BLUMEA 31 (1986) 341–371

THE INSTABILITY OF THE TROPICAL ECOSYSTEM IN NEW GUINEA

R. J. JOHNS

L. J. Brass Memorial Herbarium, P. N. G. University of Technology, Lae, Papua New Guinea

INTRODUCTION

The tropical ecosystem has been considered by many authorities as a stable vegetation type that, in some areas, has 'existed uninterruptedly since a very remote geological time' (Richards, 1952). The long term stability of rainforest ecosystems was first questioned when studies showed that there was a marked contraction of rainforest areas in the tropics during Pleistocene times (Flenley, 1979). Within New Guinea two major effects are reported: altitudinal fluctuation of the major vegetation zones at higher altitudes, as described by Flenley (1972), Hope (1976), Powell (1970), and Walker (1970); and a decrease in precipitation. As a result of the lower rainfall during the Pleistocene era (17,000–14,000 yrs BP) extensive areas of New Guinea were characterised by a very dry savanna type climate (Nix & Kalma, 1972). This is still reflected in the distribution of savanna elements in the present vegetation, in both lowland and lower montane areas.

However, extensive disturbances are by no means restricted to the Pleistocene times. Studies in New Guinea show that the environment has been recently subjected to major disturbances caused by natural disasters. These phenomena are often easily plotted from aerial photographs and by using remote sensing techniques. An understanding of environmental instability is important, not only for the interpretation of the structure and floristics of the extant vegetation, but is also of major importance in the management of the tropical environment in New Guinea.

During historical times natural disasters have resulted in the destruction of extensive areas of vegetation in New Guinea. Where isolated landslides, localised cyclonic winds or lightning strikes occur, small areas of vegetation can be destroyed. River meanders in the flat alluvial plains cause intricate patterns in the vegetation. While the areas destroyed are in themselves small, in total the areas of disturbance can be large. Extensive tracts of forest can be destroyed where areas are subject to earthquakes, which are often associated with a dense pattern of landslides; rainforest fires are common following periods of drought; volcanic activity also has caused the destruction of vegetation on both a local and regional scale. Subsidence and uplift of

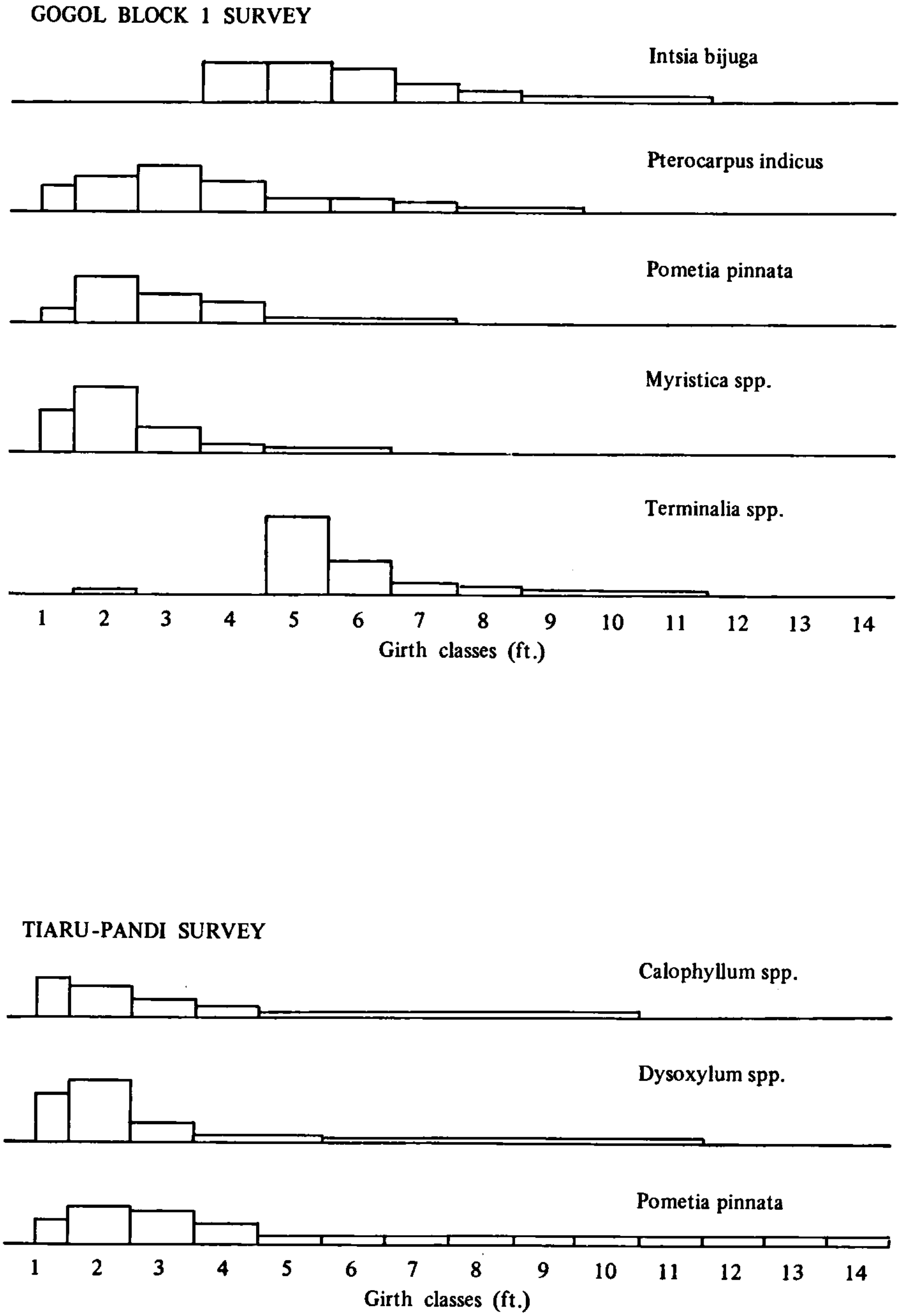


Fig. 1. Size-class distribution of selected New Guinea forest tree species.

areas has had a marked effect on the floristics of some coastal forests, particularly in the inland occurrence of mangrove species (Johns, 1985). In areas of Southeastern Papua cyclones have flattened extensive areas of rainforest. At higher altitudes, drought and frosts, usually followed by fires, are the cause of the development of many areas of grassland. White (1976) published a paper on the importance of natural phenomena on the vegetation but much of the historical data from New Guinea was not discussed. Unless ecologists are aware of the frequency of natural disasters, informed interpretation of the structure and floristics of the rainforest communities is not possible. Historical factors receive little emphasis in most recent surveys of the rainforests of Southeast Asia.

The earliest reports of destructive phenomena are to be found in the Annual Reports of German and British New Guinea. These, with the reports of early missionaries and scientific workers, provide interesting data. The earliest appreciation of the instability of the physical environment in the tropics is found in the literature of agricultural geographers, geomorphologists, anthropologists, climatologists and foresters (White, 1976). Unfortunately this literature has, as yet, had little impact on the rainforest ecologist. Whitmore (1974), in the most recent survey of the rainforests of Southeast Asia, gives historical factors little attention.

The existence of young disturbed forests, dominated by one or a few species, is characteristic of many areas in New Guinea. Data extracted from the files of the Office of Forests suggests that the present forest dominants, *Anisoptera, Hopea, Intsia, Pterocarpus, Pometia, Albizia*, etc., are not regenerating in the subcanopy of the forests (fig. 1). While many of these species do successfully regenerate in rainforest gaps, their domination of the rainforest canopy suggests that extensive historical disturbance occurred allowing widespread regeneration of these 'secondary' species. That these secondary species are not regenerating and dominating the forest at present negates the argument that it merely reflects gap regeneration.

The impact of historical instability on the vegetation of New Guinea is partly a result of the geological history of the region (Barlow, 1981). With the exception of the areas to the south of the Fly River, the New Guinea mainland has been profoundly affected by the recent movements of the Australian Plate and its collision with the Indonesian and Pacific Plates. Rates of uplift have been rapid. In the last 10,000 years (since the last glacial advance) the Sarawagged Mountains have been uplifted some 1,000 metres (Costin, unpubl.). This rapid rate of uplift, a result of the tectonic instability of the region, is reflected in the large number of earthquakes and volcanoes in the region. The volcanic activity is concentrated in three zones (fig. 2): the Highlands of New Guinea, which was active particularly in the Pleistocene times up until some 50,000 years ago; the group of volcanoes in Eastern Papua including the mountains Lamington and Victory; and the line of volcanoes along the north coast of New Guinea from Manam to Ritter, continuing along the north coast of New Britain and forming the central mountain chain of Bougainville. Whilst the most pronounced effects of these volcanoes has been localised, at times over the last five hundred years there have been ash showers that have affected the vegetation over hundreds of square kilometres.

