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Fire in the Tropical Biota

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2 The Impact of Droughts and Forest Fires on Tropical Lowland Rain Forest of East Kalimantan*

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2.1 Introduction

Lowland tropical rain forests have generally been regarded as ecosystems in which natural fire was excluded by fuel characteristics and the prevailing moist environment (Richards 1966; Mutch 1970; Mueller-Dombois 1981). However, recent findings demonstrate that climatic conditions since the late Pleistocene have favored the occurrence of natural and anthropogenic fires in the Amazon Basin and in East Kalimantan (Sanford et al. 1985; Saldarriaga and West 1986; Goldammer and Seibert 1989). It has also been demonstrated that the fuel characteristics, and the influence of drought on the microclimate and flammability of rain forest, may create conditions suitable for the occurrence and spread of long-return interval wildfires in today's primary rain forests (Uhl and Kauffmann this Vol.). Modern human impact on tropical forest lands is rapidly increasing, causing overall degradation, and conversion of rain forest vegetation to pyrophytic life forms with increased flammability and fire frequency (Mueller-Dombois and Goldammer this Vol.; Goldammer 1991).

The 1982–1983 wildfires in Borneo left behind more than 5×10^6 ha of burned primary and secondary rain forest. These fires were the result of extensive land-clearing activities, and an extreme drought which was attributed to the El Niño-Southern Oscillation complex. In the aftermath of the fires, which the media largely regarded as an "ecological disaster" (Seibert 1988), a strong and growing scientific interest developed, focusing on the impact of fire on rain forest vegetation.

This chapter will provide a synthesis of various studies intended to clarify the role and the impact of fire in the dynamics of lowland tropical dipterocarp rain forest in East Kalimantan. In order to understand past and current fire regimes, a brief description of the influence of climatic change and climatic oscillation on rain forest flammability and fire occurrence follows.

*Kalimantan is the Indonesian part of the Island of Borneo with four provinces in its center, west, south; and east. Sarawak and Sabah in its northwest and north are states of Malaysia; Brunei is on the northwest coast of Borneo.

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2.2 Climatic Variability and Fire Regimes

It is generally recognized that during the last Ice Age the transfer of water from the oceans to continental ice caps lowered the sea level of the earth by at least 85 m (McIntyre et al. 1976).

Besides exposing land, especially on the Sunda Shelf, the drop in ocean water levels caused the development of an overall arid climate at that time. In the highlands of Malesia, reliable palynological and radiometric information has clarified the climatic and vegetational history since the last glaciation, as well as human impact (Flenley 1979b; Morley 1982; Maloney 1985; Flenley 1988; Newsome 1988; Newsome and Flenley 1988). In his holistic appraisal of the geologic and biogeographic history of the equatorial rain forest, Flenley (1979a) suggested that the most acute differences in the Quaternary climate of equatorial Indo-Malesia, compared to present conditions, occurred during the period ca. 18,000 to ca. 15,000 B.P. At that time, for example, the upper forest limit in the New Guinea highlands was 1700 m below its present value, while the mean temperature was 8 to 12 °C lower.

Although palynological evidence from the tropical lowlands is still very scarce (Flenley 1982), it must be assumed that lowland vegetation was generally that of areas with a more pronounced dry season. Lowland pollen analyses from West Malesia are, or appear to be, of Holocene age (Maloney 1985), and no data from East Kalimantan are available.

However, the only study available from South Kalimantan may serve as an auxiliary argument for the climatic change which occurred during the Holocene. Morley (1981) suggested that the ombrogenous peat development of a peat swamp in the Sebangau river region had been initiated by a change from a more continental to a less seasonal climate during the mid-Holocene. This implies that the lowland climate of East Kalimantan, which today is still slightly seasonal (Whitmore 1984), must have been considerably drier within the period between the last glaciation and the development of today's rain forest climate. At that time, fuel characteristics and flammability of the prevailing vegetation must have created conditions suitable for the occurrence of wildfires, as was assumed, although never proved, for north Sumatra at ca. 17,800 B.P. (Maloney 1985).

The first evidence of ancient wildfires in the eastern part of Borneo was found by Goldammer and Seibert (1989). The radiometric age determination of charcoal recovered along an east-west transect between Sangkulirang at the Strait of Makassar, and about 75 km inland, showed that fires had occurred between ca. 17,510 and ca. 350 B.P. These events must have occurred in situ, as upper-slope hill terrain was selected for sampling, to avoid data-sampling from charcoal dislocated by sedimentation, deposits of which were found in the lower areas of Kutai National Park (Shimokawa 1988) and dated ca. 1040 B.P. (Goldammer and Seibert 1989). Charcoal residues suggesting ancient forest fires were also recently found in several places in Sabah (Marsh personal commun.).

The fire dates of 350 to 1280 B.P., as presented in the study, reveal that wildfires occurred not only during the dry Pleistocene, but also after the present wet, rain forest climate stabilized, at about 10,000 to 7000 B.P. These fires can be explained by periodic droughts such as those caused by the El Niño-Southern Oscillation complex (ENSO).

The ENSO phenomenon, which has been comprehensively described (Troup 1965; Julian and Chervin 1978; Philander 1983a; Mack 1989), is regarded as one of the most striking examples of inter-annual climate variability on a global scale. It is caused by complicated atmospheric-oceanic coupling which is not yet entirely understood (Behrend 1987). The event is initiated by the Southern Oscillation, which is the variation of pressure difference between the Indonesia low and the South Pacific tropical high. During a low pressure gradient, the westward trade winds are weakened, resulting in the development of positive sea surface temperature anomalies along the coast of Peru and most of the tropical Pacific Ocean. The inter-tropical convergence zone and the South Pacific convergence zone then merge in the vicinity of the dateline, causing the Indonesian low to shift its position into that area. Subsequently, during a typical ENSO event, the higher pressure over Malesia leads to a decrease of rainfall, the severity of the dry spells depending on the amplitude and persistence of the climatic oscillations.

