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Fire in the Tropical Biota

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3 The Role of Fire in the Tropical Lowland Deciduous Forests of Asia

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Each dry season from January onwards the litter on the jungle floor ignites spontaneously and creeping ground fires clear away old matted vegetation, making way for the new season's growth. Some of these fires reach considerable size and provide one of the most impressive of jungle sights when viewed from a distance on a dark night. Long, jagged fronts of flame advance across the black backdrop of hillsides, exploding into pyrotechnics as clumps of dry bamboo are engulfed by the everchanging scarlet patterns of destruction . . . .

A teak-wallah's description of forest fire in Northern Thailand (H.N. Marshall, Elephant Kingdom, London: The Travel Book Club, 1959, p. 133).

3.1 Fire: An Alien Ecological Pressure?

Throughout the lowlands of tropical Asia, in regions experiencing either a monsoon forest (Köppen's Am) or a savanna forest (Aw) climate, both natural and human-induced annual or biennial fires have long been a common ecological phenomenon during the dry season, which may extend from three to seven months. Such burns occurred quite naturally through a number of causes before the appearance, around 12,000 years ago, of agriculture in the region, but, with the advent of Neolithic communities, swiddening, and stubble burning, dry-season fires inevitably became much more frequent and widespread. In modern times, this fire pressure has grown even more intense, and the ecological role of fire is now a matter for serious debate, as it is seen to affect diminishing forest resources in closer and closer proximity to human settlements (Goldammer 1988). In Burma, for example, the total annually burnt area of forested land has been estimated at 3.5 to 6.5×10^6 ha yr^{-1} (Goldammer 1986). For Thailand, data collected from 1984 to 1986 show that fire affected 20.92% of the forested area or 3.1×10^6 ha yr^{-1} (Royal Forest Department 1988), while worldwide, for all ecosystems, a figure of 630–690 $\times$ 10^6 ha yr^{-1} has been suggested by Seiler and Crutzen (1980), 98% of which occurs in the tropics and subtropics. In response to this, the clear temptation is for governments

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throughout the Asian tropics to try to outlaw dry-season burning completely, particularly in protected habitats, like national parks, forest reserves, and wildlife sanctuaries. Unfortunately, this policy often proves impossible to enforce effectively, and the result is an unpredicted wildfire, feeding on the abundant fuels that have been allowed to accumulate under the regime of fire protection. The cure can all too easily become worse than the disease. There is thus an increasing need to understand fully the ecological role of fire in the tropical lowland deciduous forests of Asia, so that we can manage fire safely as a tool, making humans the masters, not the fire (Mather 1978).

The ecological impact of fire, however, varies markedly from vegetation formation to formation, and it is quite wrong to assume that a program of fire management which is suitable for one habitat can be automatically transferred to another. Even within the same habitat, different management practices will be required to achieve different ecological and productive goals. Unlike lowland tropical rain forest, most of the vegetation formations characterizing the seasonal tropics of Asia, which range from the celebrated monsoon forests with teak (*Tectona grandis* L. f.), through the drier sāl (*Shorea robusta* Gaertn. f.) forests of the Indian subcontinent and the dry deciduous dipterocarp forests (savanna forests) of mainland South East Asia, to the more localized open grassland savannas and thorn forests, are all naturally preadapted, in differing degrees, to the ecological stress of fire. Indeed, in certain areas, fire will be the stabilizing factor, preventing the formation from progressing to a more evergreen alternative. The dry deciduous dipterocarp forests of Manipur State, Burma, Thailand, Laos, Kampuchea (Cambodia), and Viet-Nam, for example, are now known to possess ancient core communities, which were largely determined by topographic and edaphic factors, but from which the formation has since been spread by fire and the axe into more fire-sensitive formations, such as lowland tropical semi-evergreen rain forest, where savanna forests are now maintained by dry-season burning (Barrington 1931; Stott 1976, 1984, 1988a). In the core areas, fires also occur, but they are clearly not the key ecological factor, and fire protection will not normally cause one formation to succeed another, although it may alter the structural balance between trees, shrubs, and grasses. In contrast, outside these core areas, fire protection will trigger the succession to a more evergreen type. It is thus vital to decide what is required, and to exclude or to use fire accordingly.