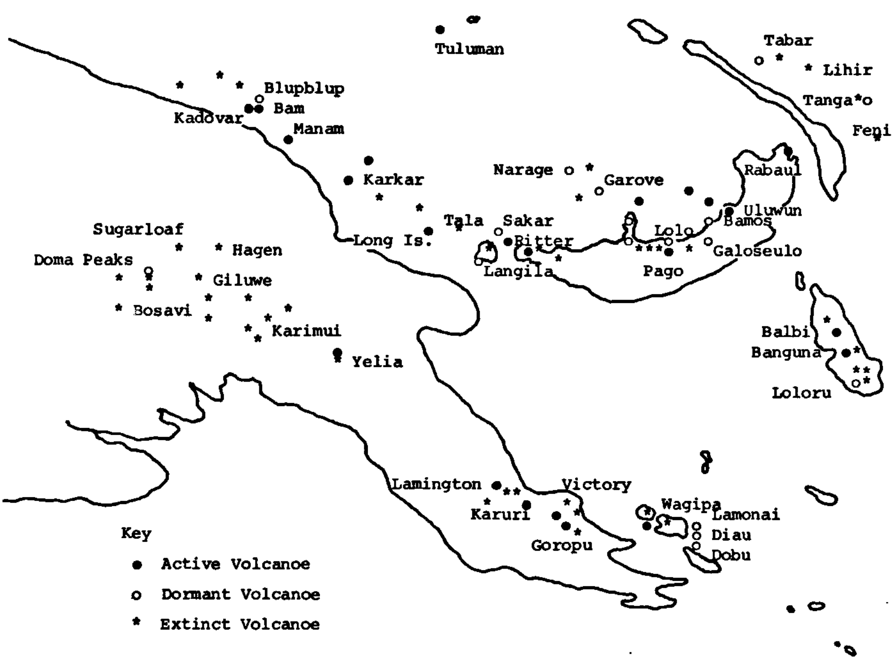


Fig. 2. The distribution of Quaternary volcanics. Active volcanoes include those with possible recent eruptions.

NATURAL PHENOMENA WHICH HAVE AFFECTED THE VEGETATION

In the following sections the major phenomena which have affected the vegetation of New Guinea are discussed.

Landslides

Landslides occur throughout New Guinea but are particularly common in areas of high local relief. They occur under conditions where the soil strength is exceeded and, as a result, the overlying vegetation and soils move down a shear plane. Three major contributing factors cause landslides: excessive biomass, excessive soil water an and earthquakes. Each will be discussed separately.

a) Excessive biomass often builds up on forested slopes and this can result in a dense pattern of landslides at various stages of regeneration. These can be seen on various slopes in New Guinea such as Blue Point (Wau) and at Lake Louise (West Sepik) (plate 1).

b) Intense rainstorms concentrated in small catchments can cause dense patterns of landslides. These are pronounced in many areas throughout New Guinea. The valley area around Mumeng shows many of the types of landslides and mass movement phenomena resulting from storm action. Landslides can be particularly common on mudstone areas (plate 2) but are also common on sandstone (plate 3) and most other rock types.

c) The importance of earthquakes as triggering actions for extensive landslides was first noted by Miklaucho-Maclay, who in his diary in July 1876 recorded the following statement:

> "I received some very interesting information from the natives about the earthquake that occurred during my absence. The changes in the appearance of the summits of the Mana-boro-boro (Finisterre Mountains) surprised me on my return to the coast. At my departure (in December 1872) the vegetation covered even the peaks of the range, but now in many places the summits and steep slopes were completely bare. The natives told me that during my absence there had been several earthquakes on the coast and in the mountains ..... abnormal high waves followed the earthquakes tearing out the trees ..... near the beach."
>
> (Miklaucho-Maclay: New Guinea Diaries 1871–1883, pp. 236–237)

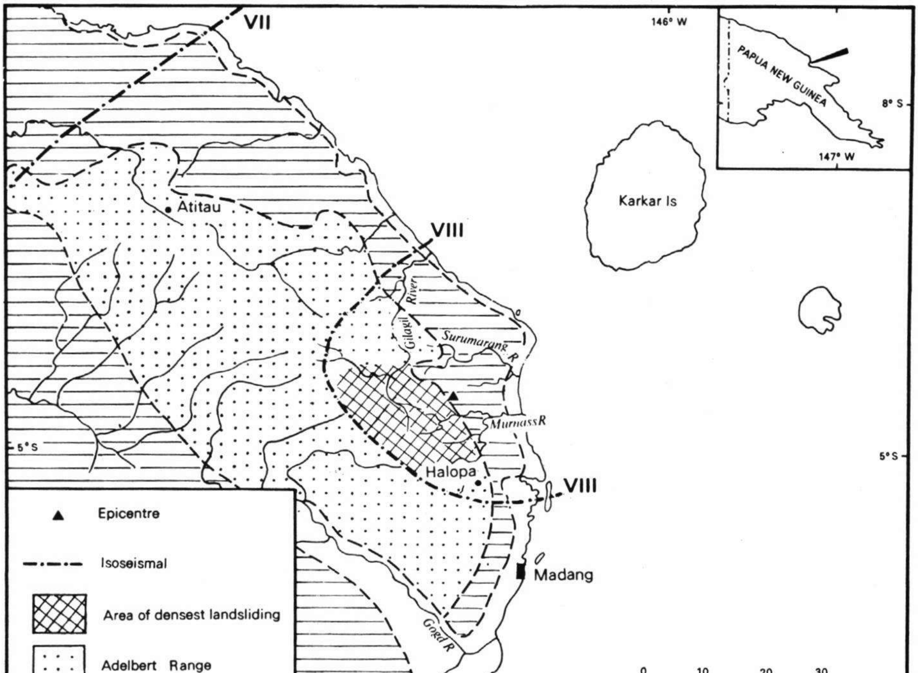


Fig. 3. Location of earthquake epicentre and the areas of densest landsliding. Adelbert Range. Source: Pain & Bowler (1973).

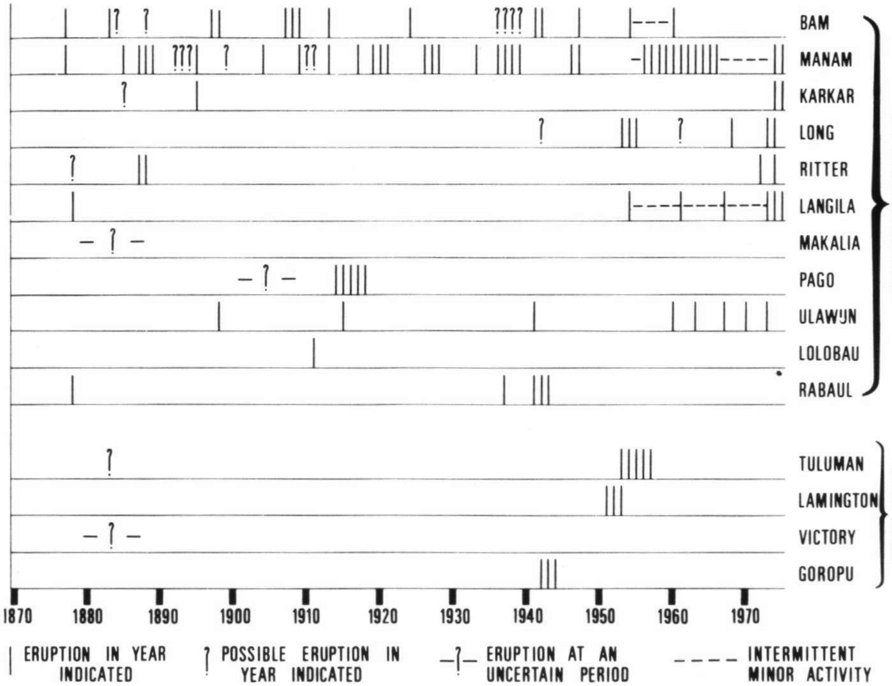


Fig. 4. Eruptive histories of some Papua New Guinea volcanoes, 1870–1975. Source: Cook et al. (1976).

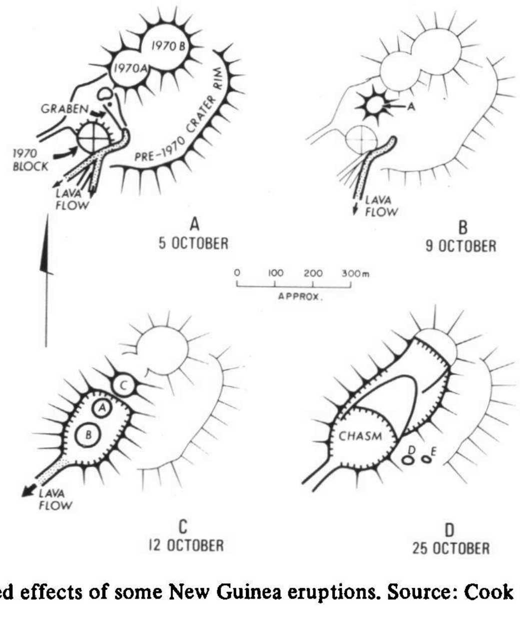


Fig. 5. Localised effects of some New Guinea eruptions. Source: Cook et al. (1976).

Simonett (1967) conducted aerial photo interpretation of the parts of the Torricelli Ranges in which intensive landslides occurred during the earthquakes of 1935 (Marshall, 1937) and the earlier earthquake of 1918. He calculated a denudation rate of 7.4 to 12 cm for sedimentary rocks in areas of intensive landslides following the 1935 earthquake. It is interesting to note that he was still able to locate landslides from both the 1918 and 1935 earthquakes on aerial photographs flown in 1965.

In November 1972 an earthquake of force 8.2, in the Madang area, resulted in an intensive pattern of landslides with the removal of up to 60 percent of the vegetation and soils from some catchments. From aerial photograph interpretation (plate 5, with drawn pattern) over an area of some 240 square kilometres, the average loss of vegetation was 25 percent. The denudation rate of 11.5 cm of soil was calculated by Pain & Bowler (1973). Pain and Bowler calculated that as a very conservative estimate an earthquake of the intensity of the Madang earthquake occurs every 200 years: there is a probability of 63 percent that an earthquake of this intensity occurs every 100 years (fig. 3; plate 6). Recently (May, 1985) intensive landslides have occurred in the Biella region of West New Britain, due to an earthquake of 7.4 intensity.

Volcanic activity

A series of volcanoes occur throughout New Guinea (fig. 2). Many have erupted in the last 300 years (fig. 4), sometimes as a small eruption with only localised effects (fig. 5), but at other times the eruptions have had marked effects over hundreds of square miles of forest.

