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Fire management on *Imperata* grasslands as part of agroforestry development in Indonesia

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Abstract. Fire is an important factor in the *Imperata* grassland ecosystem. It prevents or slows down the natural succession to shrubs and/or secondary forest vegetation and is a major threat to (agro)forestry options for *Imperata* grassland rehabilitation. Forest fires can also be a primary cause of the extension of *Imperata* grasslands. In this review an attempt is made to integrate biophysical and socioeconomic aspects of the causation of fires in a conceptual model. Fire effects on vegetation are examined. The management options at the level of a farmer, a village community and a national government are analyzed.

Introduction

Fire is well known as an inexpensive tool for land management, such as land clearing for farming and forestry. However, in the forest, fire can become a cause of destruction. A severe forest fire in East Kalimantan burnt about 3.2 million ha of tropical rain forest in 1982–1983. Smaller forest fires occur almost every year in Indonesia. Sumardjo et al. (1990) reported an annual average area of 21,000 ha of forest fires.

Fire in the forest is caused by the combination of three elements: oxygen, heat and fuel. Oxygen is always available in the forest. The heat can be developed naturally through a prolonged dry season and/or by human activities, on purpose or by accident. In the forest, fuel can be litter, under-growth vegetation, slash, and even the tree canopies. In the grasslands, fuel mostly consists of surface litter and dead leaves.

Imperata cylindrica (*alang-alang, cogon*) is an important fuel type for bush and (secondary) forest fires in Indonesia. Its ability to survive in poor soils and to colonize open areas has caused this species to spread extensively in response to fires. The area of *Imperata* grasslands in Indonesia is about 8 to 10 million ha (Garrity et al., this issue). Extensive areas of *Imperata* grasslands can be found in Sumatra and Kalimantan. *Imperata* occurs in mosaics with broad-leaved herbs, shrubs, and trees, or as vast areas of nearly monospecific vegetation.

During the dry season, *Imperata* is very dry and highly flammable.

Therefore trees that have been planted in grasslands can be killed by an *Imperata* fire. Thousands of hectares of reforestation trees burn every year, especially on *Imperata* grassland (Sagala, 1988).

Fire is an important factor in the *Imperata* grassland ecosystem. It prevents or slows down the natural succession to shrubs and/or secondary forest vegetation and is a major threat to (agro)forestry options for *Imperata* grassland rehabilitation. Forest fires can also be a primary cause of the extension of *Imperata* grassland.

In this review we will discuss a framework for combining biophysical and human factors in a model of fire causation and discuss fire spread in landscapes and fire effects on vegetation. We will describe the organization of forest fire control in Indonesia and discuss research priorities for dealing with fire on *Imperata* grasslands in the context of agroforestry development.

A model of fire causes and effects

Figure 1 summarizes a conceptual model of the major causes and effects of fires in the context of agroforestry development in grasslands. The amount of inflammable material depends on the vegetation, which can be summarized