In perhumid equatorial Asia, annual fire is largely an alien ecological force, although there is increasing evidence that even here fire may have affected vegetation patterns on a long-term cycle. On the other hand, throughout the seasonal tropics of Asia, where the dry season is prolonged, the total annual rainfall is usually much less than 2000 mm, yet the mean temperature of the coldest month rarely less than 20° C, fire is an integral ecological element, year in, year out, one which needs, however, to be managed correctly to produce the required results. In some circumstances, the exclusion of fire may, in fact, be itself alien to the environment; in others, as on steep slopes, fire may lead to severe biological disruption and to considerable geomorphological problems, such as increased soil erosion. The right application of fire to limited fuels at the appropriate time under sensible controls in the correct location is the key objective. It is the purpose of this chapter to explore the implications of these ecological subtleties for the drier seasonal forests of lowland tropical Asia.

3.2 Fire Patterns in Time and Space

Throughout the seasonal tropics of Asia, dry season fires vary markedly in character according to a whole range of variables, but above all in relation to timing, fuels, and topography, the first two of these, however, being themselves largely determined by the overarching variable of climate. Understanding the timing, origins, and fuel characteristics of the fires is especially vital if we are to learn how to manage fire safely and effectively.

3.2.1 Timing and Origins

The end of the great South West Monsoon is constant in neither space nor time, so that the potential for ignition can be delayed from early November to late January in any given year. In mainland South East Asia, the peak period for forest fires normally lies between late December and early March, by which time most sites will have been fired, although some burning may continue even into May. This peak period correlates strongly with the optimal provision of ignitable fuels, in that some 90% of leaf-fall will be generally completed by the end of December (Nalamphun et al. 1969), while the standing crop of grasses and pygmy bamboos of the genus *Arundinaria* will have dried and be ready for sustained burning (Chanatip 1973; Ruangpanit and Pongumphai 1983). However, enormous regional variations in timing are apparent, savanna forests around Chiang Mai in Northern Thailand, for example, tending to be fired early in December and January, whereas those near Korat in North East Thailand, by contrast, usually burn much later in February and March, following the late January rains that can come up suddenly from the Gulf of Thailand. The fiercest burns seem to be mid-season fires, each regionally defined, which tend to be "hot" fires, with high scorch heights. In contrast, early- and late-season burns are less dramatic, so that early-season burning in particular, defined in relation to the potential for fire ignition and sustainability in any given year and location, is often the best management option to follow to prevent uncontrolled and damaging mid-season conflagrations. Such a pattern closely parallels the ancient aboriginal burning practices recorded for the eucalypt savanna woodlands of Northern Australia (Braithwaite and Estbergs 1985; Bowman 1987; Stott 1989). Although floristically distinct, these eucalypt savanna woodlands are strikingly similar to the savanna forests of tropical Asia in terms of their structure and physiognomy, while both formations share clear resemblances to the miombo (*Brachystegia-Julbernardia* woodlands) of Central and Southern Africa (Chidumayo 1988; Guy 1989). All three are surprisingly homogenous in structure when compared with savanna and savanna forest formations in other parts of Africa and Latin America.

The percentage of burns that are natural is difficult to assess, although it is not uncommon to encounter fires far from any human settlement. One possibly classic example is reported to occur annually in the west of Thailand, in Kanchanaburi province, where the sun's rays are thought to be deflected into the forest from a crystallized quartzite cliff [Saranarat (Ôy) Kanjanavanit personal commun. 1988]. A more common cause is lightning strike. Lightning scars can be observed on many trees, such as the resinous *Pinus merkusii* Jungh. and De Vriese, and, although an immediate outbreak of fire is often prevented by the accompanying rain, the tree can continue to smolder within, leading to fire after the storm has passed. Not all lightning strikes, however, will lead to widespread burns, for many will simply result in the local "torching" of a tree, although this is less likely in the dry savanna forests. Other causes may include friction, particularly of dry bamboo stalks in the mixed deciduous forests or of pygmy bamboos (*Arundinaria* spp.) in the savanna forests. It is clear, however, that there are sufficient natural causes of fire to put at risk even the best protected of seasonal forests, which must, therefore, have a proper system of fire breaks and observation posts if the risk of widespread wildfire is to be minimized.