The best documented eruption is that of Long Island. The eruption occurred between 1800 and 1840, with an average C^{14} age of 1814 (Oldfield et al., 1978). It was accompanied by the violent eruption of large quantities of volcanic ash (fig. 6). In a recent study of the ash deposits in the Central Highlands of New Guinea (Blong, 1975) it has been shown that ash from this eruption covered extensive areas of New Guinea. A series of legends from the Gogol Valley refer to a period when the sky was dark for three days and famine occurred throughout the valley because of the lack of food (Blong, 1982). It is difficult, however, to assess the effects of ash showers on the vegetation.

There is extensive documentation on the recent volcanic history of New Guinea, but few discussions centre on the effect of such eruptions on the vegetation. During 5 days in May and June 1937 Vulcan in the Rabaul Caldera erupted some 300,000,000 cubic metres of ejecta. The eruption of Ritter, an uninhabited remnant of a formerly much larger island, destroyed in 1888, caused widespread destruction of the local vegetation on Umboi and West New Britain. The large scale tsunamis which accompanied the event destroyed coastal vegetation at least as far away as Madang. Beds of volcanic ejecta, ash and lapilli, make up the parent materials of most of the soils along the volcanic zones of New Guinea. Taylor (1957) has discussed the patterns of vegetation succession on volcanoes in Papua.

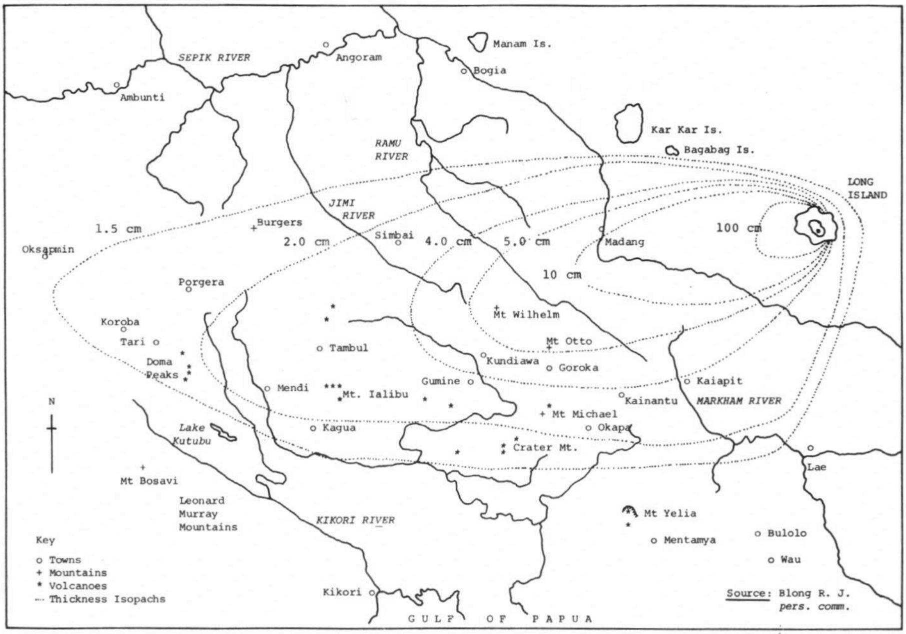


Fig. 6. Thickness isopachs and theoretical distribution of the Tibito Tephra Long Island.

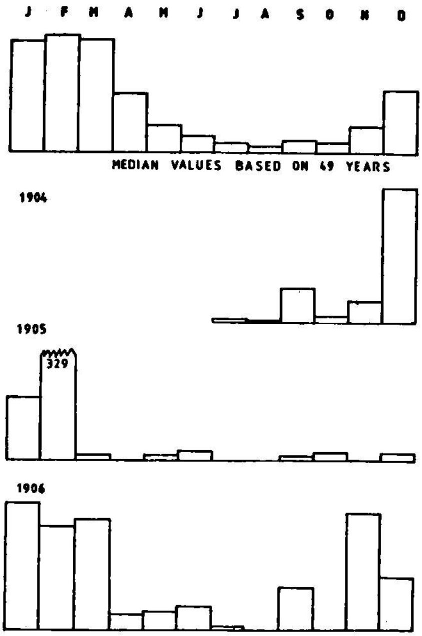


Fig. 7. The 1906–1907 drought at Port Moresby.

Drought and Fires

Because of the paucity and unreliability of rainfall data, it is difficult to present a clear picture of the history of droughts in New Guinea. Prior to 1940 there were no rainfall stations established in the Highlands of New Guinea; all stations were at low altitudes and most were coastal. Despite the lack of rainfall data, records of droughts are widely reported in the literature.

The first severe drought, for which limited information could be found, was in 1885. During this time, as with the latter severe drought in 1914, it was accompanied by extensive forest fires. Klein (1935) reported that coastal shipping was stopped for days during this time along the northern coast of New Guinea. Visibility was reduced at sea to less than 100 m by the dense 'smog' resulting from the forest fires. It is interesting to note that the Gogol River is reported to have been dry for a considerable period of time from 1914 (possibly up to three years).

From July 1895 to June 1896 there was a very dry period in the western parts of Papua. In the preceding 12 monthly period, Daru received 291.3 cm of rain compared with 173.73 cm during the drought year. A reduction in the rainfall at Port Moresby was also noted, down from 100.2 cm to 80.37 cm. The Rev. Copeland King also reported a drought at Dogura Station during 1896.

In the annual reports from British New Guinea (1906–1907) they report an exceptionally dry year at Port Moresby (fig. 7). It was noted that in the Eastern District there was a disastrously dry year. Extensive forest fires apparently occurred.

Pratt (1906, p. 65), who left England in 1901, reported extensive droughts from the Port Moresby area:

> "As we drew near the shore we noted unmistakable evidence of the drought which had set in and lasted for nine months. The vegetation was entirely brown and burnt up. The drought, it was said, extended as far west as the Fly River ..... Even at an altitude of 2000 m (as I found afterwards), epiphytes were falling off the trees."

At Dinawa (opposite Yule Island), Pratt reported some months later that the drought showed no signs of breaking. He reported extensive destruction of the forest areas at present covered with mixed tropical rainforest:

> "..... we could see, in the lower grounds, great forest fires, which consumed the undergrowth throughout large tracts of country, miles and miles being black and burnt up."

M. Ch. Kokkelink (undated) includes the following report from Manokwari:

> "1939 was also in other respects a year not to be forgotten. We got through a period of drought lasting for nine months. Our wells used to give a good jet of clean water, but they diminished to a dreary trickle. Bathing and washing were out of the question ..... The worst was our land. The soil burst open as in an earthquake, the crops withered and new plantings or sowing was, of course, senseless." (Translated by Dr. W. Vink)

Droughts were also common in 1940 and 1941. De Bruijn reports a drought for several weeks in the Wissel Lakes region which resulted in the deaths of plants, espe-

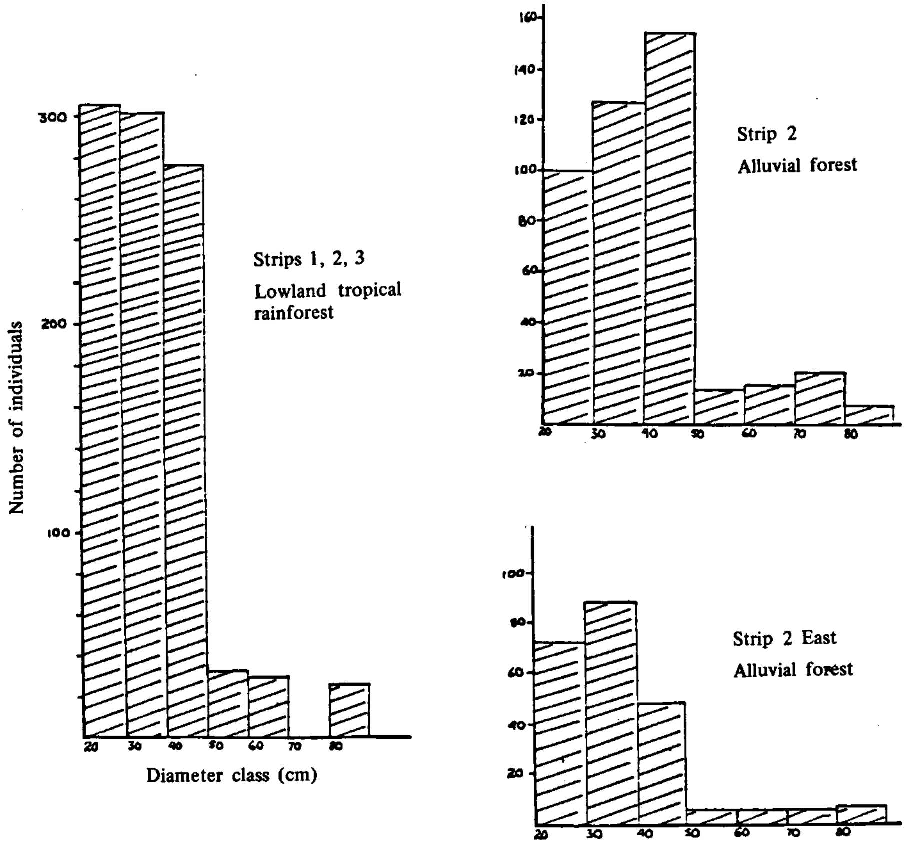


Fig. 8. Size-class distribution of secondary forest in the south Naru region, Madang provinces. Forests in the area were burnt during the 1941 fires.

