

# Explanatory Notes to the Vegetation Map of Papua New Guinea

By K. Paijmans

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## MAP

Vegetation Map of Papua New Guinea (4 sheets)





# EXPLANATORY NOTES TO THE VEGETATION MAP OF PAPUA NEW GUINEA

By K. PAIJMANS\*

## I. INTRODUCTION

The vegetation map at a scale of 1 : 1 000 000 is based mainly on interpretation of aerial photographs. Features of the structure and floristics of the vegetation that can be distinguished on aerial photographs as well as environmental factors such as topography, drainage and altitude have been used to define mapping categories and to establish their boundaries. Hence the map and its legend are intended to give the user information both on the various vegetation types and on their ecology and habitats.

Over the past 20 years plant ecologists in land resources survey teams from the Division have carried out field observations in various parts of Papua New Guinea covering about 40% of the country. These observations have made it possible to relate air-photo and ground features of the different vegetation types. These features are discussed in some detail in the following notes, and are briefly summarized in the map legend.

## II. CLASSIFICATION AND DEFINITION OF VEGETATION TYPES

The vegetation of Papua New Guinea is subdivided into nine major categories which are readily distinguishable on aerial photographs and are based largely on canopy structures and tones. The categories are:

- |               |                                 |
|---------------|---------------------------------|
| (a) Forest    | (f) Mixed herbaceous vegetation |
| (b) Woodland  | (g) Pioneer vegetation          |
| (c) Scrub     | (h) Mangrove vegetation         |
| (d) Savanna   | (i) Garden                      |
| (e) Grassland |                                 |

These are defined and further subdivided into mapping types as follows.

### (a) *Forest*

In the forest category the trees of the canopy have crowns that touch or overlap. Thirteen types of forest have been mapped—five on plains and fans, seven on hills and mountains and one restricted to south-west Papua New Guinea.

\* Division of Land Use Research, CSIRO, P.O. Box 1666, Canberra City, A.C.T. 2601.

Forest on plains and fans	Large- to medium-crowned forest Open forest Small-crowned forest Littoral forest Swamp forest
Forest on hills and mountains	
Lowland hill forest zone (sea level to 1400 m)	Medium-crowned forest Small-crowned forest Large-crowned forest
Lower montane forest zone (1400–3400 m)	Lower montane forest, general type Coniferous lower montane forest Very small-crowned lower montane forest
Montane forest zone (3400 m to the forest limit at 3900 m)	Montane forest
Forest restricted to south-west Papua New Guinea	Dry evergreen forest

Differences in the structure and floristic composition of the forests on plains and fans are related mainly to drainage and soil conditions. These forests are found mostly in the coastal lowlands but also occur further inland along the larger rivers.

Changes in the forests of the hills and mountains are largely related to variations in altitude and associated changes in temperature and length of time the vegetation is enveloped in cloud. The altitudinal forest zones chosen are those that are more or less clearly distinguishable on aerial photographs. Zone boundaries are not precise because forest types grade into one another; they also vary in altitude from place to place due to local effects of topography and climate. Lower montane elements first appear in lowland hill forest vegetation at about 900 m or even lower, and gradually gain in importance with increasing altitude. On the basis of ground observations the upper limit of lowland hill forest has been put by many observers at about 1000 m. However, as the air-photo image generally becomes markedly darker-toned and smaller-crowned at about 1400 m, this altitude is taken as the upper boundary of the zone.

A general lower montane type occupies most of the lower montane forest zone; a smaller-crowned and darker-toned coniferous lower montane type occurs locally in the upper part of the zone; and a dense, very small-crowned lower montane type is associated with ultramafic parent rocks and limestone.

Montane forest is characterized by a very dark-toned, small-crowned, smooth canopy, and covers relatively small areas on the tops of the highest mountains.

Dry evergreen forest is restricted to south-west Papua New Guinea. It cannot be distinguished by air-photo pattern from adjoining lowland hill forest, and the boundary between these two forest types is based on ground observations.

(b) *Woodland*

Woodland consists of an open upper storey of trees and an undergrowth of shrubs. The two types that have been mapped are woodland on permanently dry to periodically inundated terrain and woodland in swamps. The latter type is taken to include stands of sago palm and pandans, although neither is strictly woody and both form a dense canopy.

(c) *Scrub*

Scrub consists of either dense shrubs or very low trees or both together; these are not subdivided on the map. Scrub does not normally cover large areas and is usually found in mosaic with other vegetation types.

(d) *Savanna*

Savanna consists of a ground cover of grasses or grass-like plants overtopped by an open tree layer. On aerial photographs savanna is distinguished from woodland by a more open tree layer and a light-toned background caused by the ground layer of grasses. The category has not been further subdivided on the map. Tree-fern savanna has been mapped as grassland and swamp savanna has been mapped as swamp woodland.

(e) *Grassland*

Grassland is a vegetation community dominated by grasses or grass-like plants. The two types that have been mapped are grassland on permanently dry to periodically inundated terrain and grassland in permanent swamp.

Grassland is very light-toned on aerial photographs, except for parts recently burnt which register in dark grey to black tones. Trees and shrubs are normally present in addition to the grasses, and as the tree density increases grassland grades into savanna. However, grassland and savanna have been maintained as separate categories as they are in general readily distinguished on aerial photographs.

(f) *Mixed Herbaceous Vegetation*

Herbs, sedges and ferns determine the aspect of this vegetation. Only one type, herbaceous swamp vegetation in the lowlands, is mapped as a separate category. On aerial photographs this type shows as a patchwork of grey and white tones, distinguishable from the uniformly light tone of swamp grassland. Two other types, mixed herbaceous sedge-grass bog vegetation within mountain grassland, and mixed herbaceous vegetation on dry terrain, cover areas too small to show on the map and are included mainly in the categories Grassland and Pioneer Vegetation.

(g) *Pioneer Vegetation*

Pioneer vegetation includes all vegetation communities pioneering on terrain that was previously bare, such as recent stream deposits, or where the original vegetation has been destroyed by volcanic activity or flooding. It comprises plant communities ranging from mixed herbaceous vegetation to forest, but has been mapped as a single type.

*(h) Mangrove Vegetation*

Mangrove vegetation consists of mangrove forest, woodland and scrub; it includes other categories such as mixed herbaceous vegetation and grassland on salt flats that also occur in the coastal tidal environment, often in intricate mixture with mangroves. It is also taken to include nypa palm vegetation and some pioneer communities in estuaries. Normally mangrove vegetation is readily distinguished from adjacent freshwater swamp vegetation as it has a relatively darker air-photo tone and a smooth, small-crowned canopy. Differences between finely white-speckled nypa palm vegetation and darker sago vegetation have helped to establish the boundary between brackish and freshwater environment.

*(i) Garden*

This category comprises present gardens, plantations and young regrowth on old gardens.