Today, however, the main causes of the dry-season burns are undoubtedly human, and it is especially difficult to protect dry tropical forests from the pyrogenic activities of humans in the densely peopled lands of Asia (Goldammer 1987). Many deliberate fires are actually set within the forest itself, to produce new grazing or thatching material (such as the large leaves developed by *Dipterocarpus tuberculatus* Roxb.), wood-oil from the dipterocarps, edible shoots of plants like *Melientha suavis* Pierre or tasty fungi on the forest floor, paths easy of access, a "drive" in hunting, or nutrients which are later rain-washed down to cultivated land with the yearly return of the South West Monsoon (Stott 1988b). In contrast, other deliberate fires are set outside the forest, but then get out of control, later spreading or "jumping" into nearby forest vegetation. The clearing of roadside vegetation and shifting cultivation (swiddening or slash-and-burn agriculture) are clearly the main culprits in this category of fire causes. On a world scale, Seiler and Crutzen (1980) have estimated that some 41×10^6 ha yr^{-1} of forest land are burnt or cleared through shifting cultivation alone. Deliberate fires are also employed for more specialized reasons, such as the stimulation of better growth in "tendu" leaves (*Diospyros melanoxylon*), which are used for cigarette (bidi) wrapping in Maharashtra, India.

Many fires, however, are not deliberate at all, but arise accidentally from a wide range of causes. The sheer number and variety of people crossing the forests of Asia, such as graziers, collectors of one sort or another, migrant hill peoples, prospectors, monks, guerillas, not to mention whole armies, in training or live combat, clearly provoke a high probability for accidental wildfires. One of us (Stott) has witnessed evidence of the potential for fire from army training camps in Thailand, while Goldammer (1986) shows that, in Burma, the predilection of the rural population for smoking "cheroot" cigars when working in or walking through forest lands may be a serious hazard. These cheroots normally comprise a mixture of tobacco leaves and stem particles, with the latter glowing for a considerable time and acting like sparks. In Thailand, one estimate suggests that no less than 66% of all forest fires are caused by people traversing the forests (Royal Forest Department 1988). Finally, fire may be set purely for the sake of fire itself, the phenomenon having a mesmeric effect on both children and adults alike.

The regularity of burning throughout the seasonal tropics of Asia is therefore apparent, although the exact pattern varies from formation to formation. One of the present authors (Werner), using data from 118 experimental plots in Thailand, has shown that for plots studied during January to March 1988, 62% of the pine-dipterocarp forest plots had been burnt, but only 14% of the plots in pine-oak forest. For plots studied during May-June of the previous year, the figures were 69 and 50% respectively, although, in this case, there was no way of checking whether the fires had all occurred in 1987. In January-March 1988, 35% of plots in the pine-savannas had been burnt, despite the fact that the majority lay within a national park, where complete fire prevention was being attempted, yet more evidence that a policy of total fire exclusion is often impossible to enforce.

3.2.2 Fire and Fuel

The nature, amount, and spatial distribution of ignitable fuel will largely govern the character of the fire in any forest location. In the tropical lowland forests of Asia, fires may be low-level litter fires, groundcover fires of various intensities and heights, or mixtures of the two, where there is a complex or mosaic of rock outcrops, litter, and groundcover (Stott 1986, 1988a,b). Each of these fire types, however, will in turn also vary in character with prevailing climatic conditions, such as humidity and wind, whether a backfire or headfire, and in relation to topography. It is important to recognize, therefore, a whole range of fire types, each of which has different direct and indirect effects on the vegetation formation involved, and which pose varying levels of threat from the human point of view. The extremes are slow-moving litter backfires, with a maximum flame height of 0.5 m and a fireline intensity of around 230 kW m^{-1}, which contrast with fast-moving, jumping, and "spotting" groundcover headfires, with mean flame heights of well over 2 m and a fireline intensity of anything from 2000 to 5000 kW m^{-1}, which is beyond the limits of human control, even with heavy mechanical equipment (Stott 1986, 1988b). Where the fuel load is kept down by regular burning on an annual or biennial basis, the latter dangerous type of wildfire is unlikely to occur, and the fires will tend to be moderate fires, which are largely within human control and which cause little *direct* ecological damage (Fig. 1).