Fig. 9. The areas affected by the 1941 drought.

cially the staple food, kaukau. During 1941, extensive forest fires are reported from the north coast of New Guinea. Areas of the Gogol River valley (probably east of Baku) were burnt. Data from the South Naru area (Madang Province) shows that few trees exceed 50 cm d.b.h. (fig. 8). In discussions with the village people, they stated that all small rivers and streams were dry in 1941 and the Gogol River was only c. 25 cm deep. Because of the drought 'all the forests were burnt' (Johns, 1985). The forests and grasslands of the Sepik Valley were also extensively burnt (Cavanaugh, pers. comm.) and the drought extended as far as Mt Ialabu (discussions with village people) and Kulumadau (fig. 9). In the Bulolo-Wau region some 120 hectares of mature hoop and klinkii forest were burnt at Pine Tops in the Wau Gorge.

The most recent severe drought occurred throughout the New Guinea Highlands and the Morobe, Madang and Sepik Provinces in 1972. Hope (1983) reports the occurrence of a crown fire in *Nothofagus* forest in 1972 during which some 2.5 square kilometres of beech forest was killed near Mt Capella. Extensive grass fires occurred, and some small bush fires were seen along the coast near Kui. At the time of the 1972 drought, the level of the Fly River at Kiunga dropped 5 metres. Large areas of subalpine and upper montane forest were damaged where drought, fire and frost all combined to affect the vegetation. The subalpine grasslands were extensively burnt and Hope (pers. comm.) reports a loss of up to 5 centimetres of peat from some areas on Mt Giluwe. On a trip to Mt Giluwe in 1975, I failed to find any plants of *Rhododendron saxifragoides* in an area in which they were common in 1969, before the 1972 fires.

In 1979 a severe drought occurred, in the northwest coastal region of New Guinea near Wewak. Wewak was without rain for several months and a missionary in the area remarked that 'the drought was almost as severe as the 1941 drought, when the forest could be burnt from lighting small fires' (Brother Patrik, pers. comm.).

Frost and Snow

The first record of extensive and heavy frost from New Guinea is from 1940–1941, when for weeks frost occurred down to 1980 m altitude and sleet and snow were recorded at 2280 m on the ranges of the Central Highlands. This occurred at the time of the 1941 drought (fig. 9). H.C. Brookfield records severe frosts in 1949, 1950 and 1962. In 1963 screen temperatures at Tambul (2250 m) were -3.3 degrees centigrade (Bowers, 1968). Unfortunately there is a lack of climatic data for areas above 2100 m. Generally ground frosts commence about 1500 m and light frosts are common above 2000 m.

Frost hollows (plate 7) are a common feature of the vegetation of the mid and upper montane zone.

From June to October 1972 a serious frost, accompanied by severe droughts, occurred in the Western and Southern Highlands. Continuous heavy frosts at low altitudes were recorded for up to one week in the upper Lai and Marient valleys in the Kandep basin, the Margarima area and the upper Mendi valley. Lighter frosts were recorded in the upper Kaugel valley near Tambul, at Laiagam and in the Sirunki basin. Above 3000 m these frosts resulted in extensive damage to the upper montane and subalpine vegetation.

Brown and Powell (unpubl. report) record:

> "The nature of the ground surface and the type of vegetation cover are also significant in the development of frost hollows. Accumulations of cold air are favoured by a surface that is rough, giving a large radiation area, and flat or slightly hollow. Soils which have a low heat conduction capacity, such as dry sandy soils, are particularly prone to local radiational losses of heat and the development of strong temperature inversions in the air above them. Swamps and the margins of lakes are less susceptible to radiation frosts, but are subject to cold-air drainage and advection frosts. Strong nocturnal radiational loss of heat is also favoured by a short grass cover, even with scattered shrubs.
>
> In forest areas many fleshy vines and herbs and some trees have been noted as wilting and dying under the present drought conditions. Survival of some rare New Guinea species may be in danger.
>
> Many herbaceous, woody regrowth and forest species were also affected by the 1972 frosts. Stands of *Phragmites karka* and *Miscanthus floridulus* on the Egari swamp-land and the swamp margins showed 'burnt' leaves and most of the associated regrowth trees and shrubs were affected: *Ficus* spp., *Alphitonia incana, Glochidion* spp., *Homolanthus* sp., *Macaranga* sp., *Schefflera* sp., *Saurauia* sp., and *Acalypha* sp., and the ferns, *Gleichenia* spp., *Pteridium esculentum* and *Sphenomeris chinensis*. Tree ferns also showed frond damage."

They report extensive damage to the broadleaf tree species, vines and shrubs in the Kandep area. Although the conifers in this region, *Dacrydium elatum* and *Podocarpus papuanus*, were not affected, stands were seen at the western end of Mt Hagen where these species and *Dacrycarpus compactus* had suffered extensive damage. Between Kandep and Margarima well developed regrowth and *Nothofagus* forests on steep slopes had been frosted from the narrow valley base to the ridge top (an elevation of 30–50 m): few species escaped damage.

In the Tengo area, above Margarima, the following species were affected: *Eurya* sp., *Syzygium* spp., *Decaspermum* sp., *Drimys* sp., *Saurauia* sp. and *Schefflera* sp. Many shrubs and vines in the Ericaceae and Melastomataceae had been damaged. Many orchids and grasses and the herbaceous plants, *Rubus moluccanus, Polygala paniculata* and *Hypericum* spp. were damaged or killed.

The subalpine forest above 3000 m on Mt Giluwe showed signs of extensive damage. When these forests were examined in 1975, the forest patches had been virtually destroyed, although some plants were suckering from the base. It will take many years for the trees which have been killed to re-establish and for the epiphytes and associated herbaceous plants to grow (plates 8 & 9).

Once the areas have been frosted and the trees adjacent to the margin damaged, they become more susceptible to forest fires. In most areas, under wet conditions, the grassland fires seldom penetrate into the forest margins. However, after frost damage considerable areas of forest can be burnt. This may accentuate the cold-air drainage and thus increase frost damage.

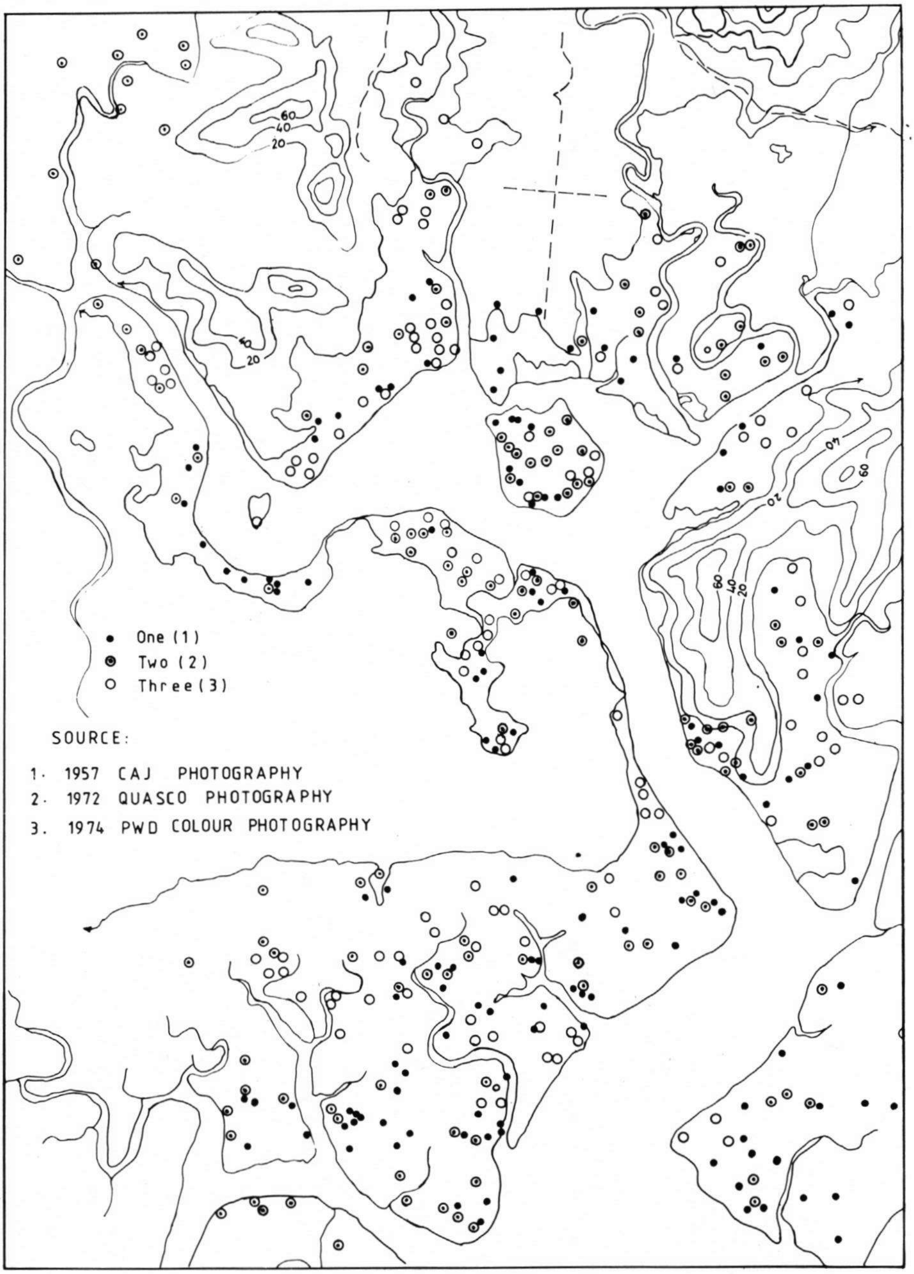


Fig. 10. Lightning strikes in the Galley Reath area. Source: Office of Forests, Papua New Guinea.