In the rain forest biome these prolonged droughts drastically change the fuel complex and the flammability of the vegetation. Once the precipitation falls below 100 mm per month, and periods of 2 or more weeks without rain occur, the forest vegetation sheds its leaves progressively with increasing drought stress. In addition, the moisture content of the surface fuels is lowered, while the downed woody material and loosely packed leaf-litter layer contribute to the build-up and spread of surface fires. Aerial fuels such as desiccated climbers and lianas become fire ladders leading to crowning fires, or the "torching" of single trees.

Peat swamp forests found in the lowlands of Borneo represent another fuel type. With increasing precipitation deficit and the dropping of the water table in the peat swamp biome, the organic layers progressively dry out. During the 1982–1983 ENSO, various observations in East Kalimantan confirmed a desiccation of more than 1 to 2 m (Johnson 1984). While the spread of surface and ground fires in this type of organic terrain is not severe, deep burning of organic matter leads to the toppling of trees and a complete removal of standing biomass. It is further assumed that smoldering organic fires may persist throughout the subsequent rainfall period, to be reactivated as an ignition source in the next dry spell (Goldammer and Seibert 1989). This re-ignition is similar to the patterns of fire behavior in the organic soils of northern boreal and circumpolar biotas.

The climatic variability during the past 18 millennia, with long-term changes and the short-term oscillations, may give sufficient explanation for environmental prerequisites for wildfire occurrence. However, the origins of the fires are not clear and cannot be interpreted through the ^{14}C-data of charcoal. Under the drier and more seasonal climate of the last glaciation, early anthropogenic fires and frequent lightning fires may have played a role similar to the conditions in today's deciduous savanna forests of continental South Asia (see

Stott et al. this Vol.). Volcanism as another natural fire source may have influenced vegetation development on Southeast Asian islands with high volcanic activities, e.g., the highlands of Sumatra and Java.

Long-lasting fires in coal seams extending to, or near, the surface (Fig. 1), are found in various rain forest sites in East Kalimantan and are another important natural fire source there (Goldammer and Seibert 1989). It was assumed that all of the 29 coal fires known to be burning at present had been ignited by the 1982–1983 wildfires. This is questioned by Goldammer and Seibert (1989), since there are numerous oral reports about burning coal seams made before the 1982–1983 drought.

Goldammer and Seibert (1989) also investigated the "baking" effects of subsurface fires on sediment or soil layers on top of the coal seams. The effects of ancient, no longer burning coal seam fires can still be seen today. The material, locally called "baked mudstone", is utilized at present for road construction purposes. Thermoluminescence analysis of burnt clay, collected on

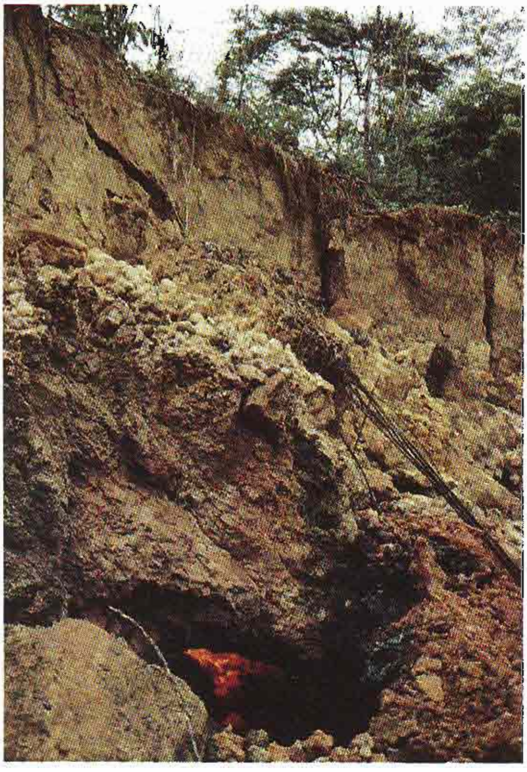


Fig. 1. Subsurface coal fire under primary dipterocarp rain forest near Muara Lembak, East Kalimantan (January 1989)

top of an extinguished coal seam in the vicinity of active coal fires, proved a fire event 13,200 to 15,300 years B.P. It must be assumed that both old, and most ongoing, coal fires have been ignited by lightning.

The edges of the burning coal seams progress slowly through the ground of the rain forest and cannot be extinguished by water. Even a water body cascading over the edge of a burning coal seam cannot affect the combustion process, as observed by Goldammer and Seibert (1989).

During the 1987 ENSO, the authors witnessed the ignition of a forest fire by a burning coal seam and its spread from there into the Bukit Soeharto forest reserve (Fig. 2). Figure 3 shows how trees, and other forest debris which falls over the progressing fire edge, may carry the fire into the surrounding forest land.

These observations, together with the data on ancient fires and the longevity of coal fire occurrence, suggest that burning coal seams represent a permanent fire source from which wildfires spread whenever a drought occurs and the fuel conditions are suitable for carrying a fire. This interaction between climàtic variability, fire sources, and wildfires seems to be unique. However, the phenomenon may well help to clarify the role and impact of long-return interval disturbances, like fire, in the evolutionary process of the rain forest biome which, until now, has generally been considered to be infinitely stable.

