaston 1920). Under today's man-caused fire pressure, however, lightning as a natural fire source becomes relatively less important compared to the extent and frequency of anthropogenic fires. The main causative agencies of tropical wildfires which are related to the social and cultural environment are escaped shifting cultivation fires, fires set by graziers, hunters, and collectors of

nonwood forest products and fires originated at the wildland/residential interface (Goldammer 1988); in addition, numerous fires are started by carelessness (cigarettes, torches, playing children).

Although a variety of local and traditional slash-and-burn cultivation methods exist, the fires are generally set at a similar time of the dry season and time of day when weather conditions are suitable for successful burning. Many of the land-clearing fires then escape into the drought-stressed surrounding forest lands because wildfire risk and fire behavior are poorly understood and preventive measures to confine the fires are hardly taken. Fires started by forest travelers and collectors of nonwood-forest products are very common throughout the seasonal mixed pine-broadleaf forests of tropical Asia. Fires set by graziers and hunters aimed to stimulate growth of palatable grasses are encountered in many rural cultures of the world (see Bartlett 1955, 1957, 1961). Occasionally, local particularities evolve, such as the habit of graziers to burn on the steep slopes of the Indian Himalaya. The needle litter layer of *P. roxburghii* occupying these slopes is extremely slippery and dangerous for cattle and therefore is burnt annually (Goldammer 1988).

The extent of wildfire occurrence and the area of seasonal forests annually affected by fires are not known because of the lack of systematic monitoring of the fire scene (see Malingreau this Vol.). Most fire statistics based on ground observations greatly underestimate the fire occurrence. This is not only due to the general difficult accessibility of the terrain. Fire reporting in many cases is restricted to plantation-type forests and not related to other forest land. Fire figures in many places are kept low in order to prevent sanctions against responsible fire control officers.

It is interesting to note that two independent assessments on annual fire occurrence in Burma (Goldammer 1986) and Thailand (Royal Forest Department 1988) show a similar dimension. In Burma the appraisal was based on extensive communication with various authorities of the Forest Department and yielded a total estimate of up to 6.5×10^6 ha \times yr⁻¹ of forest fires (equaling ca. 14% of the total forest cover of the country). This number comprises the pine forests, which covered a total area of ca. 300,000 ha in the early 1980's (FAO/UNEP 1981), and which are predominantly burned in short-return intervals.

The Thailand figures reveal annual fires on 3.1×10^6 ha equaling ca. 21% of the forested area. The source does not provide information about the extent of fires in the pure or mixed pine forests.

Little exact information about the area affected by fires in the *P. kesiya* forests in the Philippines is available. Most of the ca. 238,000 ha of closed and open pine forests is found in the Central Cordillera of Luzón (DENR 1988). The small reported fraction of severe wildfires does not represent the total amount of pine forest-grassland biomes regularly burned over (see Goldammer 1985, 1987a). Similar uncertainties about fire occurrence and size in the pine forest biomes exist in all other South Asian countries, especially in India, Kampuchea, Lao, Nepal, Pakistan, and Viet Nam (Goldammer 1987b).

4.4 Management Considerations

This section aims to elaborate on a case study by demonstrating the complexity of the *Pinus kesiya* fire climax forest in Northern Luzón, The Philippines. As was stressed in the introductory remarks, fire plays an extremely ambivalent role in the development and future of the tropical pine forest ecosystems. On the one hand, the steadily increasing impact of swidden agriculture (kaingin) and carelessly escaping kaingin fires has resulted in extended deterioration of the steep highlands of Northern Luzón. On the other hand, the influence of kaingin and grazing fires has created a forest environment capable of providing sustained yield of valuable timber and other forest resources, ensuring at the same time the landscape potential and the survival of the indigenous mountain population. Both the ecological and managerial challenges are highlighted in the following.

4.4.1 Distribution of the Pine-Grassland Fire Climax in Luzón

Pinus kesiya Royle ex Gordon (formerly *Pinus insularis* Endl.) occurs mainly in the Central Cordillera of Northern Luzón at 120° W and between 15°30'N and 18° 15'N within an altitudinal range of 750 to 2450 m. The pine, locally called Benguet Pine, is also found between 600 and 1400 m on the spurs and ridges of the Caraballo mountains, and a small provenance occurs in the Zambales mountains at altitudes from 450 to 1400 m (Armitage and Burley 1980). Recently, plantations have been established below these boundaries.