## III. MAPPING PROCEDURES

The vegetation has been mapped from vertical black-and-white aerial photography at scales ranging from 1 : 20 000 to 1 : 100 000, the most common scales being 1 : 40 000 to 1 : 50 000. The oldest photographs used were taken in 1943 and the most recent in 1972.

Most of the mapping was carried out using stereomosaics, which were prepared as follows. About 20 aerial photographs forming parts of three to five adjacent runs were mounted on large sheets of paper which were then photographically reduced to one-third of their original size. At this reduced scale the photographs were the correct distance apart for viewing with a pocket stereoscope. This enabled the air-photo interpretation and mapping of large areas to be done much more quickly than by mapping on normal aerial photographs using a mirror stereoscope. (The reduction in scale is offset by the use of a  $2\frac{1}{2} \times$  enlarging pocket stereoscope.)

The small scale of the map limits the amount of detail that can be shown, and each mapped vegetation type contains inclusions of other types. The degree of precision of the boundaries is not indicated, so that a sharp and precise boundary, e.g. between forest and grassland, is shown in the same way as poorly defined and more or less arbitrary boundaries, e.g. between merging forest types.

Two or more vegetation types are shown on the map as a mixture where they are important components of a complex but cannot be mapped separately. Mixtures of up to four components have been mapped along the lower courses of the Fly and Sepik Rivers, where very low hill ridges form an intricate and irregular mosaic with partly swampy valleys and plains.

A dot symbol indicates old secondary forest and areas of garden and garden regrowth that are too small or too scattered to be mapped in the Garden category. Gardens occur mostly within forest or woodland, but occasionally within mangrove vegetation on beach ridge inclusions and areas of crab mounds. The great number of dots on the map indicates the extent of man's interference with the original vegetation. As felling of forest for gardens is a continuing process, the map is up to date

only where recent aerial photography has been used. The dots have been omitted from mixtures of forest and woodland with grassland, as these are partly secondary or disturbed by implication.

The presence on aerial photographs of a high proportion of light-toned tree crowns in the canopy often indicates semi-deciduous forest. However, this feature has not been used to distinguish between semi-deciduous and evergreen forest, as the correlation is not absolute: evergreen canopy trees that are in flower or have large leaves evenly spread over the crown surface also show up light-toned, and deciduous trees do not show light tones except on photography taken during the main period of new leaf flush.

#### IV. DESCRIPTION OF VEGETATION TYPES

The vegetation types are described here in the same order as in the legend on the map. For each type the habitat and the main occurrences are given first, followed by the structural and floristic characteristics of the main type, including those visible on aerial photographs. Different aspects of the type and the relationships with other vegetation types are then discussed.

Vegetation types that could not be mapped in the appropriate category are described under the relevant heading. For example, *Casuarina equisetifolia* forest, an unmapped inclusion in both Mangrove Vegetation and Littoral Forest, is described under Pioneer Vegetation.

The terms 'tall', 'mid-height' and 'low' refer to >30 m, 20–30 m and <20 m respectively for forest, woodland and savanna canopies and for individual trees; and to >1.5 m, 0.5–1.5 m and <0.5 m for grassland and herbaceous vegetation.

Crown classes used are based on average crown diameter of canopy trees: large-crowned, >15 m; medium-crowned, 8–15 m; and small-crowned, <8 m.

Frequency refers to the proportion of the observations in which a given species or characteristic was recorded in a given vegetation type. Commonness refers to the number of individuals of a species in a certain area. Plant names are listed in approximate order of frequency.

##### (a) Forest

(i) *Large- to Medium-crowned Forest on Plains and Fans* (Plate 1, Fig. 1; Plate 4, Fig. 1; Plate 18).—This type of forest occurs on well to imperfectly drained alluvial plains and gently sloping fans that are either not flooded or are flooded infrequently and for short periods only. Pools of standing water may form during heavy rains, however, and may remain for several days. The largest areas are found along the north coast on the foot slopes of Mt Lamington and the Goropu Mountains, and along the south coast east of Marshall Lagoon.

This forest has an irregular structure throughout all layers. The canopy is usually rather open and has many gaps, a feature that is particularly striking from above, either from a helicopter or on large-scale aerial photography. On well-drained sites with deep permeable soils the emergents and most canopy trees have wide crowns and the canopy is well over 30 m high; emergents reach 50 m or more, and some trees attain girths well over 2.5 m. On less well-drained sites with heavier-

textured, less permeable soils the average canopy crown size is only medium and the forest is less tall. Most trees have straight boles and many are buttressed, canopy and emergent trees often having very high and wide buttresses. The lower tree strata are usually rather open and normally contain many palms (Plate 1, Fig. 1). The shrub layer has a very variable cover which tends to be inversely related to the tree cover. Palms, such as *Licuala*, are common in the shrub layer, and tall gingers and Marantaceae locally form a dense cover; pandans are seldom common. The herb layer consists mainly of ferns and tree and rattan palm seedlings, and is very patchy; in places it is almost absent, e.g. where shrub palms are abundant, but elsewhere it is quite dense, e.g. when it is formed by *Selaginella* or *Elatostema*. Woody lianes, fleshy climbers, and climbing ferns are common; climbing rattan is always present, but is dense only in openings. Epiphytes are common only in the crowns of canopy trees.

The floristic composition is very mixed. Tree species that are invariably present in the upper storey are *Pometia pinnata*, *Octomeles sumatrana*, *Ficus* spp., *Alstonia scholaris* and *Terminalia* spp. Other genera commonly represented are *Pterocarpus*, *Artocarpus*, *Planchonella*, *Canarium*, *Elaeocarpus*, *Cryptocarya*, *Celtis*, *Dracontomelum*, *Dysoxylum*, *Syzygium*, *Vitex*, *Spondias* and *Intsia*. In areas with a marked dry season the proportion of deciduous trees in the canopy is higher than usual.

Old secondary forest is often characterized by a predominance of trees such as *Cananga*, *Endospermum*, *Canarium*, *Euodia*, *Laportea*, *Sterculia* and *Pimelodendron*; *Kleinhovia*, *Macaranga* and *Althoffia* commonly dominate in young woody regrowth stages.

In its optimum development this type of forest is probably the most luxuriant of the forests in Papua New Guinea. Where wet-season inundation becomes prolonged and drainage conditions deteriorate the type grades into open forest described below.

(ii) *Open Forest on Plains and Fans* (Plate 1, Fig. 2; Plates 2 and 3; Plate 5, Fig. 1).—This forest type occurs in the lower and middle courses of the major rivers on low levees, scrolls and riverside plains that are subject to frequent short-lived flooding; on back plains that are subject to prolonged wet-season inundation; and locally in seepage areas on fans. The water-table is generally high and in places remains near the surface throughout the year.