Fig. 2. Surface fire originated at a burning coal seam edge in Bukit Soeharto National Park during the drought of 1987 (September 1987)

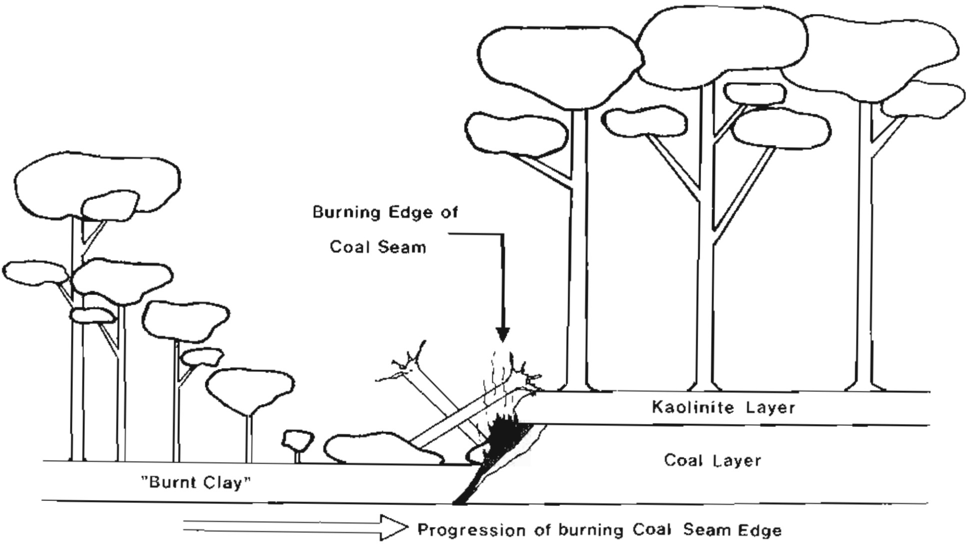


Fig. 3. Schematic progression model of a burning subsurface coal seam edge. (Goldammer and Seibert 1989)

2.3 The 1982–83 ENSO, its Predecessors and the Wildfires

2.3.1 The 1982–83 ENSO

The 1982–1983 drought in Malesia was the result of an extreme ENSO of exceptionally large amplitude and persistence (Philander 1983b). In north and east Borneo, the decrease of rainfall began in July 1982, and lasted until April 1983, interrupted only by a short rainy period in December 1982. Monthly precipitation dropped below critical values along the coast and up to around 200 km inland. In Samarinda, near the east coast of East Kalimantan, the rainfall between July 1982 and April 1983 was only 35% of the mean annual precipitation (Departemen Perhubungan, undated; Fig. 4a). Further inland, rainfall recordings from Kota Bangun (100 km from the coast; Fig. 4b) and Melak (150 km from the coast; Fig. 4c) still show critical deficits. The precipitation did not fall below the critical margin of 100 mm in Long Sungai Barang, Bulungan (300 km inland; Fig. 4d). These recordings support Brünig's (1969) observation from Sarawak, that drought stress occurs more frequently in coastal areas than in the hinterland.

Rainfall conditions in northern Borneo during the 1982–1983 drought were similar. Five stations in Sabah recorded an average precipitation decrease of 60% (Woods 1987). No significant drought and no fires were observed in Sarawak at that time (Marsh personal commun.).

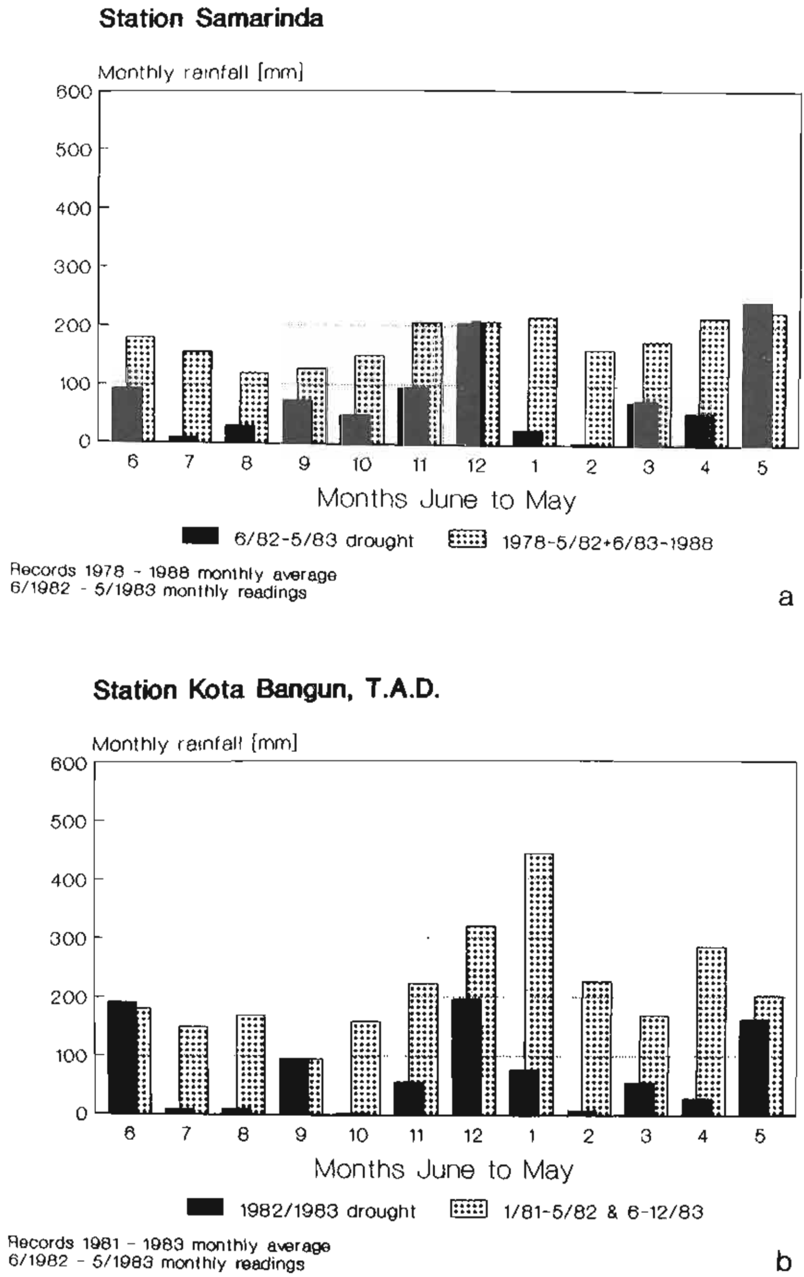
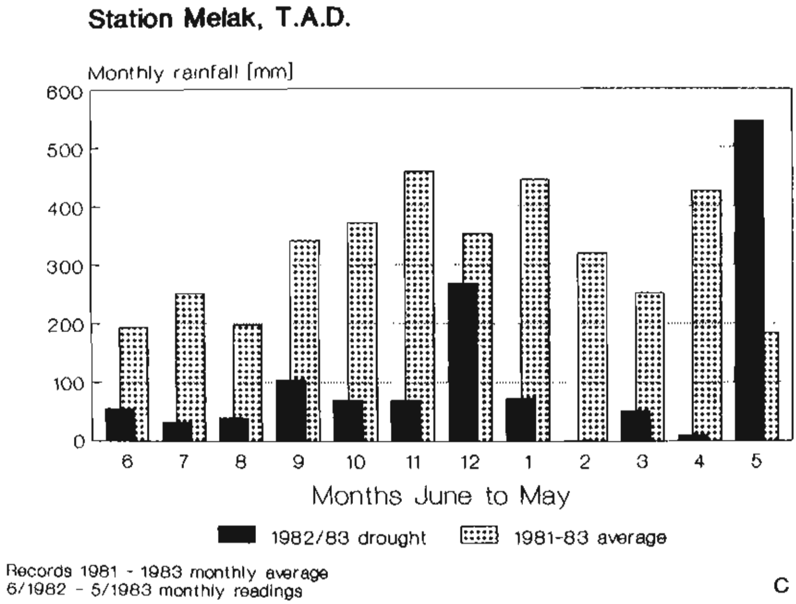
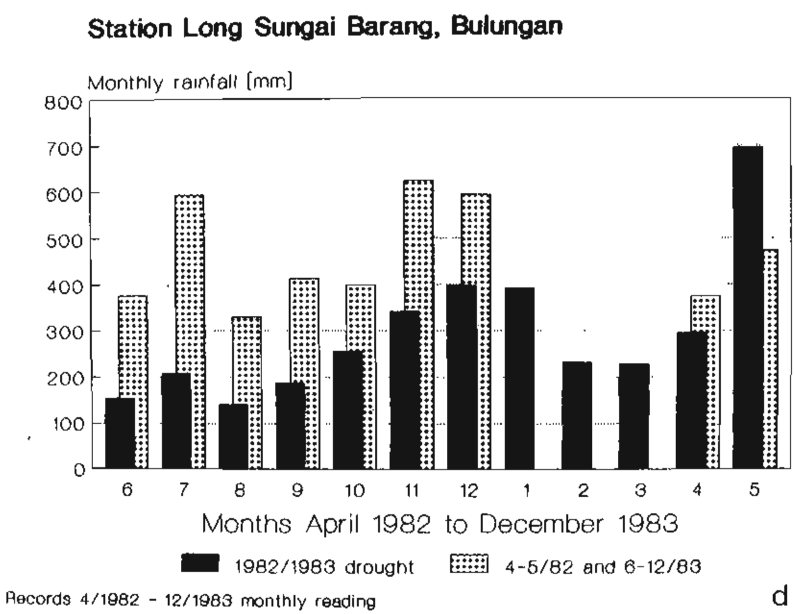