As was suggested by Kowal (1966), the original vegetation of the Central Cordillera, before being disturbed by kaingin and grazing fires, most likely was a broadleaf forest (lowland rain forest at the lower elevations, grading into tropical montane forest and “mossy” forest in the higher elevations). Kowal (1966) stressed that the pines, being essentially pioneers, expanded into gaps of broadleaf forest associations which were created by human disturbance. Kowal’s impressions of the history of fire-influenced development of the mountain forest vegetation and the potential future development are shown in his slightly modified model (Fig. 4). This model shows an increase of formerly patchy pine occurrence toward a broad submontane fire climax pine belt. At the interface between pine and broadleaf forest two main processes are recognized:

- Pine forest advancing. When fires are fairly frequent, each fire injures or kills plants at the edge of the fire-susceptible broadleaf forest. As a result, the pine forest advances slowly into the broadleaf forest area.
- Broadleaf forest advancing. When fires are less frequent, of lesser intensity, or even suppressed, the broadleaf forest reoccupies the fire climax pine land.

Within the pine belt it can be observed that the broadleaved species largely survived along water bodies, mainly in wet gullies and narrow valleys.

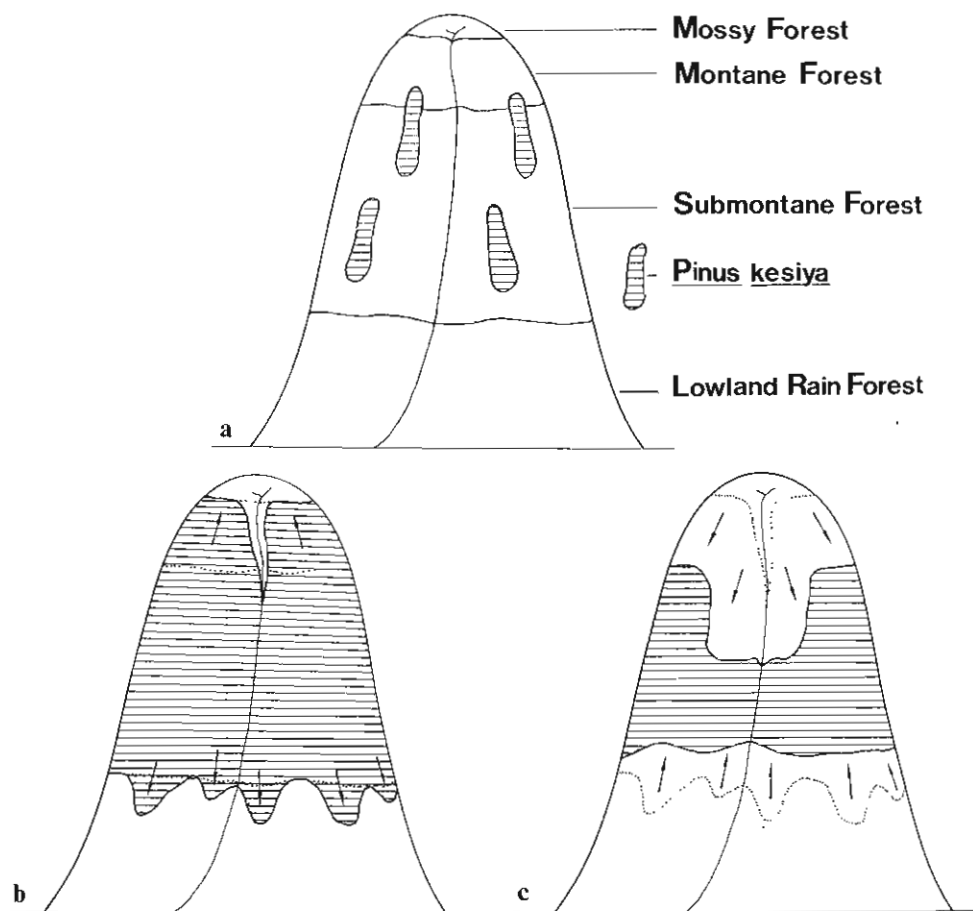


Fig. 4a-c. Probable changes of forest types in the Central Cordillera of Luzón (Philippines) during the past, characterized by scattered occurrence of *Pinus kesiya* in the submontane/montane broadleaf dipterocarp forest (a), present expansion of the fire climax pine belt (b), and probable future retreat of pines if forests are protected from fire (c). (After Kowal 1966)