Compared with the preceding forest type the canopy is somewhat smaller-crowned and lower, with a greater number of large gaps; emergents are wide-crowned, but are lower and more widely spaced; there are fewer trees of medium and small girth, the shrub layer is denser and the herb layer is generally sparser; palms, pandans and climbers, particularly rattan, are more common. On sites that have a high water-table throughout the year small groups of sago palms are commonly present (Plate 1, Fig. 2) and tall sedges and shrub pandans are prominent in the undergrowth. A number of trees have stilt roots, and some trees and loops of thick woody climbers that descend to near ground level develop abundant adventitious roots in response to prolonged inundation.

In forest that is subject to frequent short-lived flooding the shrub layer is commonly very open, the herb layer is almost absent and the leaf litter is very sparse. In places, however, a convolvulaceous creeper forms a dense cover on the forest floor.

The frequency of trees such as *Planchonia papuana*, *Bischofia javanica*, *Terminalia complanata*, *Cananga odorata*, *Teysmanniodendron bogoriense*, *Intsia bijuga*, *Nauclea coadunata* and *Vitex cofassus* indicates poor drainage and a high ground-water table. Yet, in areas with a marked dry season an unusually large number of deciduous trees is often present in the canopy, probably as a result of temporary water stress. Forest on frequently flooded sites is often characterized by huge *Octomeles sumatrana* trees emerging above the canopy, and an abundance of *Kleinhovia hospita* in the lower storeys.

As inundation becomes more prolonged the forest becomes broken up into groups of trees and patches of shrubbery overgrown by rattan and other climbers. Usually the trees become lower and sparser to form swamp woodland, but in places the type retains its forest stature and grades into swamp forest.

(iii) *Small-crowned Forest on Plains and Fans* (Plate 4, Fig. 1).—This type of forest occurs on flat to gently undulating lowland plains and fan slopes, where soils are commonly either gravelly or poorly drained or both. The main areas are those associated with the middle courses of the Mori, Kubuna, Gira and Kikori Rivers. The type generally has a dense canopy, broken up by patches and lines of medium-crowned forest and small areas of swamp woodland and mixed herbaceous swamp. Ground observations indicate that the forest is mid-height to tall and thin-stemmed. Locally predominating trees are dipterocarps, *Intsia*, *Casuarina* and, on swampy sites, *Camptosperma*.

(iv) *Littoral Forest* (Plate 4, Fig. 2).—Littoral forest is confined to coastal sandy beach plains. Generally these plains are well drained, but parts are inundated during the wet season due to lack of surface run-off. Where a pattern of beach ridges and swales has been preserved the forest has a striped appearance on aerial photographs as it is taller on the ridges and plains than in the swales and has a different floristic composition and photographic tone. The largest areas are found along the south coast between Cloudy Bay and Amazon Bay, and in south-west Papua New Guinea.

Littoral forest is a medium-crowned, mid-height, moderately dense forest that is characterized by an abundance of palms in the shrub and lower tree layers. Many trees have a poor stem form. Climbers are usually plentiful but rattan is uncommon. In places tree trunks are covered by the climbing fern *Stenochlaena*. Gingers and ferns feature in the herb layer. Common trees in the canopy are *Pterocarpus indicus*, *Terminalia* spp., *Planchonia papuana*, *Nauclea coadunata*, *Pongamia pinnata*, *Syzygium* spp., *Melaleuca* and, in south-west Papua New Guinea, *Acacia*. Where *Melaleuca* dominates in the canopy the forest is smaller-crowned and denser than the average mixed littoral forest.

(v) *Swamp Forest* (Plate 4, Fig. 2; Plate 5, Fig. 1).—In swamp forest the water-table is permanently above or at the surface, but often fluctuates strongly. Fluctuations are mainly seasonal with the rise and fall of the rivers that feed the swamp, but may be daily in estuaries where the ocean tide backs up river water through the maze of creeks and tidal channels. In the lowlands this forest occurs on low-lying back plains, old scroll ridges, and deltas of the larger rivers; in mountainous areas it is found in intermontane basins. The main areas are those associated with the middle and lower courses of the Turama, Fly, Strickland, Purari and Sepik Rivers.

The canopy of swamp forest is medium- to very small-crowned, open to very dense, and usually of relatively even height. One tree species often predominates in the canopy and this, with the even height, gives swamp forest a rather uniform appearance on aerial photographs. The canopy is 20–30 m high; emergents, some of which are wide-crowned, reach 40 m. The lower tree strata are open, because most trees have their crowns in the canopy. Either sago palm or pandans, or both together, often form a second stratum which, where the forest canopy is open, is visible on aerial photographs. The shrub and herb layers are usually sparse, but dense patches of *Hanguana* and tall sedges occur locally. Thin lianes, fleshy climbers and climbing ferns often thickly cover tree trunks but rattan is usually rare. Epiphytes may be plentiful in the tree crowns and on the trunks in open stands. Buttresses are not conspicuous but stilt roots, knobby and peg-like breathing roots, and sprawling surface roots are common. Adventitious roots are often prominent in swamps that have a strongly fluctuating water-table.

Swamp forest is rich in species, though in many places only one or two predominate. Trees that are often found in the canopy are *Campnosperma brevipetiolata*, *C. auriculata*, *Terminalia canaliculata*, *Nauclea coadunata*, *Syzygium* spp. and stilt-rooted *Myristica hollrungii* (in deltas), but many others are frequent. Characteristic of the lower strata are *Alstonia spatulata*, *Barringtonia* spp., *Diospyros* spp., *Garcinia* spp., *Gynotroches axillaris* and, in monsoonal areas, *Carallia brachiata* and *Acacia* spp.

Taxa that characteristically form almost pure stands are *Campnosperma*, *Melaleuca* and, in mountain swamps, conifers. *Campnosperma* swamp forest, occurring in river back plains, has a flat, often rather dense canopy recognizable on aerial photographs by its smooth appearance and uniformly grey tone (Plate 5, Fig. 1); the trees grow straight, up to about 30 m tall and well over 1.5 m in circumference. *Melaleuca* swamp forest forms usually narrow bands in seasonally dry swamps along rivers and creeks. It is a dense, slender forest most commonly formed of *Melaleuca cajuputi*. The trees grow to 30 m or more, but rarely reach a girth of 1.5 m. The shrub and herb layers are very sparse, sometimes absent. Most tree trunks are charred, indicating frequent burning. Coniferous swamp forest occurs locally above about 1700 m. It occupies shallow depressions in valley floors and fringes around sedge bogs in intermontane basins. The conifers *Podocarpus*, *Dacrycarpus* and *Dacrydium* and broad-leaved, commonly myrtaceous trees are prominent and locally dominate the canopy.