Fig. 4a-d. Monthly rainfall in East Kalimantan during the 1982–83 drought, compared with average years (Fig. 4c,d see page 18)


Station Melak, T.A.D.
Monthly rainfall [mm]
600
500
400
300
200
100
0
6 7 8 9 10 11 12 1 2 3 4 5
Months June to May
1982/83 drought
1981-83 average
Records 1981 - 1983 monthly average
6/1982 - 5/1983 monthly readings
c


Station Long Sungai Barang, Bulungan
Monthly rainfall [mm]
800
700
600
500
400
300
200
100
0
6 7 8 9 10 11 12 1 2 3 4 5
Months April 1982 to December 1983
1982/1983 drought
4-5/82 and 6-12/83
Records 4/1982 - 12/1983 monthly reading
d

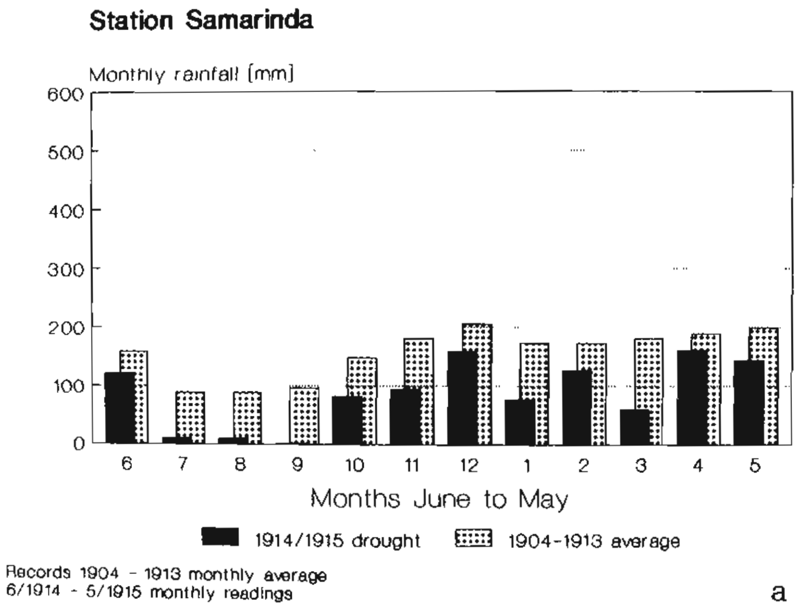
Berlage (1957) found that between 1830 and 1953, about 93% of all droughts in Indonesia occurred during an ENSO event. In a systematic evaluation of precipitation data since 1940 (Leighton 1984), most of the 11 droughts recorded in 1941/42, 1951, 1957, 1961, 1963, 1969, 1972, 1976, 1979/80, 1982/83, and 1987 accompanied an ENSO event. The worst droughts during that period were in 1941/1942, 1972, and 1982–1983, while the 1961 drought occurred independently of an ENSO event, and the 1965 ENSO did not cause drought in Indonesia.