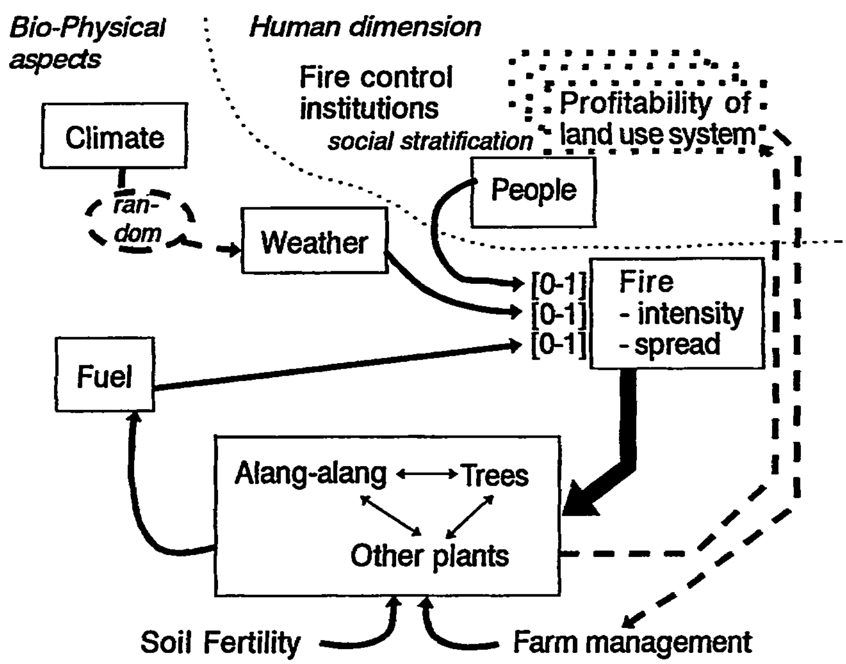

Figure 1. A conceptual model of the causes (fuel, weather and people) and effects of fire in the context of agroforestry development on *Imperata* grasslands.

for the present purpose as consisting of trees, *Imperata* and other plants. Fire has a pronounced effect on the composition of the vegetation, but this is also influenced by soil conditions and farm management. From the amount of inflammable material we can derive a factor F between 0 (no fuel) and 1 (maximum or above threshold).

Weather (which can be seen as a random realization of long term climatic conditions) enters as an external variable, mainly through the effective length of the dry season. Its effect on the chances of fire in any given year may be expressed as a multiplier W between 0 and 1.

Initiation of fire is mainly by people, either deliberately or accidental. Individual decisions on fire initiation probably depend on a combination of the profitability of the land use system, social stratification and the existence and enforcement of fire control institutions. The interface between the human dimension and the biophysical aspect may be expressed as a single multiplier H between 0 and 1. H can be interpreted as the difference between I (fire initiation) and C (fire control; by definition C can not exceed I):

$$H = I - C \tag{1}$$

A tentative multiplicative model can thus be formulated for the probability of fire starting in any unit of land in a given year as:

$$p(\text{fire}) = F * W * H = F * W * (I - C) \tag{2}$$

where F, W and H are indices between 0 and 1. The multiplicative form puts equal weights on three options to prevent fire: absence of fuel ($F = 0$), absence of dry conditions ($W = 0$) and absence of ignition or complete control ($I = 0$ or $C = I$). Maximum fire hazards occur where fuel and weather factor reach their maximum or threshold value ($F = W = I = 1$) and there is no control ($C = 0$). If p is constant, the chance of having no fire for n years is:

$$p(\text{no fire during } n \text{ years}) = (1 - p)^n = (1 - F * W * (I - C))^n \tag{3}$$

During the establishment of a tree cover, shade may reduce the amount of fuel (F) over time, and the probability of survival of a tree plantation may thus become age-dependent. The human factor (H) is likely to introduce further age-dependence.

Once fires are initiated, their spread depends on the landscape structure, both in physical terms (slope) and in spatial context (zoning of vegetation, natural or man-made firebreaks).

Although real quantification of all interactions is beyond the scope of this review, a number of interesting relationships is suggested off-hand:

- management efforts enhancing tree growth may reduce the number of years of high fire risks, due to a more rapid replacement of *alang-alang* (reduction in F);

- the need for these management efforts changes along climatic gradients in the duration and intensity of the dry season (*W*);
- at the same time, such efforts to increase tree growth interact with the social system and may either increase or decrease the likelihood of individuals initiating fire, depending on the social structure, benefit sharing and fire control mechanisms (*H*).

Depending on how the spatial structure of the landscape is described, the need for firebreaks can be balanced against the chances of fire initiating in any land unit.