Swamp forest is best developed in riverside swamps with regularly moving water. Towards stagnant swamps away from rivers the forest becomes lower and smaller-crowned and passes through a zone of swamp woodland into herbaceous swamp vegetation (Plate 5, Fig. 1). Towards the coast swamp forest contains elements at home in brackish environment such as *Inocarpus fagiferus*, *Sapium* sp., *Campostemon schultzei*, *Heritiera littoralis*, *Dolichandrone spathacea* and *Brownlowia argentata*, and eventually grades into mangrove vegetation. Swamp forest in river deltas is sometimes called 'freshwater mangrove', because it has many features in common with mangrove forest—it occurs on the coasts, stilt-rooted trees are common, and on aerial photographs the canopy appears even and dark-toned.



(vi) *Medium-crowned Lowland Hill Forest* (Plate 3; Plate 6, Fig. 1; Plate 7).—This type covers the largest area of the forests below 1400 m. It occurs on many different land forms and rock types, and in a variety of climatic conditions, and as a result it has a variable structure. In general terms, it differs from large- to medium-crowned forest on plains and fans in the following respects. The forest canopy is less variable in height (25–30 m), closure (60–80%) and crown size. Emergents, except *Araucaria*, are lower, reaching 40 m but rarely 50 m. Trees with very large girths and large buttresses are less common, but the total number of trees with a girth over 30 cm is greater, and there are more trees in the pole and sapling stages. The shrub layer, consisting mainly of slender saplings, has a lower cover, but the herb layer is generally denser, though very patchy. Thick woody lianes, rattan, palms, and fleshy climbers and climbing ferns on tree trunks are less common. Tall palms in the canopy are a normal feature, though they usually occur in small numbers only.

Medium-crowned lowland hill forest is very mixed floristically. Frequent canopy trees throughout are *Pometia*, *Canarium*, *Anisoptera*, *Cryptocarya*, *Terminalia*, *Syzygium*, *Ficus*, *Celtis*, *Dysoxylum* and *Buchanania*, with many more as frequent as *Buchanania*. Some trees, such as *Koompassia*, *Dillenia*, *Eucalyptopsis* and the dipterocarps *Vatica* and *Hopea*, are common to abundant in certain regions but absent in others. Scattered *Araucaria* is present in many localities and in some places forms dense stands (Plate 5, Fig. 2); the tree reaches heights of over 70 m and a girth well over 3 m. Emergent *Albizia falcataria* usually indicates old secondary forest; the tree is recognizable on aerial photographs by its light-toned, wide, flat crown.

Factors such as altitude, amount and distribution of rainfall, steepness of slope and position on the slope influence the structure and floristics of the forest. With increasing altitude the initially very mixed forest becomes poorer in tree species, and lower montane trees such as *Castanopsis*, *Lithocarpus*, *Elaeocarpus* and *Sloanea* are prominent. At the highest levels tree ferns and epiphytic mosses become conspicuous.

In areas that have an annual rainfall between about 1200 and 1800 mm and a marked dry season, the forest has many deciduous and semi-deciduous trees in the canopy (Plate 6, Fig. 1), but the lower storeys remain evergreen. Such forest is similar in structure to its evergreen counterpart except that the canopy is somewhat more open and commonly contains scrambling bamboo.

On steep and unstable slopes the forest canopy is open, irregular and smaller-crowned, and many trunks are leaning or are bent at the base. Soil erosion causes roots to become exposed and some trees develop adventitious roots.

The structure of hill forest on foot slopes in valleys resembles that of large- to medium-crowned forest on plains and fans. *Pometia* is a very common tree on such sites.

(vii) *Small-crowned Lowland Hill Forest* (Plate 6, Figs 1 and 2; Plate 7; Plate 8, Fig. 1).—This type is either a mixed forest which is poorly developed because of adverse conditions of climate and soil, or a forest in which a naturally small-crowned tree species predominates in the canopy.

Mixed small-crowned lowland hill forest occurs on steep terrain with thin soils, e.g. in many mountainous areas, and on undulating to low hilly terrain with poor, strongly weathered, acid clay soils, e.g. locally in south-west Papua New Guinea. Trees are thin-stemmed and low to mid-height. The forest is evergreen where rainfall is adequate and slightly to strongly deciduous in low-rainfall areas with a marked dry season; scrambling bamboo is prominent in many places.

A belt of slightly deciduous mixed small-crowned forest is present inland from the south-central coast, occurring between savanna and grassland towards the sea and medium-crowned evergreen forest inland. This belt is probably due to a combination of seasonal drought stress and shallow soils. Frequent deciduous trees are *Garuga floribunda*, *Brachychiton carruthersii*, *Intsia bijuga*, *Terminalia* spp., *Protium macgregorii* and *Sterculia* spp.

Strongly deciduous mixed small-crowned forest is restricted to coastal mainly limestone hills near Port Moresby where the annual rainfall is less than 1200 mm and severe seasonal moisture stress is common (Plate 8, Fig. 1). Deciduous trees in addition to those mentioned above include *Gyrocarpus americanus*, *Bombax ceiba*, *Albizia* sp., *Maniltoa* sp., *Adenanthera pavonina* and *Erythrina* sp. This forest has a low and open canopy, and in places grades into woodland. The tree storey below the canopy consists of deciduous and evergreen trees, and in the undergrowth many shrubs are spiny and scrambling.

The species that most frequently grow gregariously to form small-crowned lowland hill forest are *Casuarina papuana*, *Castanopsis acuminatissima* and *Hopea papuana*. *Casuarina papuana* tolerates dry conditions and is most common on shallow stony soils, particularly on ultramafic rocks and limestone (Plate 6, Figs 1 and 2). Occurring in many places from sea level to well above 1400 m, and extensively in the mountain ranges west of Mt Suckling and north of Milne Bay, it forms an emergent dark-toned layer 20–30 m high over mixed broad-leaved trees. *Castanopsis acuminatissima* mostly forms narrow bands of dense, mid-height to tall, almost monospecific forest on ridge crests and upper slopes. Where such forest covers larger areas, as on closely dissected plateau surfaces, it has a characteristic smooth, dark grey appearance on aerial photographs. The type extends from about 500 m into lower montane forest and is widespread. *Hopea papuana* forms tall, slender, dense forest from sea level to about 450 m. The type is particularly common in the eastern end of Papua New Guinea (Plate 3).

(viii) *Large-crowned Lowland Hill Forest*.—On plateaux and gentle slopes, provided drainage and moisture conditions are favourable, lowland hill forest has an above average crown size, height and girth and its structure approaches that of large-crowned forest on plains and fans. Such forest occurs, for example, on the lower slopes of volcanoes such as Mounts Lamington, Victory, Karimui and Bosavi. Frequent trees are the same as those in medium-crowned lowland hill forest.