P. kesiya forms extensive, more or less even-aged stands which, at higher elevations above 1500 m, may be densely stocked but which become more open at lower altitudes. Most of the forests consist of two strata: the pine canopy and the herbaceous layer dominated by grasses such as *Themeda triandra*, *Imperata cylindrica*, *Eulalia trispicata*, *Eulalia quadrinervis*, *Miscanthus sinensis*, and bracken fern (*Pteridium aquilinum*). During the dry season the cured grasses and the highly flammable pine litter favor the spread of surface fires which tend to kill pine seedlings and other upcoming fire-sensitive vegetation. Those pine stands that are regularly affected by short-return interval fires (1- to 3-year intervals) show hardly any successful establishment of pine regeneration (Goldammer 1985).

Fire intensity and fire impact vary according to the return interval. Annual fires usually consume the grass layer and the annual shed of needles and other dead organic matter, not exceeding a total of more than $3 \text{ to } 5 \text{ t} \times \text{ha}^{-1}$. After long-lasting fire exclusion wildfires tend to be of extreme intensity due to high fuel accumulation and its spatial distribution (surface fuels, understory, draped fuels); the fuel load varies considerably, depending on the understory vegetation. Since the annual rainfall in the Central Cordillera (above 2500 mm) is concentrated in the rainy season between May and October, most fires take place between the middle and the end of the dry season (end of January until the break of the rains in May).

The other anthropogenic fire climax is found in the lower elevations, mainly in the foothills of the Cordillera at the interface of agricultural and forest lands. These are grass savannas with scattered brushes and trees. Among the grasses the most important species are *Imperata cylindrica*, *Themeda triandra*, *Chrysopogon acciculatus*, and *Cappilipodium parviflorum*. The associated trees are *Piliostigma malabricum*, *Antidesma frutescens*, *Syzygium cumini*, and *Albizia procera*. Thick bark, hard seat coats, and resprouting organs characterize these species as xerophytic and pyrophytic remnants of formerly closed broadleaved forests being capable of coping with a fire environment (Fig. 5). The annual grass fires which originate in the pasture lands generally advance upslope to the edge of the dipterocarp forest and gradually increase the grasslands.

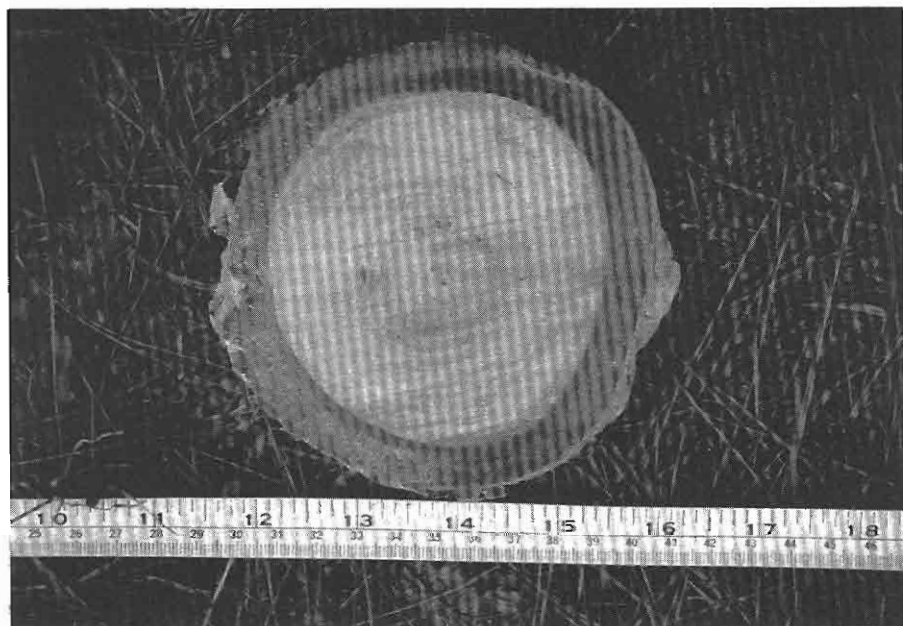


Fig. 5. As a typical xerophytic and pyrophytic remnant of the former lowland dipterocarp rain forest, *Syzygium cumini* shows the formation of thick bark enabling this species to survive in a fire-degraded environment

The shrinking area of the low-elevation dipterocarp forest is not only due to the progressing ecotones induced by fires from above (pine belt) and from below (foothill grass-tree savannas). With increasing population pressure the formerly observed fallow periods of the kaingin agriculture cycles have resulted in the expansion of grassland in the remaining broadleaved forest belt.