The ecological significance of fire is therefore complex and depends above all on the nature and the distribution of the fuels available for burning. Because the majority of regular fires in the lowland deciduous forests of Asia tend to be

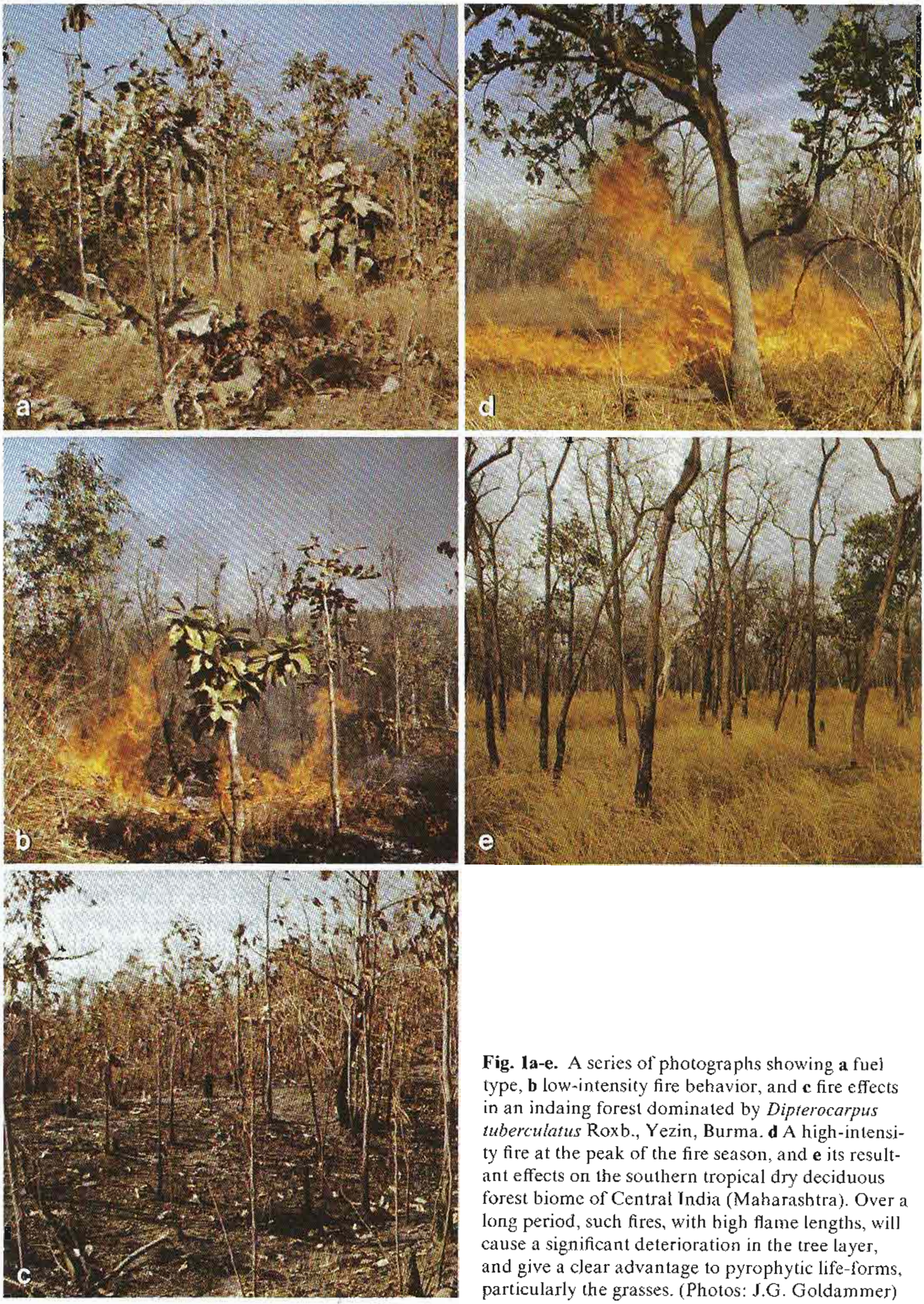

Fig. 1a-e. A series of photographs showing **a** fuel type, **b** low-intensity fire behavior, and **c** fire effects in an indaing forest dominated by *Dipterocarpus tuberculatus* Roxb., Yezin, Burma. **d** A high-intensity fire at the peak of the fire season, and **e** its resultant effects on the southern tropical dry deciduous forest biome of Central India (Maharashtra). Over a long period, such fires, with high flame lengths, will cause a significant deterioration in the tree layer, and give a clear advantage to pyrophytic life-forms, particularly the grasses. (Photos: J.G. Goldammer) small-scale surface fires feeding on limited fuels, it can be argued that they pose little direct threat to the main forest types, which are clearly adapted to moderate levels of fire. However, in taking this view, it is important to remember that different formations will respond in contrasting ways, and, above all, that these low-level fires will still affect the balance between trees, shrubs, and grasses in a formation, controlling, in particular, the rate of tree seedling survival and persistence. The synergism of fire and forest will therefore be immensely subtle, and will be perceived very differently by foresters, scientific ecologists, botanists, zoologists, landscape planners, politicians, peasants, and the general public. Hence the management dilemma. Foresters will largely want to exclude fire to improve tree stocks, but this policy may prove disastrous if it results in the build-up of immense fuel banks, which will eventually undoubtedly feed severe wildfires. Whatever the policy adopted, it must include some element for the control of fuel build-up, whether litter or ground cover. If the controlled application of prescribed fire is not appropriate, then it must be replaced by systems of grazing, cutting, trampling, or