2.3.2 Predecessors

The first written information about the impact of an extreme drought in East Kalimantan is given by Bock (1881). This Danish zoologist traveled through the lowlands of the Kutai district of East Kalimantan in 1878 and reported drought and famine which had occurred in the year before his visit. He recorded that about one third of the tree population in the forests around Muara Kaman in the Middle Mahakam area had died due to the drought. More recent observations in various peat swamp forests of the Middle Mahakam Area of East Kalimantan confirm that significant disturbances of this ecosystem must have occurred around 80–100 years B.P. (Weinland 1983). The rainfall records of Jakarta (Java) 1877/78 explain these observations: between May 1877 and February 1878, rainfall in Jakarta was reduced by two thirds; a second severe precipitation deficit followed in the period July to December 1878 (Kiladis and Diaz 1986).

Bock did not report any forest fires. Nevertheless, the authors looked for evidence of forest fires in East Kalimantan and were informed by Amansyah (personal commun.) that, according to his grandmother, fires had occurred in the area of Muara Lawa on the Kedang Pahu river during the period of investigation. Also Grabowsky (1890) mentions a forest fire which had occurred some years before his visit in 1881–1884, on two mountains, Batu Sawar and Batu Puno, in the central part of South Kalimantan, about 70 km inland. These two mountains, according to Grabowsky, had been totally deforested by the fire, and the approximate date of the fire coincides with Carl Bock's remarks on the severe drought in East Kalimantan.

In 1914–15, forest fires were again reported from Borneo. Published records were found for Sabah, where an area of 80,000 ha of rain forest and its superficial peat soil layer were destroyed by fire after an exceptionally dry period (Cockburn 1974). This area now forms the Sook Plain grassland of Sabah. Amansyah (personal commun.) also reported fires, during the same period, in the Muara Lawa area. Endert (1927) confirms these reports in his reference to fires which had occurred about 10 years before his visit to East Kalimantan in 1925. According to the farmer Rajab (personal commun.) of Modang (Pasir District of East Kalimantan) serious fires swept through his farmland from the coast, in the same year, before proceeding inland. Rainfall records from Balikpapan (Fig. 5a), and Samarinda (Fig. 5b) close to the east coast of East



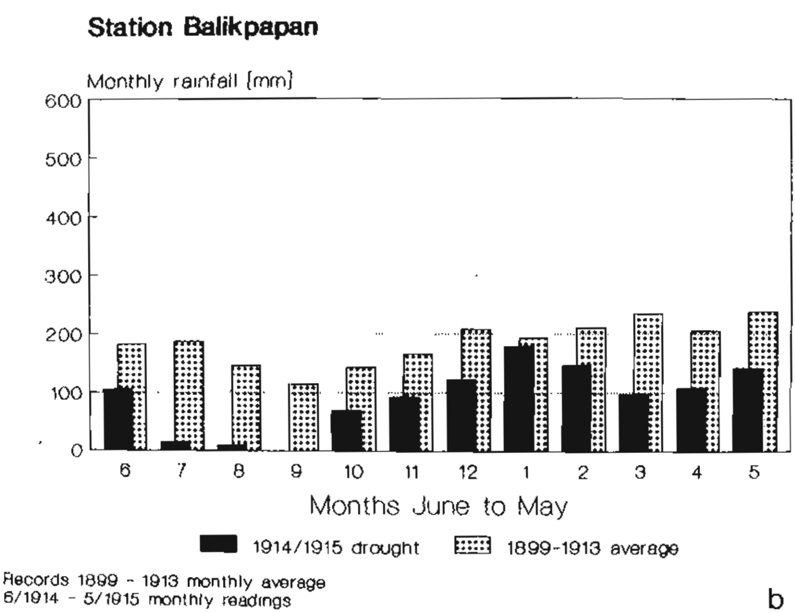
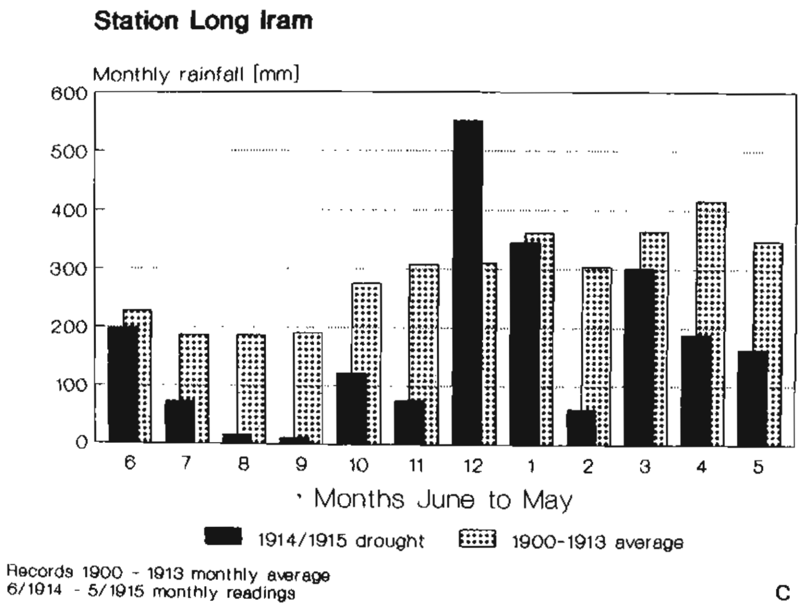


Fig. 5. Monthly rainfall in East Kalimantan during the 1914–15 drought, compared with average years



Kalimantan, and from Long Iram, about 180 km inland (Fig. 5c), prove a severe drought in 1914–1915.

Severe forest fires in Brunei following a drought of 6 weeks in 1958 were observed by Brünig (1971). Smaller fires in lowland dipterocarp forests and in *Dacrydium elatum* forests were recorded for 1969 and 1970 in Sabah and Brunei by Fox (1976, cited by Woods 1987). Brünig (1971) has also described an exceptional drought at this time, but no fires.