4.4.2 Main Ecological Challenges

The ambivalence of fire in ecological processes in the seral pine forests and grasslands can be demonstrated by some selected examples of species composition, site degradation, and insect infestation.

4.4.2.1 Grass Species Composition and Site Degradation

In unburned *Imperata cylindrica*-dominated grasslands thick swards of undecomposed grasses cover the mineral soil. The slow decomposition process and dense growth of *Imperata* shoots has been used as explanation for the lack of other short grasses and legumes (Peñafiel 1980). In *Themeda triandra* grasslands, the net primary production of 90 days on unburned sites was ca $30 \text{ g} \times \text{m}^{-2}$ vs. ca. $135 \text{ g} \times \text{m}^{-2}$ on burned sites (Peñafiel 1980). On the other hand, burning enhances the tillering capacity of *Imperata* (Sajise and Codera 1980). With the increase of fire frequency and dominance of *Imperata*, the amount of nutrients removed by volatilization and surface runoff gradually leads to soil impoverishment and site deterioration (see Soepardi 1980; Tjitrosemito 1986; Dela Cruz 1986).

The effects of soil depletion by regular burning on surface runoff and erosion has been demonstrated in the pine-grassland biomes of the Central Cordillera. Table 1 shows the significantly higher surface runoff in a freshly

Table 1. Comparison of monthly total surface runoff^a collected in burned and unburned plots. (Costales 1980)

Month	Total Rainfall (mm)	Total surface runoff		Difference (mm)
		Burned	Unburned	
June	57.06	7.45	1.67	5.78*
July	558.53	57.78	32.01	25.77**
August	921.95	113.28	72.82	40.46**
September	242.60	39.65	23.04	16.61**
October	105.00	25.21	17.58	7.63*
November	53.51	2.19	2.24	-0.05 NS
Total	1,938.65	245.56	149.36	96.20

^a Mean of ten surface runoff plots in the burned and unburned areas.

NS Not significant.

* Significant at 5% level.

** Significant at 1% level.

underburned pine forest at the beginning of the rainy season. At the end of the rainy season these differences between burned and unburned sites disappear. The same trend is observed in sediment yields (Table 2). Figure 6 shows the typical erosion patterns in the pine-grassland biomes of tropical South Asia.

Comparing the annual sediment yields of an annually burned grassland, a dipterocarp forest, and a reforested grassland, Dumlao (1987) reported that the

Table 2. Comparison of monthly total sediment yield^a collected in burned and unburned plots. (Costales 1980)

Month	Total rainfall (mm)	Total sediment yield		Tons/hectare Difference (mm)
		Burned	Unburned	
June	57.06	0.42	0.10	0.32*
July	586.83	6.51	2.27	4.24**
August	921.95	21.28	13.52	7.76**
September	242.60	4.08	1.34	2.74**
October	105.00	3.18	1.04	2.14**
November	53.51	0.07	0.16	-0.09 NS
Total	1938.65	35.54	18.43	17.11

^a Mean of ten surface runoff plots in the burned and unburned areas.

NS - Not significant.

* - Significant at 5% level.