(ix) *Lower Montane Forest* (Plate 8, Fig. 2; Plates 9 and 10).—Lower montane forest occurs throughout the mountain ranges between about 1400 and 3400 m. The evergreen canopy is generally 20–30 m high and is smaller-crowned and more even in height than that of most lowland hill forest; closure is greater and more regular. The trees are of small to medium girth, buttresses are inconspicuous, and many

trunks are low-branched and crooked or leaning. Tree density is often very high. The shrub layer is generally denser than in lowland hill forest, the density varying with its composition and with the height and density of the trees. In many places it consists of a greater number of slender shrubs, elsewhere tall ferns or giant gingers are more common than woody vegetation. The herb layer is also variable in density. The thick, springy layer of humus, leaves, surface roots and fallen logs and branches covering the ground is in places almost completely overgrown by mosses; elsewhere ferns or *Elatostema* form a dense layer. Woody lianes are rare, but a thin climbing bamboo often forms a dense tangle particularly where the forest is open. Climbing rattan and other palms are rare, but tree ferns are often common, and stilt-rooted pandans, sometimes very tall and reaching into the canopy, occur both singly and in groups. Epiphytic mosses, ferns and orchids are common and become more abundant with increasing altitude.

Frequent canopy trees are *Nothofagus*, Lauraceae, Cunoniaceae, Elaeocarpaceae, *Lithocarpus*, *Castanopsis*, *Syzygium*, *Ilex* and conifers. *Nothofagus* spp. (southern beech) and *Araucaria cunninghamii* (hoop pine) tend to grow gregariously, forming tall lower montane forest. *Nothofagus* (Plate 9) often grows in pure, small stands on sites such as ridge crests, limestone pinnacles, and doline rims, but may also form a continuous cover over several square kilometres of plateau, e.g. in central New Britain. Hoop pine also forms dense stands reaching to over 40 m high, and occasionally covers large areas, e.g. in the Goropu Mountains.

In young regrowth stages tree ferns, *Alphitonia incana*, *Dodonaea viscosa*, *Weinmannia*, *Wendlandia*, *Saurauia*, *Eurya* and *Olearia* are common in many places; *Castanopsis*, *Lithocarpus*, *Euodia* and *Elaeocarpus* are often prominent in older regrowth.

As in the hill forests below, the structure of lower montane forest is influenced by topography and climate. On gentle slopes and plateau areas at the lower levels of the zone it grows to a height of 40 m, and many trees have a girth over 1.5 m. On exposed high crests and upper slopes the forest is dwarfed and often very dense, and consists of thin-stemmed, crooked and gnarled trees generally less than 20 m high, known as 'elfin woodland'. In regions that are frequently covered by low cloud, lower montane forest occurs well below the normal lower limit for this forest type, whereas in strongly monsoonal areas this lower limit is much higher than normal. Generally, the higher the altitude of the forest, the longer it is enveloped in clouds, and the greater the abundance of epiphytic and ground mosses and filmy ferns; at the highest levels it is sometimes called 'cloud forest' and 'mossy forest'. However, field observations indicate that above about 3400 m the amount of moss cover decreases again, probably as a result of less frequent and shorter periods of cloud cover, and here lower montane forest grades into montane forest.

The floristic composition also changes with increasing altitude. In the upper levels of lower montane forest Myrtaceae, Elaeocarpaceae and conifers become increasingly common. In addition, trees in the families Myrsinaceae and Ericaceae, and the genera *Drimys*, *Carpodetus*, *Olearia* and *Schuermansia* are prominent, and parasitic woody epiphytes in the families Loranthaceae and Santalaceae are a characteristic feature.

(x) *Coniferous Lower Montane Forest* (Plate 8, Fig. 2).—In many places above about 2400 m altitude, conifers of the genera *Dacrycarpus*, *Podocarpus*, *Phyllocladus* and *Papuacedrus* dominate in the canopy and emergent tree layers. On aerial photographs this type of forest is distinguished from mainly broad-leaved lower montane forest by a dark-toned and smaller-crowned canopy. It is similar to the broad-leaved type in structure, except that many coniferous trees reach a girth well over 1.5 m, even at altitudes above 3000 m, and have a better stem form than most of the associated broad-leaved trees.

(xi) *Very Small-crowned Lower Montane Forest*.—This forest type occurs on ultramafic parent rocks, e.g. on the highest parts of the Otava and Ajule Kajale Ranges, and on limestone, e.g. on the east side of the Saruwaged Range. The canopy of forest on ultramafic rocks appears dark-toned and smooth on aerial photographs, which suggests a predominance of *Casuarina papuana*, and in many places on limestone the canopy appears to be composed of *Nothofagus*.

(xii) *Montane Forest* (Plate 10; Plate 11, Fig. 1).—Montane forest is present above about 3400 m on the highest mountain tops. It is structurally and floristically poorer than lower montane forest. The canopy, 7–15 m high, is generally lower than that of lower montane forest, the shrub layer is more open, and epiphytic mosses and orchids are less common. The trees grow densely and are generally thin-stemmed and crooked. Montane forest is nowhere continuous over large areas but forms small isolated stands surrounded by grassland (Plate 10). Towards the tree limit, at about 3900 m, the trees are lower, much branched, and shrub-like, and montane forest either grades into a dense shrubbery or opens out to form a woodland. However, *Dacrycarpus compactus*, a frequent canopy and emergent tree, is relatively wide-crowned and tall (Plate 11, Fig. 1), and even near the tree limit reaches a height of 15 m.

(xiii) *Dry Evergreen Forest*.—Dry evergreen forest is restricted to a relatively low-rainfall area (1800–2500 mm) in south-west Papua New Guinea. It grows on well to imperfectly drained, very gently undulating to low hilly terrain that lies between mainly *Melaleuca* savanna to the south and lowland hill forest to the north.

Dry evergreen forest is structurally rather similar to slightly deciduous lowland hill forest in other low-rainfall areas, but its main trees are different and mainly non-deciduous. Structurally it differs from evergreen lowland hill forest in having a lower and rather more open canopy, a generally smaller leaf size, more woody lianes, and fewer fleshy climbers, rattan, epiphytes, tree palms and pandans. Frequent trees are *Acacia* spp.; Myrtaceae, particularly species of *Tristania*, *Syzygium*, *Rhodamnia* and *Xanthostemon*; *Maranthes* (= *Parinari*); *Mangifera*; Rutaceae such as *Halfordia* and *Flindersia*; and Proteaceae such as *Oreocallis* and *Grevillea*.

Frequent fires lead to the replacement of dry evergreen forest by woodland which is poorer in species, and ultimately by savanna consisting of only a few fire-resistant tree species from the original forest. Where drainage is impeded, dry evergreen forest gives way to a savanna of low and small-girthed trees which are tolerant of both fire and seasonal waterlogging. Near the border with Irian Jaya, dry evergreen forest locally grades into woodland that has a dense understorey of tall bamboo. Northwards, as rainfall increases, the characteristic trees of dry evergreen forest

disappear, oaks and dipterocarps become more common, and the forest gradually changes into evergreen lowland hill forest.