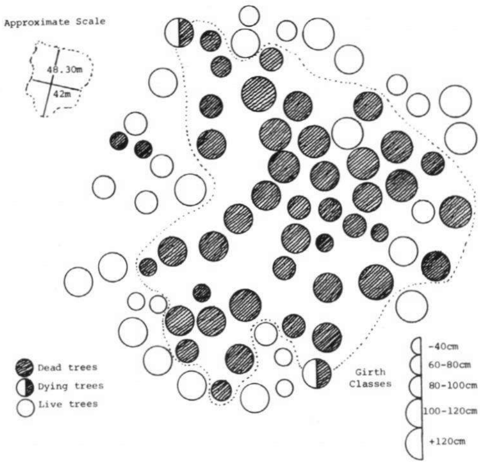


Fig. 11. A plot from a lightning strike at Labu.

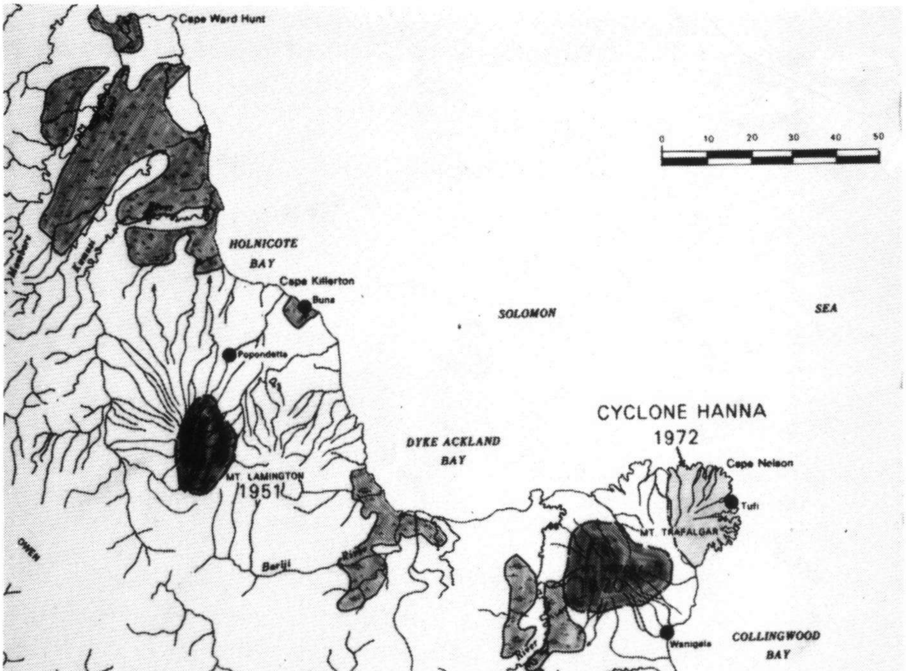


Fig. 12. Cyclone areas of Eastern Papua. Source: Office of Forests, Papua New Guinea.

Lightning strikes

The occurrence of lightning strikes has been widely documented, in particular in North America, where they are a major cause of forest fires (Taylor, 1977). The earliest documentation of lightning in New Guinea was found in Pratt (1906), where he reported a tree that 'was struck and split from top to bottom.' Greenwood (pers. comm.) states that lightning is a common phenomenon in Papua New Guinea.

Shaw et al. (1969) report lightning strikes as a common occurrence in Papua New Guinea. In this situation an area of trees surrounding the central strike dies. Recent studies of lightning strikes in Galley Reach (fig.10; plates 10 & 11) show that these features are common. The lightning strikes were mapped from aerial photographs taken in 1957, 1972 and 1974. At this intensity a complete turnover in mangrove biomass would be expected in 200–300 years.

A plot was established in the mangrove forests at Labu (fig. 11). All canopy trees had been killed by the lightning (plate 12) but a dense ground flora has developed. This was dominated by *Xylocarpus* (to 5–6 m high) with small patches of *Acrostichum aureum* and abundant seedlings of *Rhizophora apiculata* (plate 13). The areas affected measure up to 50 m diameter and all trees within this zone are killed. Presumably the lightning travels laterally from the central tree by means of root grafts, which are common between mangrove trees of similar or related species. This destroys the membrane structure thus allowing salt uptake and killing the trees.

Recent studies by Shaw in the *Nothofagus* forests of Papua New Guinea attributed large circular patches of dead *Nothofagus* trees to infestation by *Phytophthora* spp. However, the occurrence of this is probably secondary and I suggest that lightning strikes could be a major cause of these phenomena. Root grafting in *Nothofagus* is common, as with mangroves, and any lightning strikes would presumably kill a series of trees. In terrestrial situations, the effect of lightning on membranes would not be as instantly apparent as in mangrove communities. Thus deaths would be slower and secondary infection would be widespread.

Cyclonic winds

Although New Guinea is not inside the main cyclone belt of the Southwest Pacific, cyclones at times occur in this country. At such times extensive destruction of the forests occurs. In 1972 cyclone Hanna destroyed considerable areas of forest in the Tufi area (plate 14) and destroyed the forests along the caldera wall of Mt Trafalgar (plate 15). The most extensive destruction occurred at the time of the Ioma cyclone in the 1940's (fig. 12). Extensive areas of forest were flattened and in a survey in the late 1950's large windthrown logs, up to 2 m diameter, were common throughout the area. This forest is at present dominated by regeneration of *Anisoptera thurifera* var. *polyandra.* Extensive cyclone damage also occurred in Sagarai around 1940 (O. Kasinori, pers. comm.). Cyclones destroyed the forests on Tami Island in 1976 and are regularly experienced in Misima and Sudest Islands in Eastern Papua.

Small cyclonic winds have destroyed large areas of forests throughout New Guinea. In 1966 some 60 hectares of forest were flattened in the Herzog Ranges. A similar

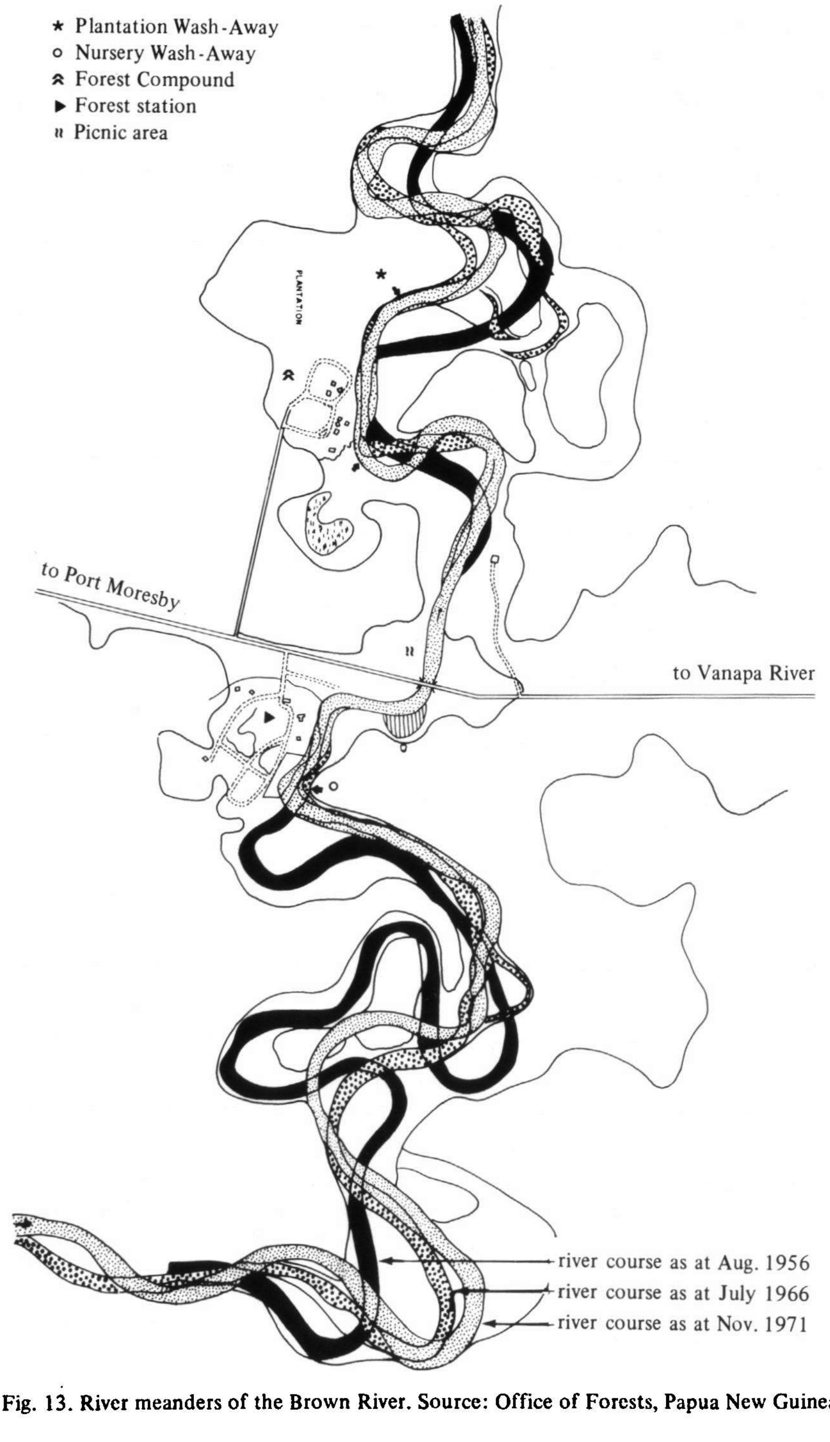


Fig. 13. River meanders of the Brown River. Source: Office of Forests, Papua New Guinea.

event occurred in 1976. Some 20 hectares were flattened. A.J. Hay (pers. comm.) noted that in mid–late 1978 intensive wind throw occurred on Mt Missim in ridges dominated by *Castanopsis*. This coincided with a period of fruit maturation in *Castanopsis*, and a dense mat of seedlings of this genus grew under the condition of increased light penetration. A similar event occurred in December 1979 on the Manki Divide in *Castanopsis* forest (plates 16 & 17).