Causes of forest fires in Indonesia: *F*, *W* and *H* factors

A number of factors increase the probability of forest fires in Indonesia. Related to the *F* factor:

- excessive forest exploitation by logging operations (HPH) cause forest to be exposed, dry, and susceptible to fire; secondary vegetation is a bigger fire hazard as it has more fuel on the ground and dries up faster in periods without rain;
- land conversion or switching the function of forest lands through land clearing for transmigration programs, big plantations, mining, industrial timber estates (HTI) is often directly based on fire, and leads to fire-susceptible vegetation;
- forest plantations are especially susceptible to fire because of their homogenous condition (monoculture), often over large areas. Moreover, forest plantations are usually established on open areas and critical lands dominated by potential fuel such as *Imperata*.

As regards the *W* factor:

- years with exceptionally long dry seasons in Indonesia appear to be linked with the El Nino Southern Oscillation (ENSO) (Nicholls, 1993) and lead to fire hazards in climate zones which are humid on average;
- natural phenomena such as lightning are not a major cause of forest fire in Indonesia, because lightning usually comes together with rains.

As for the *H* factor:

- in forest plantations, there is often a lack of attention to prevent fires and inadequate resources (personnel, organizations and equipment) to control forest fires. Sabaruddin (1988) reported the reasons for people to start fires in the reforestation area in Benakat, South Sumatra;
- for most farmers who live near the forest, the use of fire is inexpensive and effective for opening new land and/or fallow vegetation, and it increases soil fertility for a short period of time. Some farmers also burn grassland

for stimulating the germination and growth of favourable plant species (young grass) for their cattle. Uncontrollable fire from land clearing may lead to the occurrence of forest fires;
- hunters sometimes burn grassland to create an area of young grass to attract wild animals;
- carelessness with cigarettes and campfires by forest workers and tourists, and people who ignite fires for enjoyment or unclear reasons, have been recorded as causes of forest fires;
- a special category of deliberate fire initiation is linked with social protest. Knowledge about such arson is, for obvious reasons, more in the realm of speculation than of hard facts.

The cause of the widespread fires in Indonesia in 1994 is still subject to considerable debate. The Forestry Department of Indonesia considers that shifting cultivators were the main cause of forest fire. The shifting cultivators with their cultivation system, especially when opening new areas during the dry season (July–August), practice clear-burning. Frequently the fire becomes uncontrollable and spreads to neighbouring forest areas.

In this context, a distinction should be made between four types of farmers practicing slash-and-burn methods:

- traditional communities with strong local institutions restricting the actions of individual farmers;
- communities which are more fully integrated in the market economy, often combined with a loosening of traditional restrictions;
- spontaneous settlers/migrants;
- government sponsored (trans)migrants.

Shifting cultivators who entered the market economy and migrant settlers may try to open as much forest as possible. The justification is that they can sell the timber and plant more crops, for subsistence as well as for profit. Consequently, the fallow period and forest cutting cycle is shortened, causing disruption in natural regeneration of trees. The loss of forest cover makes it possible for the sun's rays to reach the ground, thus facilitating the growth of *Imperata*.

However, the traditional shifting cultivators in remaining forest areas are generally believed not to disrupt the ecological balance since they are very much aware that their livelihood depends on the forest.

Imperata fires

Imperata *as a fuel (F)*

The richness of the vegetation in Indonesia results in a variety of fuel types. However, most of the fire problems occur in areas of forest plantation or on open land adjacent to forests and plantations. Pickford (1992) stated that the most serious fire problems occur in *Imperata*.

A study of *Imperata* in Depok, West Java in July 1991, quantified fuel at different heights. Fuel depth (height above the ground of the highest fuel particle) was 150 cm, and total fuel loading was 18.6 Mg ha^{-1}. Seventy-five percent of the fuel loading occurred below the 50 cm height (Figure 2).

The dead fuel component in *Imperata* had a moisture content of 18%. The presence of large quantities of dead fuel (nearly 50% of the total fuel bed) means that the flammability in *Imperata* changes very rapidly with changes in relative humidity.