(b) *Woodland*

(i) *Woodland on Permanently Dry to Periodically Inundated Terrain* (Plate 11, Fig. 2; Plate 13).—Woodland mainly replaces marginal forest after the forest's delicate balance has been disturbed by fire, but also occurs naturally on sites where adverse conditions of climate and soil have prevented the development of forest. It is found on a variety of land forms mainly in the monsoonal areas of the south-central coast and south-west Papua New Guinea.

Woodland has a low and open canopy, but the shrub layer is usually dense and thin woody climbers often abound. Grasses, ferns and sedges form a sparse ground cover. The most frequent trees are those of the forest it replaces or grades into, i.e. small-crowned lowland hill forest, dry evergreen forest and littoral forest.

Woodland that is subject to periodic flooding occurs on poorly drained flats mainly in south-west Papua New Guinea, and throughout the country forms narrow bands around permanent swamp, lakes and lagoons that have a fluctuating water-table. Frequent trees in such woodland are *Carallia brachiata*, *Nauclea coadunata* and, in south-west Papua New Guinea, species of *Melaleuca*, *Acacia* and *Tristania*.

Gallery woodland lines small streams within savanna and grassland, and on aerial photographs this accentuates the drainage pattern as it is denser, higher and darker in tone than the adjacent vegetation. Many of its canopy trees are deciduous and bamboo is a common feature in the undergrowth. It is probably the remnants of more extensive forest or woodland cover.

Woodland on beach ridges occupies a zone between pioneering herbaceous vegetation and scrub to seaward, and forest to landward. It characteristically contains pantropic trees such as *Calophyllum inophyllum*, *Barringtonia asiatica*, *Terminalia catappa* and *Pandanus tectorius*.

(ii) *Swamp Woodland* (Plate 2; Plate 4, Fig. 2; Plate 5, Fig. 1; Plate 13).—Swamp woodland occurs in permanent and near-permanent shallow swamp. It is extensive in swamps associated with the lower courses of large rivers, such as the Mambare, Lakekamu and Purari Rivers.

Except for a more open tree canopy it is similar in structure to swamp forest, and many of the frequent trees are common to both types. On sites that have a strongly fluctuating water level many trees develop adventitious roots and *Carallia brachiata* and *Syzygium* sp. are common. Near the coast, trees characteristic of brackish swamp predominate and the fern *Acrostichum* appears in the ground layer. Where the environment is brackish as well as monsoonal, trees such as *Excoecaria agallocha* and *Melaleuca* spp. are common.

It is convenient to describe here two widespread swamp vegetation types: sago palm vegetation (*Metroxylon sagu*) and pandan vegetation (*Pandanus* spp.). For reasons of simplicity both types have been mapped as swamp woodland, although both normally form dense canopies and neither is strictly woody.

Sago palm vegetation (Plate 2; Plate 4, Fig. 2; Plate 5, Fig. 1; Plate 13) is best developed in shallow swamp where there is a regular influx of fresh water. Here the palm fronds are up to 14 m high, and flowering stems reach 20 m. Gradations

occur from pure sago palm virtually without trees to swamp woodland consisting of a rather dense layer of trees and an understorey of sago. The ground layer varies with the density of the sago palms and the degree of swampiness. Dense stands have no undergrowth. Open stands have an undergrowth of pandans, *Hanguana*, coarse sedges or *Phragmites* on sites that have a water-table permanently at or near the surface, and an undergrowth of grasses, gingers and ferns where the water-table is well below the surface at least for part of the year. Sago stands become stunted and do not flower in transitions to permanent herbaceous swamp, in brackish environment, and on sites where the water-table temporarily sinks deep enough to cause drought stress. Sago palm vegetation is widespread in coastal swamps and also along flat valley floors up to about 1200 m.

In pandan vegetation *Pandanus* spp. form dense, pure stands up to about 8 m high. From aerial photographs and reports pandan vegetation appears to cover large areas in the flood-plains of the middle Sepik River. Small stands are present in the lowlands in coastal brackish environment, in freshwater environment of back plain depressions and old river courses, and on swampy sites in mountainous areas.

Swamp woodland grades into swamp forest or open forest on plains as drainage and aeration improve and the trees become higher and denser. Towards deeper swamp it gives way to herbaceous swamp communities.

#### (c) *Scrub*

Scrub (Plate 11, Fig. 2; Plate 13) occurs on sites that are unsuited to the growth of forest and woodland because of harsh climatic conditions and/or soil deficiencies. In lowland regions that have a strongly monsoonal climate scrub occurs on coastal limestone hills, beach ridges, and periodically inundated, often alkaline plains. In high mountain regions it occurs above the tree line and on steep summit ridges that have shallow stony soils.

Scrub consists of dense shrubs up to about 6 m high. Scattered low trees are usually present. In coastal monsoonal scrub *Hibiscus tiliaceus*, *Desmodium umbellatum* and, on temporarily inundated terrain, *Pluchea indica* are frequent and *Flagellaria indica* is a common climber (Plate 13).

*Sinoga lysicephala* scrub, in mosaic with low sedge-grassland, covers large areas of seasonally inundated plain in south-west Papua New Guinea.

Bamboo scrub with emergent tree ferns is extensive on steep, ash-covered slopes in central and northern Bougainville mainly between 600 and 1200 m. The type appears to be rather stable and may form an arrested successional stage.

*Styphelia suaveolens* locally forms a low, heath-like scrub, in mosaic with grassland, on intermontane valley flats.

In high mountainous areas scrub consists of true shrubs such as *Coprosma divergens*, *Epacridaceae* and *Ericaceae*, and trees that are reduced to a shrub form, such as *Pittosporum pullifolium*, *Xanthomyrtus* and *Papuacedrus papuanus*.

#### (d) *Savanna*

Except for tree-fern savanna in the mountains, savanna is generally confined to low-rainfall areas (less than about 2600 mm p.a.) with a marked dry season (several

months less than 100 mm). Though the category savanna has not been subdivided on the map, it is convenient to describe separately four main types: eucalypt savanna, *Melaleuca* savanna, mixed savanna and tree-fern savanna.

(i) *Eucalypt Savanna* (Plate 6, Fig. 1; Plate 11, Fig. 2; Plate 13; Plate 14, Fig. 2).—This is the most common type, occurring from sea level to about 1700 m on a variety of land forms that are never flooded. In hilly terrain eucalypt savanna is commonly confined to crests and upper slopes, while the lower slopes and valley bottoms remain under forest. In areas with an annual rainfall of less than about 1300 mm and a severe dry season during which up to seven months have less than 100 mm, eucalypt savanna completely covers hills, undulating terrain and plains.