2.3.3 The Wildfire Scenario in 1982-83

The wildfire scenario in Borneo in 1982/83 was set by the extensive drought and by numerous slash-and-burn land-clearing activities from which the fires ran out of control. The extent and the immediately visible impact of these fires have been described by several authors and teams (Wirawan and Hadiyono 1983; Johnson 1984; Leighton 1984; Lennertz and Panzer 1984; Malingreau et al. 1985; Woods 1987).

It is assumed that the overall land area of Borneo affected by fires exceeded 5×10^6 ha. In East Kalimantan alone, a total of 3.5×10^6 ha were affected by drought and fire. Of the total area, 0.8×10^6 ha was primary rain forest, 1.4×10^6 ha logged-over forest, 0.75×10^6 ha secondary forest (mainly in the vicinity of settlement areas), and 0.55×10^6 ha peat swamp biome (Lennertz and Panzer 1984).

One of the first aerial and ground surveys of the fire damage was carried out in a totally burned area in the Kutai National Park, west of heavily logged and farmed areas (Leighton 1984). It was found that fire damage was higher in the secondary forest than in primary forest, although the degree of damage varied greatly. The fires had swept twice through the ITO timber concession southwest of the Kutai National Park, the first causing defoliation of many trees and lianas; the second completely burning this accumulated litter. No surviving trees were observed in areas which had burned twice. It can be assumed that this also occurred in the Porodisa timber concession, north of the Park, and in the Sylva Duta timber concession, west of the Park.

In his 1983 ground survey of the northern part of the National Park near the Mentoko research station, Leighton (1984) found that the primary forest had been badly damaged. He was unable to report any unburned primary forest on hills, ridges, or slopes which could have served as a control plot to distinguish damage by drought or fire. He inferred that the drier soils of the hillside and hilltop areas, and also their shallowness (as argued by Whitmore 1984), could be an important factor determining the water deficit during prolonged drought seasons.

Narrow, 5–20-m-wide belts of unburned primary forest flanking streams were also observed, but these account for only 5–10% of the total area. In the burned areas, 99% of the trees below 4 cm DBH had died, although about 10% were resprouting from the ground. In the diameter 20–25 cm DBH class, 50% had died, with 20–35% of trees above cm DBH. Among the larger trees which had died, only Bornean ironwood (*Eusideroxylon zwageri* T & B) was observed resprouting from the ground. Lianas and strangling figs had been virtually eliminated from burned parts of the forest, apparently being particularly sensitive to drought.

Wirawan (1983) made a ground survey in a less damaged area in the southern part of the National Park. Fire extended there about 30–40 km from the coast, but was able to sweep further inland wherever previous logging activities had produced suitable fuels, particularly in the surroundings of logging roads. The healthiest areas were in the southwest of the Park further inland. Dead stems of emergent trees sticking out of the canopy have apparently died from drought, not from fire. Canopy and subcanopy had regreened in these areas, while in burned forests, the subcanopy was usually defoliated due to heat rising from the fire.

Wirawan's (1983) unpublished report shows that in unlogged, unburned dipterocarp forest the effect of the long drought period was more severe on larger trees than on smaller trees: 70% of the trees above 60 cm DBH were dead, while only 40% in the DBH class of 30 to 60 cm, and 20–25% in the class below 30% respectively. Drought has produced a diameter distribution similar to that in an unburned logged-over dipterocarp forest in that area.

Only 15% of the trees in all diameter classes had died in unlogged, unburned ironwood forest. Dead individuals were mainly *Shorea* species and others, but ironwood was able to survive even on ridges. In unlogged, but burned ironwood forest, damage occurred particularly on smaller individuals: 75% of the trees below 5 cm DBH and 50% of the trees from 5 to 10 cm DBH were dead, compared with only 8–15% of the trees above 10 cm DBH. Many of the latter, however, sustained bark damage and may die in the near future.

Fire intensity in previously logged areas was directly related to the intensity of logging. The fires were severe but did not completely destroy moderately logged stands where, after the fire, a few trees with green foliage could still be observed, although spaced and scattered.

In heavily logged forest areas, where remaining trees are widely spaced, shrub had formed a thick ground cover, providing an excellent biomass source for the fires after the extensive drought. Here the fuel consumption was more complete.

Lennertz and Panzer (1984) made several ground surveys in seven timber concessions throughout the burned area, confirming the findings of Wirawan (1983) and Leighton (1984) on a larger-area scale. The damage was generally heavier in logged-over than in primary forests. On an average, diameter classes between 35 and 65 cm DBH were least damaged, while smaller trees were severely affected. Damage to trees above 65 cm DBH could also be due to drought.

Areas attributed to three damage classes:

1. Up to 10% of the tree crowns dry, indicating drought but no fire.
2. 10–50% of canopy and undergrowth trees dead.
3. Over 50% dead trees, indicating severe fires in logged-over forests.

About 75% of the total area affected by fires had to be classified as severely damaged (class 3). The damage degree generally decreased towards the west of the area.

Damage was total in most secondary forest previously used for shifting cultivation, and was also severe – with the area looking like a mikado game from the air – in the burned peat swamp forests. Only areas on shallow peat layers were less affected.

2.4 Forest Regeneration After the 1982–83 Fires

The regeneration of damaged forests after the fires was observed by several research teams between 1983 and 1987, but to date there has been no conclusive study which includes all occurring forest types, damages related to site, and previous utilization of the respective forests. For this preliminary evaluation, we distinguish the following forest types:

– Primary forest: Mainly in the Kutai National Park around 100 km north of Samarinda, and in forest reserves between Samarinda and Balikpapan (Fig. 6). Primary forest was mainly affected in the driest parts of the Province along the coastline.