The height of fire flames is often twice the height of the fuel (vegetation). Manual fire suppression is only possible when flame height is less than two m. *Imperata* vegetation is normally 0.5–2 m high, and leads to a flame height of 1–4 m. *Imperata* fires creep rapidly, but their smoke is not very thick. *Imperata* grasslands normally have a biomass of 2–3.5 kg m^{-2} (or 20–35 Mg ha^{-1}). The mature grass may burn if there is no rain for a week.

By contrast, *Eupatorium/Chromolaena* bush needs a longer dry period to burn, but as it can be 2–5 m high, its flames are higher and can be more damaging for tree canopies. In the humid forest zone *Eupatorium/ Chromolaena* can lead to fire control (as the dry season is short) and help to re-establish trees. In sub-humid zones it is a fire risk that is even worse than the grasses.

The components of *Imperata* as a fuel have been identified by Suharti

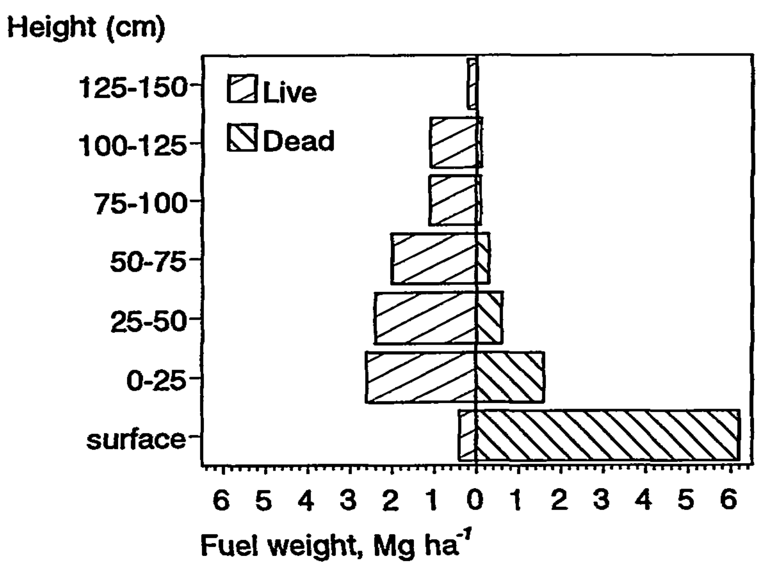

Figure 2. Fuel loads (live and dead biomass) in Imperata grassland at different heights above the ground (data from Depok, West Java; Wibowo et al., 1991).

Table 1. Characteristics results of some forest fuels.

Parameter	Fuel types				
	Imperata cylindrica	*Saccharum spontaneum*	*Acacia mangium*	*Eupatorium canescens*	*Melastoma malaba-thricum*
Ash content (%)	5.9	8.4–9.6	4.9	11.4	8.9
Silica content (%)	4.5	6.5–7.5	–	3.1	4
Caloric value (k Cal kg^{-1})	4165	4206	4490	3681	3644
Burning point (°C)	220–230	192	220–225	260–275	260–290
Ember point (°C)	315	320	–	315–340	300–330
pH	6	6–7	8	7	7
Extractives content (%)	–	–	24.6	–	–

Source: Suharti and Subarjo (1994).

and Subarjo (1994) in the laboratory of the Forest Product Research and Development Centre, Bogor, Indonesia. The analysis also compared *Imperata* with other potential fuels, as shown in Table 1. *Imperata* has a caloric value of 4,165 kCal kg^{-1}, nearly as high as the caloric value of some woods which vary from 4,285–4,994 kCal kg^{-1} (Hudaya and Hartoyo, 1988), and it has a burning point of 220–230 °C, comparable with the burning point of paper which is 210–215 °C (Hartoyo, pers. comm.).