other forms of management. The policing alone of fire high risk areas will never prove sufficient in crowded Asia. Fire education and the development of distinct policies for different forest areas and vegetation units will also be required. In many zones, the application of early-season prescribed burning on limited fuels will still be the best option.

The work of one of us (Werner in Northern Thailand) has clearly demonstrated how different fuels and their attendant fires can markedly affect patterns of seedling and forest survival (see also Santisuk 1988). In pine-dipterocarp savannas, pine savannas, pine plantations, and pine-montane oak woods, young seedlings of *Pinus kesiya* Royle ex Gord. and *P. merkusii* clearly go through their most difficult phase in the first year of growth when they are especially susceptible to fire damage. The chances of survival, however, appear to be much higher in a pure litter burn than in a groundcover burn. The seedlings of *Pinus kesiya* have short needles between 22 and 33 cm in length. The lower of these tend to wilt during the dry season, while the younger leaves around the growing point are covered by a layer of blue-green wax. Low flames of the type characteristic in litter fires tend to consume the needles, but they do not damage the stem. In contrast, severe groundcover fires will kill the whole plant. *Pinus merkusii* possesses the additional protection of a "grass stage" (Fig. 2), although this naturally delays progression to the tree form. In Northern Thailand, the young pines can persist in this stage for up to 7 years. During the grass stage the plant has a strong rootstock, and it is remarkably resistant to all but the severest of groundcover fires. Unfortunately, the grass stage means that *P. merkusii* is not favored by foresters, who tend to want quick results, although the forms of *P. merkusii* found in North Eastern Thailand around Ubon Ratchathani and Sisaket tend to have a shorter grass stage of 1–3 years, while plants exhibiting a remarkable biogeographical disjunct distribution in Sumatra have no grass stage at all.