Eucalypt savanna is most extensive along the south-central coast, but is also present in intermontane valleys in the central range some 150 km east of Port Moresby (Plate 6, Fig. 1) and, probably via these valleys, has reached the central north coast near Popondetta. The savanna eucalypts have not as yet spread to other dry areas on the north side of the central range.

Eucalypt savanna consists of a tree layer of one or more of the species *Eucalyptus alba*, *E. confertiflora*, *E. papuana* and *E. tereticornis*, and a ground layer of mid-height grasses, the most frequent of which are *Themeda australis* and *Imperata cylindrica*. *Eucalyptus tereticornis* is present over the whole altitudinal range of eucalypt savanna and tends to dominate on sites having deep soils; it usually has a straight bole and grows to a height of over 30 m. The other savanna eucalypts are present at the lower levels only; they usually have crooked stems and do not normally grow over 20 m high.

Eucalypt savanna is largely a fire disclimax, replacing semi-deciduous and deciduous forest and woodland. Mature eucalypts are to a large extent fire-resistant, but their regeneration is not (Plate 14, Fig. 2), and where fires are very frequent and fierce, eucalypt savanna degrades into grassland. Its boundary with forest is usually sharp and relatively stable. Regeneration back to forest is rare and within mature forest eucalypts are present only near the forest edge.

(ii) *Melaleuca Savanna* (Plates 2 and 3; Plate 12, Fig. 2; Plate 13; Plate 15, Fig. 2).—This is the next most common type of savanna. Occurring from sea level to c. 500 m, *Melaleuca* savanna is characteristic of seasonally inundated or waterlogged plains and fluctuating river back swamps, although it also grows on permanently dry, hilly terrain. It is found mainly in regions with a relatively low and seasonal rainfall in freshwater environment, on brackish sites behind mangroves and on slightly alkaline soils of beach plains. Although most extensive in south-west Papua New Guinea it also occurs along the south-central coast and, rarely, on the north side of the central ranges. *Melaleuca* savanna is also found on hilly terrain on the d'Entrecasteaux Islands, which have a fairly evenly spread rainfall in places as high as 2500 mm or more.

Various species of *Melaleuca* are present, all of which tolerate burning, prolonged inundation and periodic drought. Most frequent are *M. cajuputi*, *M. leucadendron* and, particularly in south-west Papua New Guinea, *M. viridiflora*. Individual stands consist predominantly of one species.

*Melaleuca* savanna on permanently dry to seasonally wet terrain (Plate 3; Plate 12, Fig. 2; Plate 15, Fig. 2) has a ground cover of mid-height to tall grasses such as *Themeda* spp. Trees are up to 20 m high and reach a girth of 1.5 m or more. The type is probably secondary after destruction of forest by fire and is maintained by burning. The boundary with forest is usually sharp, but *Melaleuca* spp., in contrast to the savanna eucalypts, occur freely in mixed forest.

*Melaleuca* swamp savanna (Plates 2 and 13) commonly has a ground layer of tall *Phragmites*. In contrast to *Melaleuca* swamp forest, trees are thin-stemmed, crooked and low. The transition to permanent herbaceous swamp is marked by scattered very thin-stemmed *Melaleuca* trees and in the ground layer swamp grasses are replaced by coarse sedges and *Hanguana*. The type may be mainly an edaphic climax, although fire also plays a part. *Melaleuca* swamp savanna commonly occurs within swamp woodland and has not been mapped separately.

(iii) *Mixed Savanna* (Plate 15, Fig. 1).—Mixed savanna is restricted to south-west Papua New Guinea and occurs on undulating to flat terrain varying from permanently dry to seasonally waterlogged or inundated. Its structure and floristics vary with the depth and duration of inundation and with the frequency of burning. On well to imperfectly drained terrain mixed savanna is 20 to over 30 m high and is relatively dense (Plate 15, Fig. 1). Shrubs are relatively tall and dense and compete with the grasses *Imperata cylindrica*, *Ophiuros tongcalingii* and *Ischaemum barbatum* in the ground layer. The most frequent of the many trees present are *Tristania*, *Melaleuca*, *Acacia* and *Xanthostemon*. Eucalypts, except *Eucalyptus alba* but including *E. polycarpa*, are present in many places but are nowhere dominant.

On poorly drained terrain mixed savanna is lower, more open, thinner-stemmed and poorer in species; with increasing wetness it grades into low *Melaleuca*–*Banksia*–*Grevillea* savanna. This in turn passes into a mosaic of *Sinoga* scrub and low sedge-grassland. Mixed savanna, in contrast with most eucalypt savanna, has no clear-cut boundary, and gradations to forest and woodland are common. There can be little doubt that tall mixed savanna on well-drained terrain is secondary after repeated fire damage to the dry evergreen forest climax, and would revert to forest if seasonal burning were discontinued. Low mixed savanna on seasonally waterlogged terrain may in part be an edaphic climax.

(iv) *Tree-fern Savanna* (Plates 10 and 16).—Tree-fern savanna covers large areas of relatively well-drained sloping terrain between about 2700 and 3300 m. It consists of an open to rather dense canopy of tree ferns belonging to the fire-tolerant and frost-hardy genus *Cyathea*, and a ground layer of mid-height tussock grasses. Tree-fern savanna often forms a broad band between forest on higher slopes and swampy grassland on foot slopes and valley floors (Plate 10) and appears to be largely a secondary community following destruction by fire of a former forest cover. It has not been separately mapped.

#### (e) Grassland

(i) *Grassland on Permanently Dry to Periodically Inundated Terrain*.—This type of grassland is found over a wide range of conditions from sea level to the highest altitudes and as a result has a wide range of species. It is very largely man-made,



even above 2600 m, the upper limit of gardening, and is maintained by burning. For ease of description grassland is subdivided into three types: mid-height, tall and low grassland.

*Mid-height grassland* is the main type, and is widespread on hilly terrain in the lowlands, particularly in areas that have a marked dry season; on the slopes of populated mountain valleys, particularly where such valleys are rain-shadow areas; and on relatively well-drained upper slope and summit areas. The main grasses are tussocky.

In the lowlands, fire-resistant trees and shrubs are always present and *Cycas* locally occurs in great numbers. Herbs, particularly legumes, are always present, though they are often rather sparse. *Themeda australis* (kangaroo grass) and *Imperata cylindrica* (kunai) are the main dominants. *Imperata cylindrica* is prominent in areas that have a long history of cultivation and on sites with relatively deep, well-drained soils either permanently dry or seasonally inundated (Plate 4, Fig. 2); whereas *Themeda australis* is characteristic of monsoonal areas and sites that have shallow soils (Plate 8, Fig. 1). Mid-height *Themeda australis*-*Ischaemum barbatum* grassland covers large tracts of alternately wet and dry upper plains in the middle Sepik River region. In areas where the rainfall is higher and less markedly seasonal other mid-height grasses become dominant, although *Themeda australis*, often in association with *Arundinella setosa*, maintains prominence on dry, shallow, stony crests and slopes. Towards the edges of forests mid-height grassland commonly grades into tall grassland due to the increased frequency of moisture-loving, tall grasses.