One of the surprising aspects of *Imperata* as a fuel type is the rapidity with which it regrows after fire. At Depok, West Java, one week after a fire which removed all dead blades and killed nearly all the live *Imperata* blades, vigorous re-sprouting was evident, and new blade elongation had reached 15–20 cm. Pickford (1992) observed that at Aek Nauli, North Sumatra, three days after a fire, new blade elongation had reached 5 cm, even without rain in the intervening period.

The significance of this characteristic is the possibility of repeated fire in the same area during a single dry season, although subsequent fires will be less violent. Such a possibility makes the hazard-reduction treatments of *Imperata* areas by prescribed burning less practical.

Fire spread

Once fires have been initiated, their spread and behaviour depends on weather, topography and fuel loads. The most important weather or weather-related factor is wind, particularly wind near the earth's surface. Wind speed is important not only for the rate of spread, but also because of its effect on combustion rate and ignition probability (by sparks). High wind-speeds increase the chance of fire starting under certain circumstances (Luke and McArthur, 1978). Except for low and very high wind speeds, the rate of spread of a fire is approximately proportional to the square of the wind speed (Luke and McArthur, 1978; Lorimer, 1982).

Like wind, topography also has a marked influence in fire behaviour (Brown and Davis, 1973). Fires burn more quickly up steep slopes, largely because heat generated by the fire front is directed more closely to the surface of the ground, therefore decreasing the moisture content and increasing the temperature of the fuels ahead of the fire. McArthur (1967) concluded from experimental fires in eucalypts and grass fuels in Australia that the rate of forward progress of a fire on level ground doubles on a 10-degree slope and increases almost fourfold travelling up a 20-degree slope (Figure 3). Fire spread is considerably reduced on down slopes.

Fuel-moisture content, fuel quantity, fuel size and arrangement are significant variables determining fire behaviour because they affect the ignition probability, combustion rate, rate of spread, radiation efficiency and consequently fire suppression (Brown and Davis, 1973). Fuel-moisture content determines whether or not fuels will ignite, how much fuel is available for burning and the rate of heat released.

Fuel quantity is described in two ways; total fuel and available fuel. Total fuel is the quantity of fuel which will burn under the driest seasonal conditions with the highest intensity fire. Available fuel is the quantity of fuel that actually burns in a given forest fire. The rate of fire spread increases in direct proportion to the quantity of available fuel, if other factors remain constant (McArthur, 1973).

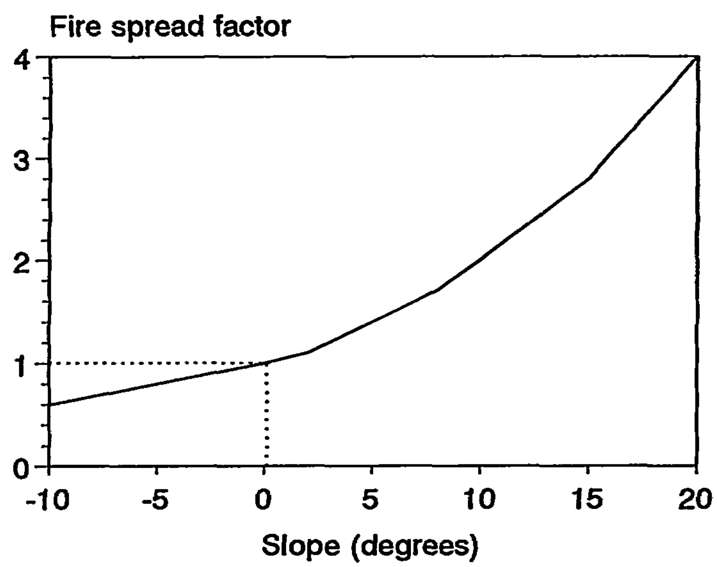

Figure 3. McArthur's slope correction for spread of fires; negative slopes refer to downhill movements of fire fronts, positive slopes to up-hill movements (Sneeuwjagt and Peet, 1985).