** - Significant at 1% level.



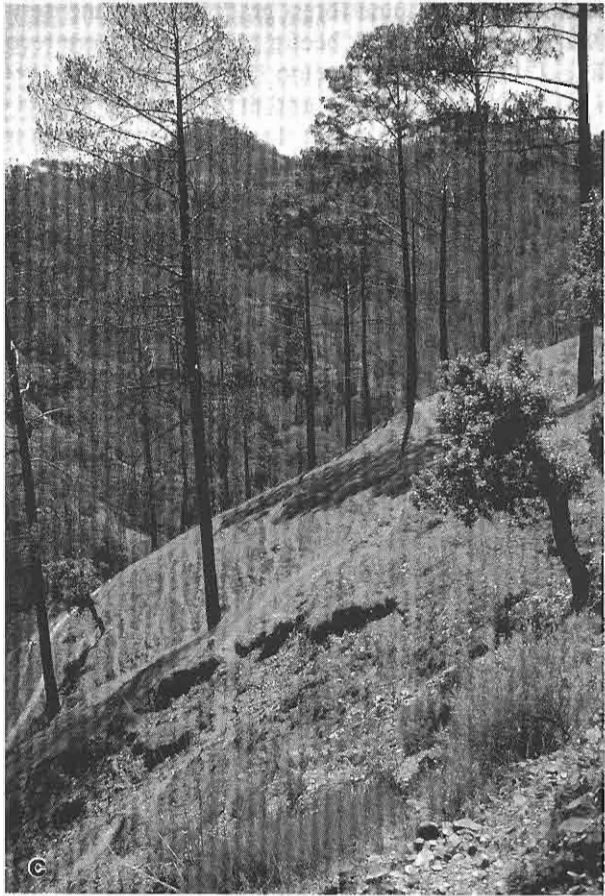


Fig. 6a-c. Increasing fire and grazing pressure in the sub-montane fire climax pine forest lead to severe erosion processes. The photographs show the degrading *Pinus kesiya* forests in Benguet Province, Luzón, Philippines (a), the *P. merkusii* remnants around Lake Toba, Sumatra (b), and the impact of cattle trampling, browsing and fire in *P. roxburghii* in Uttar Pradesh, India (c)

yearly burned grassland catchment had a mean annual sediment load of ca. $3.1 \text{ t} \times \text{ha}^{-1}$ compared to ca. $1.2 \text{ t} \times \text{ha}^{-1}$ and ca. $0.8 \text{ t} \times \text{ha}^{-1}$ for a secondary dipterocarp forest and reforestation catchment, respectively.

4.4.2.2 Fire-Host Tree-Insect Interactions

The occurrence of bark beetle species (Coleoptera: Scolytidae) is a common phenomenon throughout the pine forest biomes of the northern hemisphere. In the ecology of the patchy occurrence of *P. kesiya* within the undisturbed dipterocarp (– oak) forests, scolytids played a minor role. The proliferation of the pines by fire and the formation of an almost pure pine belt, however, have created host type stands suitable for the build-up and heavy outbreaks of bark beetle populations subsequently introduced from Central America.

With the introduction of the *Ips interstitialis* (Eichhoff) [probably *Ips calligraphus* (Germar)] from North America, most likely between 1935 and 1945 (Marchant and Borden 1976; Lapis 1985), the dynamic equilibrium between fire and pine forest gradually became destabilized. Still in the early 1960's only small bark beetle populations were recorded in the Central Cordillera (Caleda and Veracion 1963). In the early 1980's the beetle had dramatically increased its range and the severity of impact on the pine biome, and is now regarded as the major threat to the mountain forests of Luzón (Grijpma 1982; Lapis 1985).

Widely accepted observations suggest that, besides drought stress (e.g., the impact of the ENSO event on Asia in 1982–83, see Goldammer and Seibert this Vol.), the increasing fire occurrence and fire-induced damages were responsible for this recent development.

In a series of investigations employing monitor traps since 1985, Goldammer and Peñafiel (unpublished data) found that the occurrence of *I. interstitialis* in freshly burned-over forests was higher than in unburned control sites. The immediate increase of the number of bark beetles caught in pheromone traps up to three times during the first 24 h after burning and the subsequent decrease to the pre-burn population density level was observed in various experiments. The success of infestation, however, was generally nil if no crowning fire had occurred in the pine stands. Partially scorched trees without short-term and long-term (1 year) change in the regime of oleoresin exudation pressure (see Vité 1961; Goldammer 1983) provided resistant to successful infestation.

The area attractiveness of freshly burned stands to increased aggregation of bark beetles is explained by the release of monoterpenes through the heating process in resinous fuels (due to low-intensity fire and partial combustion of fuel). Field tests revealed that a high dosage of (–)- α -pinene, the major monoterpene in *P. kesiya* resin, provides in fact considerable area attractiveness (Table 3).