Individual tree fall is also common in rainforest. In a recent study of bird populations in the Gogol valley it was noted that some one to two trees were falling monthly within the plots. Similar rates of tree fall have been observed in mature *Anisoptera* forest on the Morobe coast. Pratt (1906) also observed the occurrence of a 'hurricane', presumably high local winds, which caused extensive tree fall.

W. Vink (pers. comm.) has described a possible case of wind damage from forest on ultra serpentine soils on Japen Island in Irian Jaya. A strip of mature forest, dominated by even-aged *Tristania* occurs through a forest of *Agathis*. *Tristania* occurs scattered (gaps) in the *Agathis* forest as it requires open conditions for regeneration.

River meanders

River meanders are very common in the lowland areas adjacent to the large rivers especially along the Papuan flats and in the Ramu and Sepik valleys (White, 1976). The river meanders and resultant ox bow lakes can occupy a large area of ground on either side of the river course (fig. 13 & 14). An intricate pattern of vegetation types occurs in the ox bow lakes, or in older meanders which often develop swamp forest. Frequent floods can result in continual destruction and development phases following meanders. These changes can also affect mangrove ecosystems particularly along the upper reaches of mangrove swamps.

Alluvial fans often form where rivers move from mountain areas to the lowlands. Forest development on such fans is often closely related to the water regime of the river. Movement of the river courses over the surface of the fan can cause the death of forest communities as a result of decreased water availability. Such fans are found on the Vogelkop Peninsula (W. Vink, Rijksherbarium Leiden).

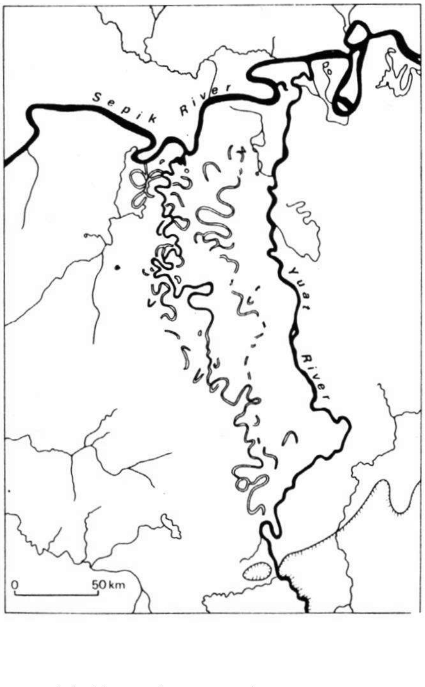


Fig. 14. Yuat River area, former and present river courses. ▬ : present river course, active flow; ═══: former river course, no active flow; ⌒⌒⌒: mountain front. Source: Löffler (1977).

CONCLUSIONS

No mention has been made of the influence of man on the tropical rainforest of New Guinea. The most obvious effects occur during the practise of subsistence agriculture. Recent studies in the Waghi valley have shown that subsistence gardening has been practised for some 9,000 years. During this time the forest vegetation has been destroyed and replaced by anthropogenic grasslands. Undoubtedly some of the 2–3 million hectares of grassland are natural but large areas probably owe their origin to gardening and fire.

Despite the enormous effects of man through 29–30,000 years in New Guinea, we are here concerned with 'natural' rather than 'man-made' effects; although this distinction should not really be made.

In table 1, I have summarised some of the major effects of disasters on the vegetation of New Guinea. In all these areas a major component of the forest canopy consists of long-lived secondary species which now only regenerate in rainforest gaps. The widespread occurrence of these areas (fig. 15) indicates the importance of natural disasters in the development of the vegetation of New Guinea.

Any study of the vegetation of New Guinea requires an intensive examination of the influence of historical factors on the vegetation. The instability of the tropical ecosystem will require new concepts in the management of the forest resources of New Guinea.

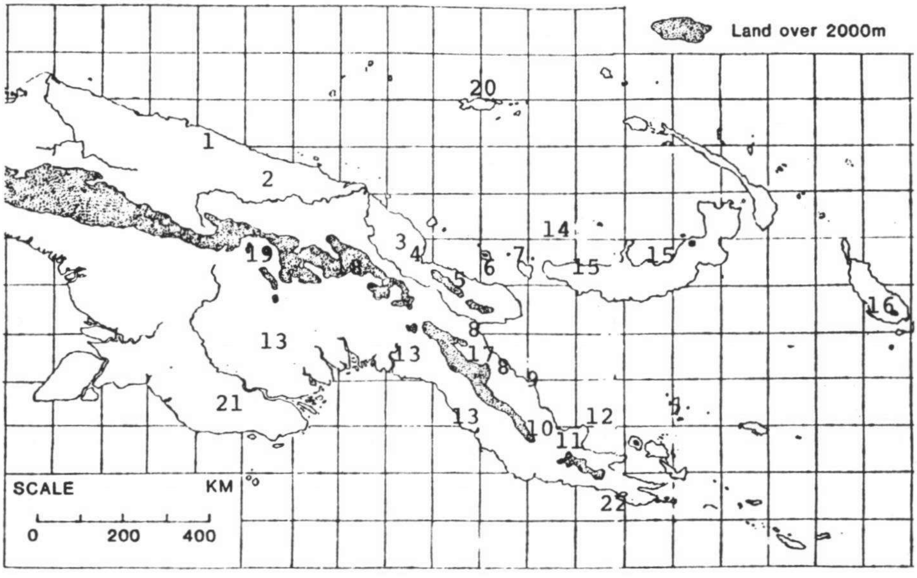


Fig. 15. Location of disturbed areas documented in table 1.

Table 1. Characteristics of the vegetation and types of natural disasters shown in figure 13.

	Locality & dominant species	Event/Time
1.	Vanimo: *Pometia pinnata, Intsia*	Droughts 1890's, 1914
2.	Torricelli Mountains: *Albizia*	Earthquakes 1918, 1935
3.	Adelbert Ranges: secondary	Earthquakes 1972
4.	Gogol/Naru/Sepik Plains: *Intsia, Pterocarpus, Pometia*	Droughts 1914+, 1941
5.	Finisterre R.	Earthquake 1873–1876
6.	Long Island: secondary	Eruption 1800–1840
7.	Umboi Island: secondary *Albizia*	Eruptions
8.	Oomsis to Mai-ama: *Anisoptera*	Gardening, bushfires?, cyclone?
9.	Ioma: *Anisoptera*	Cyclone 1940's
10.	Mt Lamington: *Octomeles*, secondary	Eruption 1952
11.	Mt Victory: *Anisoptera*	Eruption 1880's
12.	Tufi/Mt Trafalgar: secondary	Cyclone 1972
13.	Moresby to Western Province: secondary	Bush fires 1906
14.	Ritter: secondary with near areas	Eruption 1888
15.	North coast New Britain: *Pometia*	Numerous eruptions, Drought 1914
16.	Bougainville: secondary	Numerous eruptions
17.	Bulolo/Wau: *Araucaria* forest, *Castanopsis*	Fires 250 BP, 1941; Gardens, Windthrow 1978, 1979
18.	Mt Wilhelm: landslides	Numerous (1968) by rainstorms
19.	Giluwe/Hagen/Doma: secondary and death of subalpine forest and peat bog plants	Frosts and drought, 1941?, 1972
20.	Manus: *Calophyllum*/secondary	?
21.	Western Province: savannah	Annual fires
22.	Sagarai: young forest	Cyclone c. 1940

ACKNOWLEDGEMENTS

I wish to thank Dr. W. Vink and Dr. R. J. Blong for their assistance in collecting material for this paper. The following photographs and figures have been made available for my use by Mr. N. Clarke (plates 3, 16, 17); Mr. N. Boromu (plates 12, 13); Dr. R.J. Blong (fig. 6); Dr. J. Bowler (plate 6, fig. 3); Cooke et al. (figs. 4, 5); Office of Forests (plates 2, 7, 9, 10, 11, 14, 15; figs. 2, 8, 11, 12). I wish to thank the second-year Forestry students at the University of Technology for assistance in collecting the information for figure 10.

REFERENCES AND SOURCES

ANDERSON, J.A.R. 1964. Observations on climatic damage in peat swamp forest in Sarawak. Comm. For. Review 43: 145–158.

ANNUAL REPORTS British New Guinea. 1906–1907.

BARLOW, B.A. 1981. The Australian flora: its origins and evolution. In: Flora of Australia, vol. 1. Aust. Govt. Print. Service, Canberra.

BLONG, R.J. 1975. The Krakatoa myth and the New Guinea Highlands. J. Poly. Soc. 82: 213–217.

—— 1982. The time of darkness - Local legends and volcanic reality in Papua New Guinea. Aust. Nat. Univ. Press, Canberra.

BOWERS, N. 1968. The ascending grasslands: an anthropological study of ecological succession in a high mountain valley of New Guinea. Unpubl. PhD Thesis, Columbia Univ.

BROOKFIELD, H.C. & D. HART. 1966. Rainfall in the tropical Southwest Pacific. G/3. Aust. Nat. Univ., Canberra.

BROWN, M. & J.M. POWELL. Frost in the Highlands of Papua New Guinea. Unpubl. mimeo report Univ. Papua New Guinea.