Fire effects

Fires on *Imperata* grassland might kill most other vegetation, but *Imperata* itself will survive, as fire can only kill all aboveground parts of *Imperata* but not affect the ability of its rhizomes to re-sprout after fires. *Imperata cylindrica* thus has the ability to survive fire and it competes effectively with other vegetation in open areas. Fires can therefore stop the process of succession into forest. A study in Benakat, South Sumatra showed that *Imperata* dominated burnt-over area (Table 2).

The effects of fire on tree species depend largely on the duration and temperature as sensed at the growing points (meristems), the age of the trees, and characteristics of the species. In general, a very high-intensity fire can kill any species, and there are few truly fire-tolerant tree species especially when the tree is still young and its growing points are close to the ground. However, tree species with a thick bark can reduce the temperature peak reaching living cells (if the fire passes by rapidly enough) and trees with protected growing points can resprout after a fire.

Sagala (1988) gave examples of fire-sensitive tree species such as *Paraserianthes falcataria* and *Shorea* spp., and relatively fire-tolerant tree species when they reach certain ages, such as *Schima wallichii* (puspa), *Peronema canescens* (sungkai), *Eucalyptus* spp. and *Vitex pubescens* (laban). In S. Sumatra and northern Lampung *Peltophorum dasyrrachis* reaches local dominance in the secondary forest vegetation as it is particularly tolerant to fire and able to resprout quickly.

Table 2. Analysis of vegetation on *Imperata* grassland in Benakat, South-Sumatera before and one year after a fire.

Species	Importance value (%)	
	Before a fire	After a fire
Imperata cylindrica	192.4	229.4
Chromolaena odorata	21.6	11.4
Saccharum spontaneum	10.8	9.2
Melochia umbellata	14.2	8.5
Melastoma affine	5.4	9.6
Bridelia monica	9.2	4.7
Paspalum conjugatum	4.6	–
Hyptis capitata	4.2	5.2
Lantana camara	2.4	–
Trema orientalis	7.6	–
Ficus glomerata	7.1	–
Vitex pubescens	12.3	8.5
Clibadium surinamense	6.2	6.4
Calicarpa tomentosa	–	2.2
Mimosa invisa	2.2	4.7

Source: Wibowo (1990).

Acacia mangium does not tolerate fire, but due to its rapid growth it may win the race against the clock and shade out *Imperata* before fires come through. In Riam Kanan, South Kalimantan fires occur every year, however, and since 1989–1993 fires have burnt off 3,602 ha of *Acacia mangium* plantation, killing most of the young trees (age of less than five years).

Fire control at field, community and national scale

Fire control (the C factor) depends on fire spread in the landscape, as discussed before, and thus differs between the various scales at which *Imperata* grasslands occur. At the field scale (*micro* grasslands, Garrity et al., this issue) control is a matter of a single farmer. At the community scale (*macro* grasslands), community organization, sanctions, and restrictions play a role. At the regional scale (*mega* grasslands), forest management organizations become important.

Fire control at field and farm scale

At field or farm scale, fire prevention is mostly based on reducing the amount of fuel and/or reducing the spread of fires by fire-breaks. Agroforestry development on *Imperata* lands has a number of options:

- growing food crops between tree rows, especially in combination with tillage to plough in crop residues, can reduce *Imperata* and other fuel loads; cropped alleys can function as effective fire-breaks in between tree hedgerows (D.P. Garrity, pers. comm.);
- when trees reach a sufficient canopy size, they will themselves shade out *Imperata*.

For shade-based control of *Imperata* by trees, however, a reduction of light intensity to 10–20% of solar radiation is needed and no food crops can be profitably grown at such light levels. A period of increased risk thus occurs between the time that the last food crops can be grown in between developing tree rows and the time that the shade is sufficiently dense (see discussion on rubber agroforestry by Bagnall-Oakley et al., this issue).