The ongoing research shows the complexity of the interactions between fire (man-induced)-insect (introduced by man)-host tree (fire-induced) in an en-

Table 3. Field response of *Ips interstitialis* to flight barriers baited with ipsdienol, (s)-cis-verbenol and (–)- α -pinene (1:1:18) on fresh mini clearcuts and simulated clearcuts with different treatments within pure *Pinus kesiya* stands in the Central Cordillera of Luzón, The Philippines

Series A ^a		Series B ^a	
Treatment of mini clearcuts (50 m ²)	Response of <i>I. interstitialis</i> $\bar{x}^b \pm \text{S.E.}$	Treatment of simulated clearcuts (50 m ²)	Response of <i>I. interstitialis</i> $\bar{x}^b \pm \text{S.E.}$
Fire		Fire	
Surface fire consuming needle litter and other ground fuels, heating/scorching of stumps	1.8a,b \pm 0.60	Fire in container with needle litter enriched with resin	4.5a \pm 1.76
α -Pinene dispenser (5 ml)	5.2b,c \pm 1.60	α -Pinene dispenser (5 ml)	20.0b \pm 3.54
Resin		Resin	
Additional resin of <i>P. kesiya</i> in open Petri dishes	8.5c \pm 2.19	Resin of <i>P. kesiya</i> in open Petri dishes	4.3a \pm 1.44
Control		Control	
Freshly cut resinous stumps	0.3a \pm 0.25	Paper dishes, no treatment	02.0a \pm 1.00

^aSeries A: Bobok, 17–18 February 1987; Series B: Loakan. Forest Research Institute site, 21–22 February 1987. Experiment with four replications, twice interchanged. The low number of beetles is due to overall population decline in that area since 1985–86.

^bColumn means followed by different letters are significantly different: Kruskal-Wallis H-Test (Series A: $F = 0.0199$; Series B: $F = 0.0044$) and two-tailed Mann-Whitney U-Test ($p < 0.05$).

vironment which has undergone very fundamental ecological changes through a complicated pathway from stability to instability.

4.5 Conclusions and Outlook

In forest management and land-use planning, decision makers face a dilemma: Obviously, fire plays a key rôle in maintaining the tropical submontane pine forests, which at the same time offer adequate habitability conditions for man. If used properly in time and space, fire creates a highly productive conifer forest, granting landscape stability and sustained supply of timber, fuelwood, resin, and grazing land. If fire runs out of control, as it obviously does in many places of the Asian pine forest lands, the losses are great: increased runoff (floods), erosion (siltation), soil denudation (landslides) and forest degradation (destruction of regeneration, insect pests).

The pros and cons of fire protection and "let burn" in tropical seasonal broadleaf and coniferous forests have been discussed extensively since fire protection was introduced to India by Brandis in 1863 (Shebbeare 1928; see also Pyne this Vol.). Soon it became obvious that fire exclusion would bring tremendous problems in the regeneration of teak (*Tectona grandis*) and sal (*Shorea robusta*) stands (see Stott et al. this Vol.) and increase the wildfire hazard in the *Pinus roxburghii* forests. "Controlled early burning" was introduced in 1877 (Shebbeare 1928) and was one of the focal points of discussion in India's forest management in the following half century.

However, throughout the pine forests of tropical Asia no real progress has been made since then. The forest managers and fire control officers are still running behind the wildfire problem. They are not adequately prepared for an approach toward integrated fire management in which fire prescribed in time and space would allow them to profit from the benefit of fire and to exclude the negative impacts of uncontrolled wildfire.

In the Philippines, Peñafiel (1982) showed that the loss of forests by wildfires was greater than the reforestation capabilities. The call for an integrated fire management approach was mandatory. A program initiated by FAO and accompanied by a research component tried to base its concept on the historical and social fire ecology of the environment of the Central Cordillera (Goldammer 1985, 1987a). The implementation of strategies elaborated, however, stagnates due to economic constraints.

Will there be a realistic chance to pursue the ideas of integrated fire management within the tropics? The answer is yes, because the pines are one of the few genera able to cope with an environment stressed by multiple disturbance and degradation processes due to the increasing pressure of human population, fire, and grazing. The ecological plasticity of pine-grassland agroforestry systems stabilized by prescribed burning and prescribed grazing (Goldammer 1988) may even cope with the yet unpredictable climate change and physiological transition stresses. Regardless of the combustion and fermentation processes involved, these agroforestry systems may contribute to halt the net carbon flux from tropical land use into the global carbon cycle.

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