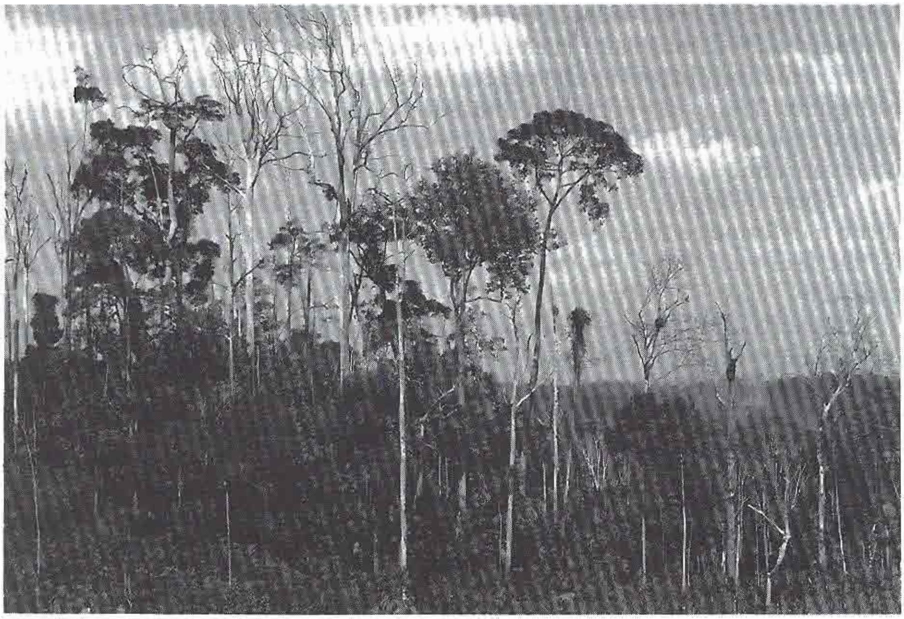


Fig. 6. Recovery process of primary dipterocarp lowland rain forest in Bukit Soeharto National Park, 5 years after being affected by drought and fire in 1982

- Logged-over forest: Besides the distance from the coast, the intensity of previous logging and the time since logging are mainly decisive in the degree of damage.
- Secondary forest (after disturbance by man, mainly through shifting cultivation): These areas were, in most cases, totally deprived of any remaining vegetation and had begun their regeneration process from zero.
- Swamp and peat swamp forests: Wherever this type was affected by fires, the damage was total, because in most cases the structure of the organic underground broke down.

The two latter forest types are not considered in this overview. Damage by fires in secondary forests is similar to the development of areas after shifting cultivation, and relevant information can be found in the respective literature (Riswan and Kartawinata 1989, Goldammer 1991, see also synoptic overview in Peters and Neuenschwander 1988). Swamp and peat swamp forests were destroyed to such a degree that the area is lost for forestry for an unforeseeable time, and recovery processes leading to forest could not be observed.

2.4.1 The Regeneration Process

Three to 4 months after the fire, a carpet of seedlings was already covering a large part of the forest floor, dominated by pioneers, particularly *Macaranga* species and grasses. Seeds, especially those of *Macaranga* species, as naturally occurring pioneers, are assumed to originate from the site's seed bank and not from outside dispersal (Leighton 1984). Dipterocarp seedlings were still absent in August 1983 (Suyono 1984), but grew after a considerable flowering of many dipterocarp species, in early 1984.

2.4.1.1 Primary Forest

A direct observation of succession after fire was carried out in a protected forest near Samarinda. Sixty percent of the area of a primary forest plot originally established for the UNESCO-MAB project and measured for the first time in 1976 (Riswan 1976, 1982) had burned, in 1983. The area was remeasured in 1983 (Riswan and Yusuf 1986). In 1983, a burnt part (0.6 ha) of this primary forest plot was measured by Suyono (1984); this plot was again measured by Boer et al. (1988a,b) in 1987. Although not consistent in size, the plots are compared in Table 1. Results of the 1988 study indicate fast recovery of slightly damaged primary forests 4.5 years after the fire. The recovery process has already increased both the number of trees > 10 cm DBH, and the basal area, by approximately 10% – halfway back to the situation before the fire. Dipterocarpaceae and Euphorbiaceae are the leading families in the diameter classes above 10 cm DBH, while *Eusideroxylon zwageri* is the single most important species.

Some of the primary forest in the Kutai National Park, particularly in areas within 40 km of the coastline, was far more badly damaged than observed in

Table 1. Damage and recovery after fire of primary forest in Lempake, Samarinda. Sources: Riswan and Yusuf (1986; data of 1976, 3. and 12.1983); Suyono (1984; data of 8.1983); and Boer et al. (1988a,b; data of 11.1987)

Date	Remarks	No. of sp.	No. of trees/ha	Basal area/ha (m^2)
12.1976		209	445	33.7
3.1983	Natural death		63	
3.1983	New in class > 10 cm DBH	42	32	
12.1983	Burnt trees (whole plots)		79	
	(weighed[a])		132	
12.1983	1.6-ha plot	199	335	26.5
8.1983	0.6-ha plot	112	403	26.5
11.1987	0.6-ha plot	116	430	29.7

[a] Assuming that the whole plots had burned; in fact only 60% of the primary forest were damaged by fire.

areas around, and south of Samarinda. The area of the National Park and north of it receives precipitation, even in normal dry seasons, at the lower limit of the 100 mm/month margin determining the occurrence of tropical rain forest. Wherever fires were strong enough to erase the upper canopy, both number and composition of species changed drastically, and no considerable recovery of primary forest communities could be seen 4.5 years later: Miyagi et al. (1988) and Tagawa et al. (1988), both based on field research in 1986–87, distinguish several shrub types in burnt primary and logged-over forests, all but one with only few dipterocarps, but dominated by site-specific pioneers. The scarcity of regenerating dipterocarps as the leading tree family in some undisturbed lowland forest communities in East Kalimantan raises questions as to what type of forest will develop in large heavily damaged areas in this region.

2.4.1.2 Logged-Over Forest

About 1.5 years after the fire, several species, including dipterocarps, had flowered, possibly also induced by stress due to the opening of the canopy and the restricted crowns of the partly damaged trees.

Consequently, in slightly logged and burned forest areas where dipterocarps still occur in the upper canopy, regeneration was often dominated by dipterocarp species (Noor 1985) able to establish easily under the moderate shelter of the upper canopy which usually covers more than 75% of the surface area. In these stands, the dipterocarps faced less competition from vigorous pioneer species. Among both saplings and seedlings, dipterocarps are considerably represented with 21 and 42% respectively (Hatami 1987), indicating that this habitat may recover fairly rapidly. Among the seedlings observed in 1986, pioneer species play only a minor role (7% of individuals).