BRUNIG, E.F.W.O. 1963. A study of damage attributed to lightning in two areas of Shorea albida forest in Sarawak. Comm. For. Review 43: 134–144.

BUREAU OF METEOROLOGY, Department of Science. Tropical cyclones in the northern Australian regions, 1967–1968 season. Dept. of Interior. Comm. of Aust.

—— 1975. Technical Report no 14: Cyclone Tracey.

COLEMAN, F. 1972. Frequency, tracks and intensities of tropical cyclones in the Australian region, 1909 to 1969. Bureau of Meteorology, Department of Interior.

COOK, R.J.S., C.O. McKEE, V.F. DENT & D.A. WALLACE. 1976. Striking sequence of volcanic eruptions in the Bismarck Volcanic Arc, Papua New Guinea, in 1972–75. In: R.W. Johnson (ed.), Volcanism in Australasia. Elsevier, Amsterdam.

FLENLEY, J.R. 1972. Evidence of Quaternary vegetational changes in New Guinea. In: P. & M. Ashton (eds.), The Quaternary Era in Malesia. Trans. 2nd Aberdeen-Hull Symp. Malesian Ecology, Univ. of Hull, Misc. Series 13. Hull.

—— 1979. The Equatorial rainforest: a geological approach. Butterworths, London.

GREENWOOD, P. 1982. An investigation of some aspects of tropical lightning and its effect on the design of transmission lines. Unpubl. PhD Thesis, Papua New Guinea University.

HOPE, G. 1976. The vegetational history of Mt. Wilhelm, Papua New Guinea. J. Ecol. 64: 627–663.

—— 1983. The vegetational changes of the last 20,000 years at Telefomin, Papua New Guinea. Singapore J. Trop. Geography 4: 25–33.

JOHNS, R.J. 1981. Dead patches in New Guinea mangrove communities. Abstract XIII Internat. Bot. Congr., Sydney.

—— 1985. Natural disturbance in mangrove ecosystem. UNESCO Conf., Port Moresby.

KLEIN, W.C. 1935. Nieuw Guinee. Amsterdam.

LÖFFLER, E. 1977. Geomorphology of Papua New Guinea. CSIRO, Australian National Univ. Press, Canberra.

MARSHALL, A.J. 1937. Northern New Guinea. Geogr. J. 89: 489–504.

MIKLAUCHO-MACLAY, N. 1975. New Guinea diaries, 1871–1883. Translated from Russian by C.L. Sentinella. Kristen Press, Madang.

NIX, H.A. & J.D. KALMA. 1972. Climate as a dominant control in the biogeography of northern Australia and New Guinea. In: D. Walker (ed.), Bridge and barrier: the natural and cultural history of Torres Strait. BG/3. Australian National Univ., Canberra.

OLDFIELD, F., P.G. APPLEBY & R.W. BATTERBEE. 1978. Alternative 210Pb dating: results from the New Guinea Highlands and Lough Erne. Nature 271: 339–342.

PAIN, C.F. & J.M. BOWLER. 1973. Denudation following the November 1970 earthquake at Madang, Papua New Guinea. Zeit. Geomorph. N.F. 17: 92–104.

POWELL, J. M. 1970. The impact of man on the vegetation of the Mt. Hagen region, New Guinea. Unpubl. PhD Thesis, Australian National Univ., Canberra.

PRATT, A. 1906. Two years among New Guinea cannibals: a naturalists sojourn among the aborigines of unexplored New Guinea. London.

RICHARDS, P. W. 1952. The tropical rain forest: an ecological study. Cambridge.

SHAW, D. E. 1968. A lightning strike of coconuts in New Guinea. Papua New Guinea Agric. J. 14: 146–150.

—— & R. J. VAN VELSEN. 1969. Lightning strike of coca and Leucaena in New Britain. Papua New Guinea Agric. J. 20: 75–82.

SIMONETT, D. S. 1967. Landslide distribution and earthquakes in Bewani and Torricelli Mountains, New Guinea. Statistical analysis. In: J.N. Jennings & J.A. Mabbutt (eds.), Landform studies from Australia and New Guinea: 64–85. Cambridge.

TAYLOR, A.R. 1977. Lightning effects in forest. Paper presented at AAAS Annual Meeting, Lightning Symposium, Philadelphia, Pennsylvania.

TAYLOR, B.W. 1957. Plant succession on recent volcanoes in Papua. J. Ecol. 45: 233–243.

WALKER, D. 1966. Vegetation of the Lake Ipea region, New Guinea Highlands. 1. Forest, grassland and 'garden'. J. Ecol. 54: 503–533.

—— 1970. The changing vegetation of the montane tropics. Search 1: 217–221.

—— & J. R. FLENLEY. 198?. Late Quaternary vegetation history of the Enga District of Upland Papua New Guinea. Phil. Trans. Roy. Soc. B.

WEBB, L. J. 195?. Cyclones as an ecological factor in tropical lowland rain forest, North Queensland. J. Ecol.

WHITE, K. J. 1976. The effect of natural phenomena on the forest environment. P.N.G. Sci. Soc. Presid. Address. Dept. of Forests, Port Moresby.

WHITMORE, T.C. 1974. Change with time and the role of cyclones in tropical rain forest on Kolombangara, Solomon Islands. Comm. For. Res. Inst. Oxford, Paper no 46. Oxford Univ. Press.

—— 1975. Tropical rain forests of the Far East. Clarendon Press, Oxford.

(see for plates 1–16 pages 362–371)

Plate 1. A dense pattern of landslides under rainforest. West Sepik, Lake Louise.

Plate 2. Landslides on mudstone in the Purari catchment.

Plate 3. Landslide in the Wampit valley.

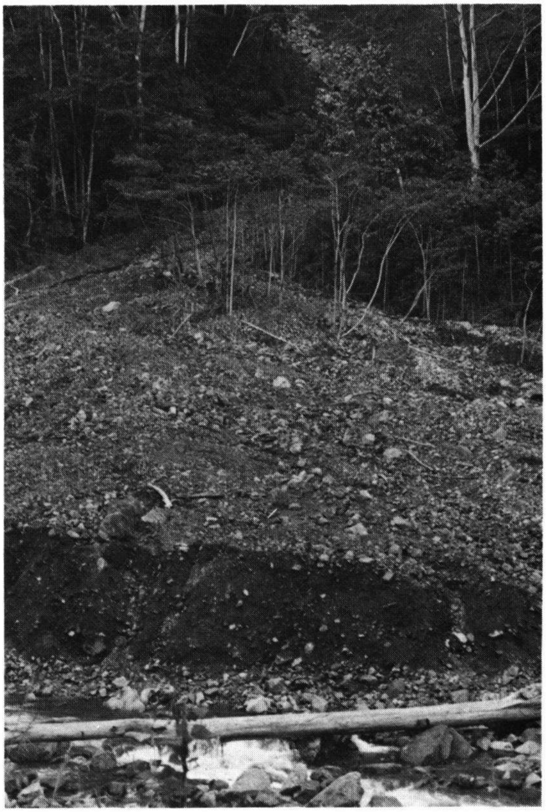


Plate 4. Landslides resulting from undercutting of the stream banks during flooding.