Recently experience was gained with fuel reduction by establishing mixed stands of *Gmelina* and *Parkia* (Petai) is S. Kalimantan. *Parkia* is a multipurpose tree grown for the pods, fodder as well as wood. *Parkia* tree growth in monoculture during the first and second year was good, as the *Parkia* was intercropped with rice, which prevented *Imperata* infestation. In year 3–6, no food crops were grown, but farmers still had to take care of the land. *Imperata* invaded and a subsequent fire destroyed the trees. Where the fast growing *Gmelina* was mixed with the *Parkia*, *Imperata* was suppressed quicker and no wild fires occurred. The *Gmelina* was used for firewood.

- replicating forest succession by starting of with fire-tolerant, dense-canopy tree species and planting more valuable fruit or timber trees after an initial tree cover and fire control has been obtained.

Fire-breaks are particularly needed along slopes and erosion gullies, as fire spreads rapidly up-hill. *Gmelina* can be used to shade out *Imperata* in a period of say two years.

Traditional fire control by local communities

The costs and benefits of fires are often not equitably distributed in communities. However, most traditional communities have found ways to resolve the ensuing conflicts and/or reduce the freedom of individual farmers.

Before setting a field on fire, Dayak people in Kalimantan remove the fuel along the border of the area to be fired, and sometimes also make a small ditch which borders around the field. The tradition of making a divider to prevent fire from spreading is based on traditional laws and rules, as well as on fines imposed by the village if fires spread to neighbouring plots. The traditional leader, based on discussion, will set dates for forest burning. There are sanctions against farmers burning too early or too late in the season.

The people living around the Ujung Kulon National Park in West Java also have rules about the season when fires are allowed. Normally, fires are set in July or August, a month before the rains allow planting of a new crop. Again, in the system of field burning, they pay attention to the borders between their fields and others people's fields or uncultivated forest. The borders of the cultivation area are discussed within the local community.

The same community involvement is described for the Baduy people in Kenekes Village, Lebak, West Java. Before carrying out burning activity, they set poles to indicate the borders of the field, including building a small hut (locally called *saung*), from where they will control the fire. When the burned field has become cold, the unburned wood is removed to the sides, and will be used in making a fence around the plot. In the Riau archipelago (Sumatra), the Sakai tribe are known to burn their plots against the direction of the wind, so that the fire front travels slower and can be more easily controlled.

Fire control in Indonesian forest management

Organization of fire control. In Indonesia, organizations of forest fire control have been established in a hierarchy from the national level to forest sub-districts. The Centre for Forest Fire Control coordinates national level policies. In every province, a Centre for Forest Fire Control cooperates with the Operational Coordinating Unit for National Natural Disaster Control (Satkorlak PBA), to take the necessary operational steps for suppressing existing forest fires. The Operational Command Unit in every Forest District Office (KPH/CDK) prepares operational plans and coordinates with other institutions to give field instructions and to prepare reports. The Operational Unit in every Forest Sub-District Office takes operational actions, and mobilizes the local community for controlling forest fires. The core of forest fire personnel are the Forest Guards (known as *Jagawana*).

Fire prevention and control as part of the management of government forest land, is based on a combination of a silvicultural, technical approach (to deal with the *F* factor), a 'prosperity approach', to deal with the *H* factor, 'early warning' methods and actual fire suppression methods when fires break out.

Silviculture approach (F). To avoid the spread of a fire in the forest, plantations should be divided into blocks and places between blocks can be used as inspection or access roads and fire breaks. Fire breaks can be green belts with relatively fire-tolerant species, and yellow belts of bare soil. Furthermore, the choice of tree species on *Imperata* grassland should also consider the following:

- the species must be fast-growing species that can compete with *Imperata* and can survive in poor conditions;
- the species must be fire-tolerant and have the ability to re-sprout after a fire;
- the species must have a wide and dense canopy in order to control *Imperata* through its shade.

Examples of fast growing species for different climate zones are given in Table 3.