In moderately damaged areas, where some dipterocarp mother trees had survived, dipterocarp seedlings of several species were observed in considerable number (Boer 1984). In these areas, dipterocarps still hold the same rank among the trees, 5 years after the fires (Boer and Matius 1988), but the regeneration of dipterocarps as the leading commercial species group is marginal, indicating that the first regeneration after the fires did not survive. In some areas, a fire-resistant palm, *Borassodendron borneensis*, is the leading element of the pole class, while saplings and seedlings are dominated by *Macaranga* species and other pioneer and shrub species of minor value. Crown closure is still in the range of only 50%.

Heavily damaged areas without surviving seed trees of primary forest species undergo the same recovery processes as the areas left behind by shifting cultivators. In areas close to settlements, where abandoned land is a persistent *Imperata cylindrica* seed source, many damaged areas were invaded by this weed and are practically lost for forestry (see also Seavoy 1975).

It is still impossible to quantify the surface attributed to the referred classes of damage and the related recovery processes. A more detailed study is presently being carried out by the International Tropical Timber Organization (ITTO).

Based on ground survey inventories and followed by the interpretation of recent aerial imagery, this study should provide answers to many currently open questions.

2.5 Conclusions

What was new about the 1982–83 drought and fires in Borneo was not the fact of their occurrence, but the extent. It is the large size of contiguous burnt areas and the high quantities of available fuel, caused by human interference with the tropical rain forest that has made the damage so bad. As demonstrated above, and supported by numerous observations in selectively logged forests, dipterocarps are able to germinate and to grow in disturbed sites. Their frequent occurrence in groups indicates the gap-opportunism of many dipterocarp species. But dipterocarp seeds, although winged, do not fly farther than about 100 m, will not keep longer than about 20 days, and symbiotic ecto-mycorrhizal fungi are no longer present once the dipterocarps have vanished from an area. If this area exceeds a certain size, it may take centuries for dipterocarps to migrate back to a former habitat.

A surprising response to fire is shown by Bornean ironwood (*Eusideroxylon zwageri*). In all surveys, ironwood trees play an important role in species composition after fire. The resprouting capability of old trees and stumps after fire is high, as is fruiting of survivors. Producing a timber of extreme density and a specific weight above that of water, ironwood is supposed to grow relatively slowly, also because it is usually a tree of the second canopy layer. Several authors refer to ironwood as the most drought- and fire-resistant species in the lowland forests of Borneo (Wirawan 1983; Leighton 1984).

Why, then, does ironwood occur so frequently and so often dominate the lowland forests of East Kalimantan? Although it is a species of relatively slow growth in the understory of the forest, ironwood has been successfully cultivated in pure stands in South Kalimantan. Could ironwood serve as an indicator of a long history of episodic drought and fires in Kalimantan? If this is so, why are dipterocarps still a leading group of species in the lowlands although they are so susceptible to drought and fire? Must they always be attributed to the "climax" phases of a forest, or are there species acting as primers, as gap and even damage opportunists? Several dipterocarp species, especially *Shorea lamellata*, were often observed growing wild on roadsides on barren soil, where no other trees had yet been able to establish. Does the clumped occurrence of many dipterocarps further indicate their opportunistic regeneration after disturbances?

There are more questions. The recent discovery of prehistoric fires in today's humid tropics of Amazonia and Borneo highlights the need to reconsider the theory of a never-disturbed and ageless climax of the tropical rain forest. In its evolution the rain forest has obviously survived long-term and short-term climatic variability, fires, storms, and flooding (van der Hammen 1974; Absy 1982; Colinvaux 1989). The role of disturbance in rain forest evolution, however, is not yet clear. One of the recent hypotheses, the controversially debated forest refuges theory, postulates that evolutionary diversification took place in isolated areas. Among those who support this theory there is still debate as to whether, during the last glaciation, the wetter uplands had become refuges for isolated evolution of rain forest species, or rain forest survived and diversified in those lowlands which were warmer but nonarid (Haffer 1969; Beven et al. 1984; Lewin 1984; Whitmore 1984; Kam-biu Liu and Colinvaux 1985; Connor 1986; Salo 1987; Colinvaux 1989; Goldammer 1991).

The mosaic of recent findings on climatic variability and forest fires in East. Kalimantan does raise more questions but at least may provide some answers. The highest impact of drought and fires during the 1982–1983 ENSO was largely restricted to the eastern lowlands and east of today's 3–3500 mm isohyet. This land area, at the steep eastern edge of the Sunda shelf, had already been a coastal ecotone when the Sunda shelf became dry during the last glaciation. Borneo's inland mountains at that time may have been more continental but still received more rainfall than the seasonal lowlands. A pronounced moisture gradient between these ecotones must have resulted in the development of a wet rain forest refuge in the highlands, eventually somewhere west of today's 3–3500 mm isohyet. The vegetation surviving on the lowland at that time had to cope with frequent droughts and fires.

Most of this former lowland vegetation of the Sunda shelf was then inundated and lost during the Pleistocene-Holocene transition. The remaining lowlands are presently covered by a highly diverse moist rain forest biome, although repeatedly disturbed by droughts and fire.

Is the lowland rain forest the result of a rapid expansion from the wet highland habitat? Or can diversity of the lowland rain forest be explained by frequent disturbances (Connell 1978)? Forest die-back due to drought stress and fire provides great evolutionary possibilities because it creates gaps and speeds up regeneration dynamics. It also prevents take-over by a few dominant species which would lead to diversity-poor forest communities.

The basis for this evolutionary hypothesis is still fragmented and inconclusive. However, as has now been demonstrated, lowland dipterocarp rain forest may recover from drought stress and fire if these events are not excessive and not associated with human interference. Further, its corollary highlights the opportunity selective silviculture methods may offer towards sustained ecosystem utilization and management.

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