The effects of dry-season fire on the regeneration systems of the different formations and taxa is thus of great significance, and will vary with both the frequency and the intensity of the fires being encountered. For example, it is

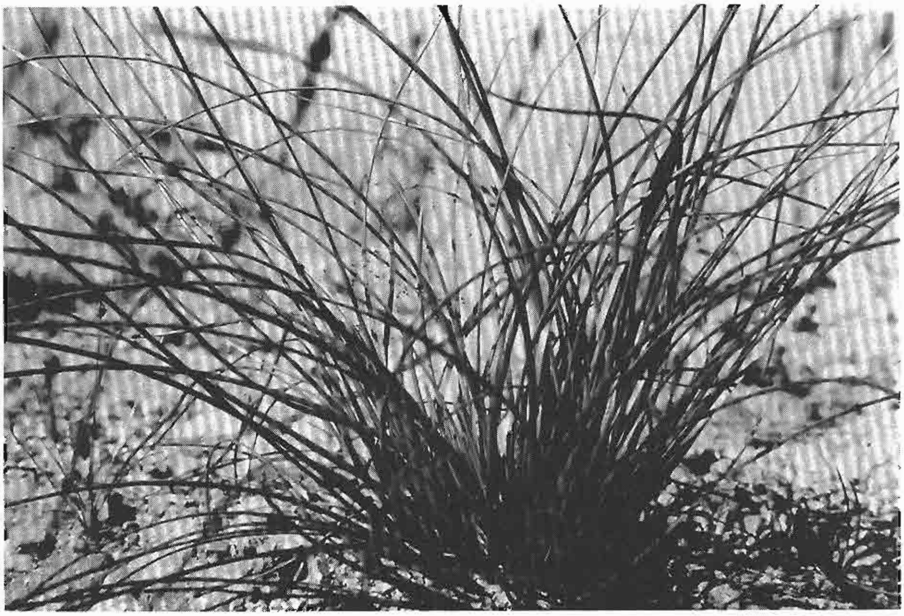

Fig. 2. Grass stage in *Pinus merkusii* Jungh. and De Vriese, Ban Wachan, Chiang Mai, Northern Thailand. (Photo: W.L. Werner)

quite clear from studies that the recovery rates of *Shorea obtusa* Wall. ex Blume seedlings after low-intensity fires is good (Stott 1986), whereas high-intensity fires can kill 95% of *S. obtusa* saplings that are less than 1 m high, although a mere 7% of taller saplings will be lost (Khemnark 1979). In some systems, therefore, short-term fire protection until saplings can withstand fire may prove an important management option, whereas long-term fire protection would trigger a change to an unwanted or less deciduous formation. Moreover, in some instances, burned stands will exhibit greater species diversity than unburned. Sukwong and Dhamanitayakul (1977) recorded 223 individuals of 30 identified species (excluding grasses) in a 320-m^2 stand of savanna forest at Sakaerat, North East Thailand, but only 181 individuals of 25 species in a neighboring unburnt plot of the same area. The number of seedlings of some important constituent tree species, e.g., *Shorea obtusa* and *Xylia kerrii* Craib and Hutch., was virtually the same in both, suggesting that the germination of dry deciduous dipterocarp tree species is little hampered by fire. The relationships between fire and regeneration are therefore far from simple, and much more detailed work is required in nearly all the formations of seasonal Asia.

Throughout the lowland deciduous forests of Asia, there is thus a complex spectrum of adaptation to different levels of fuel and fire. The most obviously adapted is the dry deciduous dipterocarp forest of mainland South East Asia, where the dominant deciduous dipterocarps, such as *Dipterocarpus intricatus* Dyer, *Dipterocarpus obtusifolius* Teijsm., *D. tuberculatus*, *Shorea obtusa*, and