Table 3. Examples of tree species that can be used in fire breaks for different agroclimate zones (climate zones are from Oldeman, 1975).

Species	Agroclimate zone	Elevation (m above sea level)
Acacia auriculiformis	C, D	0–800
Acacia mangium	C, D	0–800
Calliandra calothyrsus	A, B, C, D	150–1500
Gmelina arborea	B, C, D	0–800
Leucaena leucocephala	C, D	0–1500
Macadamia hildebrandii	B	1100–1200
Schima wallichii	A, B	800–1200
Vitex pubescens	A, B	0–600

Source: Research Institute Bogor Agricultural University, IPB, 1987.

Prosperity approach (H). About 99% of forest fires are caused by people and their activities. The welfare of people who live in the surroundings of forest areas must be increased, so that they have a 'sense of belonging' to the forest, and understand the functions of forest. The following actions can be taken:

- increasing the welfare of the local people by involving them with

(agro)forestry activities and job opportunities, and providing land which can be utilized to meet their needs;
- selection of species for forest plantations that consider people's needs. It should be a combination of species for forestry and people's need and may include indigenous tree species. An example in Riam Kanan, South Kalimantan shows that species such as *Acacia mangium* might be not appropriate;
- increasing the awareness and knowledge of the local people through extension programs. They should be aware of the danger of forest fires, and know of fire control techniques, law and regulations;
- giving local people a direct share in the (financial) benefits of forests.

Early warning or climatological approach (W). A Fire Danger Rating System can be based on regular observations of weather aspects such as rainfall, temperature and humidity. The level of forest fire danger can then be used in an early warning system. In combination with the known fuel hazard (*F*), it can provide information as to what prevention activities are required. Remote sensing trechniques and spatial databases are increasingly used for such purpose.

Suppression methods (C). Depending on forest fire intensity and resources (personnel, equipment, etc.) available, the methods of forest fire suppression can apply direct suppression (for a small forest fire), locating and preventing the spread of fire by establishing a fire break, and by using back-firing techniques.

Equipment is required for the management of forest fire control. However, availability of such equipment can vary depending on the level of fire risk, fire hazard, and the value of the areas to be protected. Basic tools and equipment must be available to control forest fires. To ensure the success of fire control efforts, forest areas must be provided with forest roads and look out towers for monitoring forest fire occurrence as soon as possible.

Priorities for research

Forest and bush fires are a serious risk in large parts of Indonesian forests, whether on private or government land. Activities for reforestation and agroforestry establishment on *Imperata* grasslands have to deal with the problem. Although past failures and successes have given many clues on how to improve the current situation and combine biophysical and human aspects of fire prevention and control, a number of research issues remain at the field, community and regional/national scales. The conceptual model on integration of human dimensions and biophysical aspects of fire prevention and control should be further developed at all scales.

At the field scale, research combining current farmer knowledge and forest ecological insights can aim at:

- knowledge of what fuel level fire-break species and configurations are effective in stopping or retarding fires;
- knowledge of what species are suitable and relatively fire-tolerant in *Imperata* grasslands and how these species can best be used;
- technology for 'slash-and-mulch' methods of land clearing without burning as alternative to the current slash-and-burn methods;
- more quantitative understanding of shade intensity and duration needed for *Imperata* control;
- more quantitative evaluation of the fire risks as a function of time for various mixed tree and agroforestry arrangements.

At the community scale, social and policy research can aim at:

- analysis of traditional community-level institutions to deal with fire and their adaptation to changing circumstances;
- policy changes to further involve local communities living around the forest in forestry activities and give people a direct benefit in their every day life.

At the regional/national scale, research can be aimed at developing:

- a *fire danger rating system*, to give early warning of conditions under which devastating fires can occur, and to help in priority setting for allocation of limited budgets for fire control;
- a *fire hazard analysis* to predict fire behaviour and controlability;
- a link between remote sensing methods, geographic information systems and human management.

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