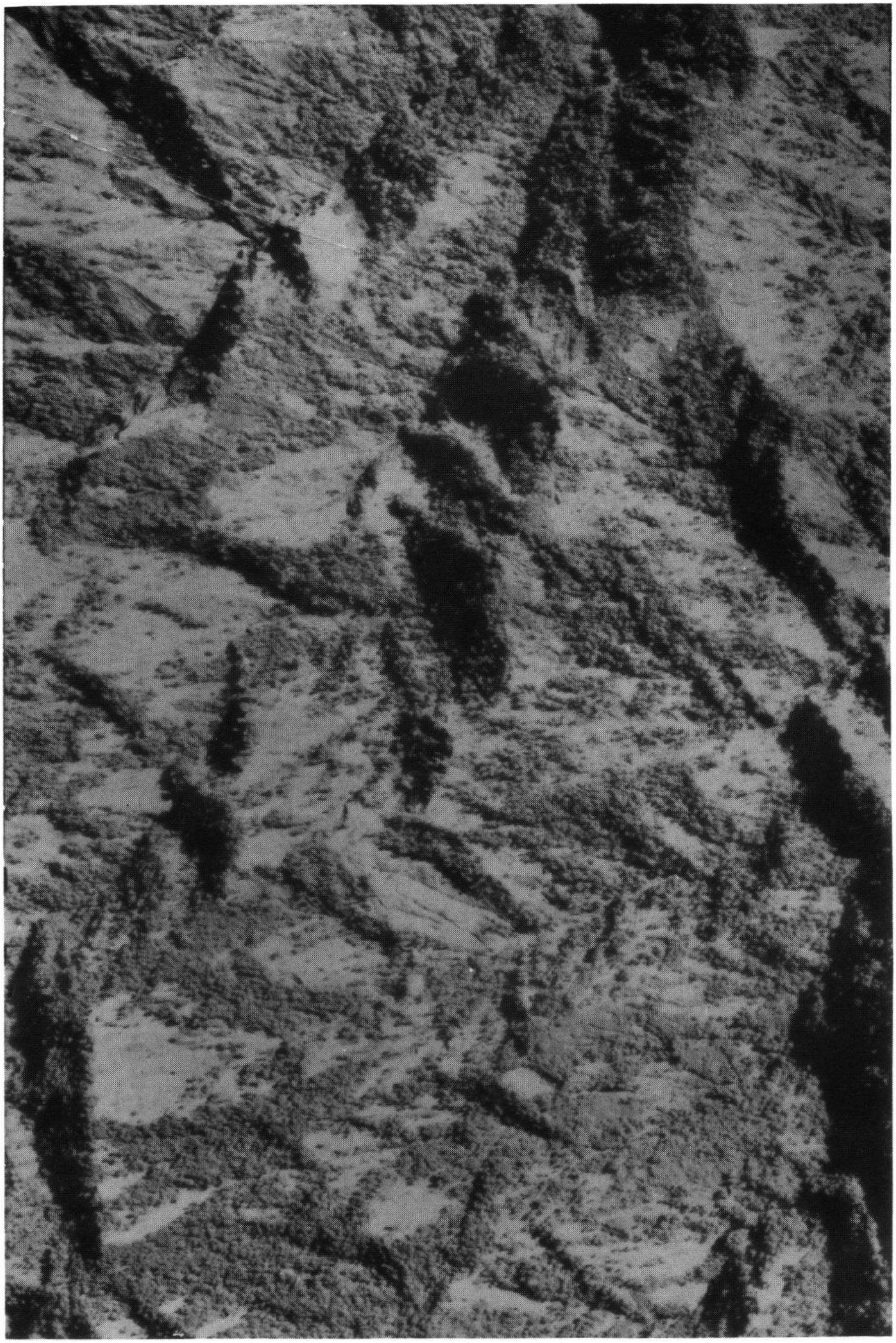
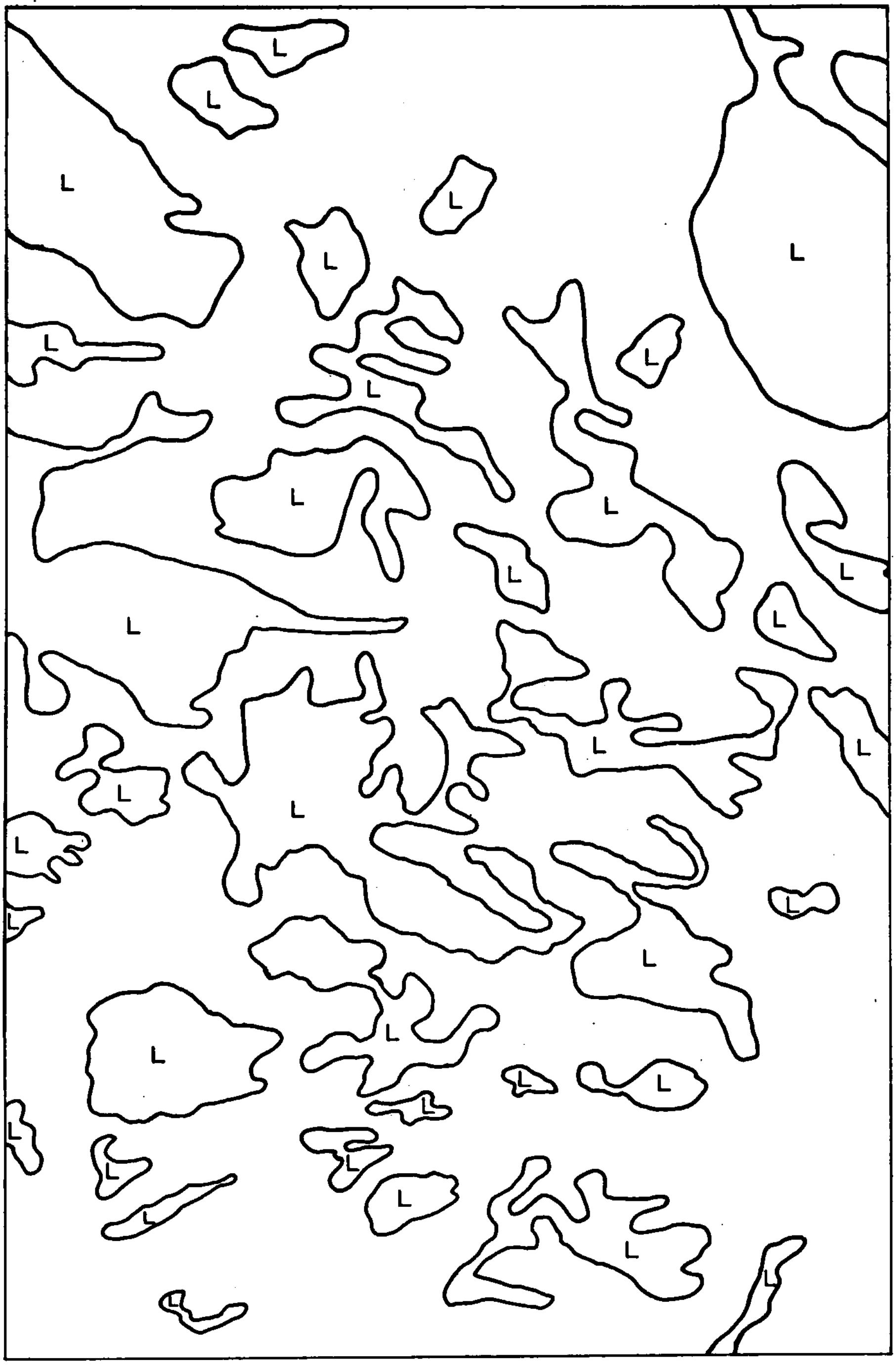


Plate 5. The pattern of landslides in part of the Adelbert Range after the Madang Earthquake.



Diagrammatic drawing of the aerial photograph on page 364.

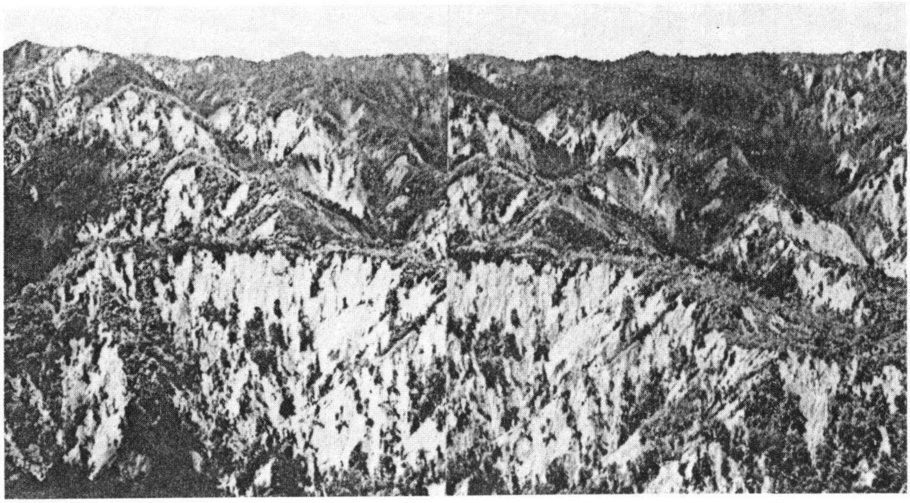


Plate 6. A dense area of landslides in the Adelbert Range following the Madang earthquake. Source: Pain & Bowler.

Plate 7. Frost hollow on the Hagen/Wabag road, showing the effects of the 1972 frosts (and fires) on the forest surrounding the grassland.

Plate 8. Subalpine forest damaged by frost. Hagen Range.

Plate 9. Damage to forest margins following frost and fire. Hagen Range.

Plate 10. An aerial photograph of a lightning strike in the Galley Reach area. Source: Office of Forests, Papua New Guinea.

Plate 11. Lightning strikes in the mangrove communities at Galley Reach. Source: Office of Forests, Papua New Guinea.

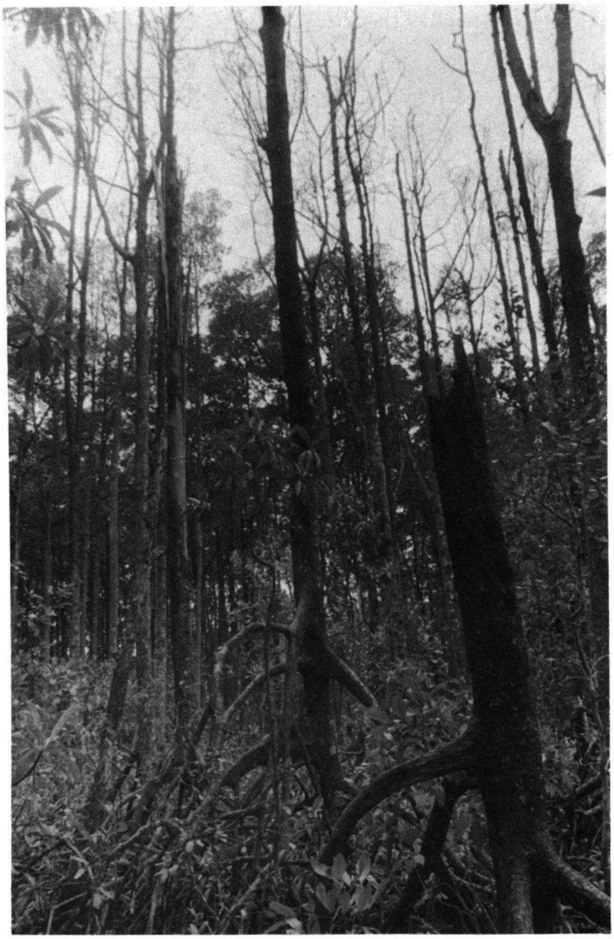


Plate 12. Lightning strike in *Rhizophora* forest at Labu.

Plate 13. Dense regeneration of *Rhizophora apiculata* in an old lightning strike area at Labu.

Plate 14. Rainforest stripped and branches shattered by cyclone Hanna in 1972. Source: Office of Forests, Papua New Guinea

Plate 15. The caldera wall of Mt Trafalgar following Cyclone Hanna. Source: Office of Forests, Papua New Guinea.

Plate 16. A small windblown area of *Castanopsis* on Manki Divide.