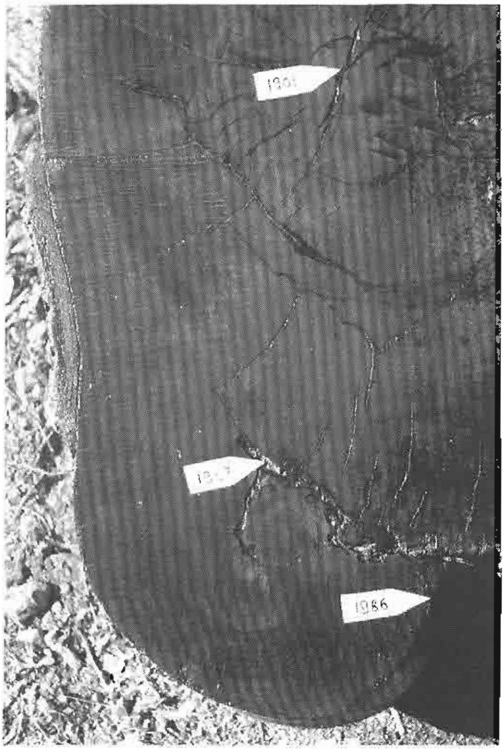

Fig. 3. *Dipterocarpus tuberculatus* Roxb. has a remarkable ability to recover from fire damage. This particular specimen is aged about 85 years, having been established in 1901 and cut in 1986. It was injured by a high-intensity fire in 1967, which created the fire scar. After 1967, the tree was affected by several low-intensity surface fires, which did not, however, delay the healing process. (Photo: J.G. Goldammer)

Shorea siamensis Miq., all possess a wide range of physiognomic, physiological, and phenological defences against both drought and fire (Stott 1986, 1988a,b; Fig. 3), and where fires rarely exceed moderate levels, unless fuel build-up is permitted to take place without any checks. Similarly, the terai forests of North India, which comprise both pure and mixed stands of sāl (*Shorea robusta*) are likewise fire-adapted (Goldammer 1987), old sāl trees having a thick, insulating bark, and the rootstock remaining normally unaffected by the low-intensity fires. Vigorous shoots soon appear after the fire has passed through, and these provide good grazing for cattle, so that local people are easily tempted to set fires deliberately in these formations. However, the frequent fires clearly affect the age-class distribution of the trees by widening the gap between the mature overstorey and the regeneration processes (Goldammer 1988; Fig. 4).

Mixed deciduous forests with teak (*Tectona grandis*) combined with a complex of other species, such as *Pterocarpus macrocarpus* Kurz and *Terminalia alata* Heyne ex Roth., also exhibit a range of adaptations to fire, but here tall bamboos are common and provide fuels for hot and damaging fires that can carry the flames high into the canopy. Indeed, in all formations, intense local burns can torch individual trees, particularly where the fire takes hold of roots, so that a localized build-up of groundcover and litter can have a damaging effect within an otherwise low-level fire. The type, the mosaic, and the loading of fuel

Fig. 4. Short-return interval fires frequently eradicate natural regeneration under old, fire-resistant sāl trees (*Shorea robusta* Gaertn. f.). The sāl stands may become moribund if not protected from fire and grazing during the critical phase of regeneration establishment. Terai forest, southern Nepal. (Photo: J.G. Goldammer)

in relation to the adaptive levels of the vegetation formation involved will therefore govern whether or not a fire has serious ecological and human consequences; in the lowland deciduous forests of Asia, the correlations are remarkably complex, and show that there can be no one solution for the management of fire in the region.

3.3 Fire Management

In the lowland deciduous forests of tropical Asia, there is therefore a vital need for a whole range of fire management systems, rather than a simple policy of "fire out" or fire control (Goldammer 1988; Rodgers 1986). Unfortunately, the latter approach is still adopted by many government organizations throughout the region (Royal Forest Department of Thailand 1988), partly through ignorance, but also because fire control divisions find it easier to battle for money and resources if they are seen as national fire fighters. The real subtleties of fire ecology are not, unfortunately, quite so easy to sell politically.

If we are really to progress, however, each situation, habitat, landscape unit, or fire problem must be approached in its own right, and the correct fire regime established, bearing in mind the main management purpose or aim at that particular location. It cannot be stressed too fully that we should choose the fire management system which is the most suited to achieving a given goal. For example:

— The general management of a tract of savanna forest in a protected wildlife area will probably demand a program of prescribed burning carried out early in the dry season on a regular rotation, so that new grazing is provided for wildlife and fuel is prevented from accumulating to the level where it would feed a severe groundcover fire that could have serious ecological consequences. A program of fire education in prescribed burning could be established for local villagers and visitors.

— If the aim is to combine high quality timber production with grazing, then a combined system of prescribed burning and prescribed grazing will be necessary (e.g., Liacos 1986; Goldammer 1988). Such systems may involve the protection of young saplings from the stresses of both fire and grazing on a short-term basis, but both grazing and fire will later be used to reduce the risk of severe fires and to maintain the basic ecosystem.

— If the aim is to control severe soil erosion on watersheds, steep slopes, or sensitive areas, then a much stricter system of fire control may be required, combined with other controls on the build-up of fuel loads. One of us (Werner) has studied such systems in *Pinus kesiya* plantations on watersheds in Northern Thailand, where fire protection tends to change the plantation into a pine-oak forest, which gives good soil protection, as well as a valuable timber and fuelwood resource. In this case, the pines are simply acting as pioneers. In other, more lowland, regions, however, the forest would remain fire-prone, with a dangerous build-up of fuel. In such areas, prescribed burning, very early in the dry season, but at longer intervals, combined with grazing, cutting, trampling, and fire protection during the intervening years, may be the necessary option. In contrast to such a regime, the regular late-season burning of teak forest near Haldwani (Uttar Pradesh, India) leads to severe soil erosion when the monsoon rains hit the newly exposed soil, one stand having lost 2000 m^3 of topsoil since its establishment 30 years ago (Goldammer 1987, 171; Fig. 5).

— In mixed deciduous forest with teak, light prescribed burning will have an important role to play in the silvicultural practices for the encouragement of teak (Kutintara 1970; Khemnark 1979, 38–39).

These, then, are just a few of the options for the management of fire in different socio-economic and ecological situations in the seasonal tropics of Asia. Fire is a tool which has long been used by humans (Sauer 1962). In many circumstances, even in crowded tropical Asia, any attempt to exclude fire completely will be bound to failure, and may, in fact, lead to disaster. However, wildfire cannot be allowed to have the mastery to itself. In the lowland deciduous forests of tropical Asia, there is a desperate need to manage fire carefully and correctly in order to produce the agroforestry systems which are required to protect the landscape, increase its productive value, and maintain ancient ecosystems, long adapted to moderate levels of burning. We cannot achieve this, however, without a full understanding of the basic ecology of forest fire in the

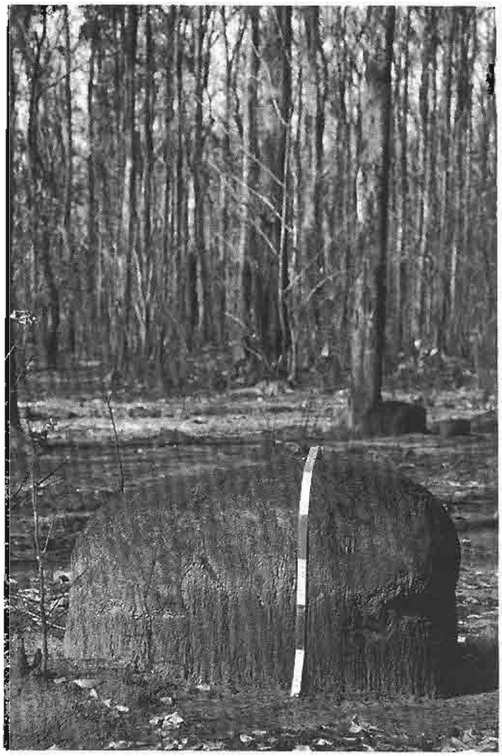

Fig. 5. Severe erosion under a 30-year-old teak (*Tectona grandis* L. f.) plantation caused by the impact of heavy monsoon rains on the soil exposed by annual fires (see text). Uttar Pradesh, India. (Photo: J.G. Goldammer)

region, a subject about which we know far too little. Research must come first, then a program of education, then the safe use of this ancient force in the monsoon lands of "fire and flood".

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