Above about 2500 m mid-height grassland is generally lower and more tussocky than in the lowlands (Plate 8, Fig. 2), and herbs form a larger proportion of the cover. Legumes, however, are absent. The main dominants here are *Danthonia archboldii* and *Deschampsia klossii*. On sites that are poorly drained or have shallow soils the grasses are stunted and form low grassland. As the altitude increases such sites become more common and hence the proportion of low grassland increases, though mid-height grassland continues on favourable sites to well above the tree line.

*Tall grassland* grows on deep and fine-textured soils of lowland plains subject to brief seasonal inundation, alluvial fans and undulating terrain. Within mid-height grassland on hilly terrain it occupies foot slopes, drainage lines and seepages. As in mid-height grassland, scattered shrubs and trees are present, but herbs are much sparser due to the denser shade. The main grasses are *Saccharum spontaneum*, *Imperata cylindrica* and *Ophiuros tongcalingii*; these usually grow in mixture. *Imperata cylindrica*, generally a mid-height grass, grows to over 1.5 m tall on favourable sites.

Tall grassland dominated by *Miscanthus floridulus* (swordgrass) covers large tracts of recently abandoned garden land between about 1500 and 2500 m, particularly in the Western Highlands. *Miscanthus floridulus* locally reaches a height of 4 m and grows either in pure stands or mixed with *Imperata cylindrica*.

*Low grassland* is the main vegetation type above the tree line. Where it is more or less continuous, dwarf grasses such as *Monostachya oreoboloides* and species of *Poa*, *Festuca* and *Danthonia* predominate. In areas where it is tussocky it is a stunted form of mid-height grassland commonly dominated by *Deschampsia klossii*. Rosette and cushion herbs, mosses, lichens and low ferns abound. Shrubs are present to well

above the tree line, but with increasing altitude they decrease in height and frequency; many have small, leathery, appressed leaves with inrolled edges.

In the lowlands low grassland covers extensive areas only on flat to very gently undulating plains in south-west Papua New Guinea. These plains are inundated in the wet season; in the dry season the vegetation is burnt off and, particularly near the coast, the plains are grazed by deer and wallabies. Sedges and grasses make up roughly equal proportions of the vegetation, with sedges predominating in places. Common grasses are *Germainia capitata*, *Eriachne* spp. and, on the coastal clay plains, *Ischaemum barbatum*; the most common sedges are *Schoenus sparteus* and *S. calostachyus*. Low herbs such as *Drosera*, *Utricularia* and *Eriocaulon* are prominent.

Another type of low grassland characteristic of south-west Papua New Guinea consists of *Pseudoraphis spinescens*. This grass forms an almost pure, dense, matted sward on river flood-plains that are shallowly inundated probably for most of the year. Towards lower-lying ground this grassland borders bare mud or open water, and towards drier land there is a usually abrupt change to *Melaleuca* forest or *Melaleuca* savanna.

Patches of almost pure, low *Sporobolus virginicus* grassland (salt couch grass) occur along the seasonally dry south-central coast, growing on alkaline clay. This grassland forms a transition zone between mangrove and inland mid-height grassland or savanna. The habitat is probably seasonally flooded by fresh water but is only rarely reached by the tidal salt water.

(ii) *Swamp Grassland*.—Like grassland on dry terrain, swamp grassland occurs from low to high altitudes. It is either a stable edaphic climax or an early stage in the development to forest, though the succession is often arrested and the grassland kept in its seral stage due to dry-season burning. Mid-height, tall and low swamp grassland are described separately.

*Mid-height swamp grassland* (Plate 17, Fig. 1) covers large tracts of permanently swampy river flood-plains, lakes and lagoons in the lowlands, as along the Sepik and Fly Rivers. It is best developed in slowly moving water. The grasses root in organic mud and rise to about 1·2 m above the water level. In the wet season masses of these swamp grasses come adrift and float downstream. Frequent grasses of the lowlands are *Leersia hexandra*, *Oryza* spp., *Hymenachne acutigluma* and, particularly in the Sepik River area, *Panicum paludosum*.

In stagnant water mid-height swamp grassland is replaced by a mixed vegetation of tall herbs, robust sedges and grasses. Towards less swampy ground it commonly grades into tall swamp grassland or swamp woodland; the transition to deeper open water is often marked by floating and submerged aquatic herbs.

*Tall swamp grassland* (Plate 5, Fig. 1) grows in shallower water than mid-height swamp grassland. It occupies permanently swampy to intermittently dry parts of river flood-plains, and lines river cut-offs. The main grasses are *Saccharum robustum*, which may reach a height of 6 m; *Phragmites karka* slightly lower; *Coix lachrym-jobi*, which grows to 2 m; and, particularly in the Sepik flood-plain, *C. gigantea*. These grasses occur mainly below 1800 m, except *Phragmites karka* which is present to over 2500 m and forms small stands in sloping seepage alcoves and occasional large stands on flat valley floors.

*Low swamp grassland* is widespread above about 1800 m, covering bogs in intermontane basins, valley floors and depressions. Frequent grasses on such sites are *Agrostis reinwardtii* (above 2000 m), *Arundinella furva* (between 1800 and 3000 m) and the very low, cushion-forming *Monostachya oreoboloides* (above 3000 m). Sedges are important in the ground cover and commonly replace the grasses on wetter and higher sites to form sedge bog.

(f) *Mixed Herbaceous Vegetation*

The only type in this category that has been mapped is herbaceous swamp vegetation. This type occurs mainly in more or less stagnant, permanent river back plain swamps in the lowlands, forming an almost stable edaphic climax. It consists mainly of a dense mixture of herbs, sedges, ferns and grasses, in places growing to 2.5 m high, which is rooted in peat or organic muck and is sometimes partly floating. The fleshy herb *Hanguana malayana* and the tall sedges *Thoracostachyum sumatranum* and *Scleria* sp. are characteristic (Plate 12, Fig. 1; Plate 15, Fig. 2). In areas with a strongly monsoonal climate this vegetation is burnt in the dry season. Depending on the depth of the water, and possibly also on chance and burn patterns, local facies are often present in which either herbs, sedges or ferns predominate. Towards land, grasses become more prominent, pandans, low sago palms and scattered small trees appear, and the type grades into swamp savanna and swamp woodland (Plates 2 and 13).

Towards deeper swamp a community of submerged and floating aquatic herbs takes over, lining oxbows and blocked channels, and in places covering entire lakes and lagoons that have a uniform, rather shallow depth. This vegetation consists of waterlilies and floating masses of *Lemna*, *Azolla imbricata* and *Pistia stratiotes*, often growing in a mosaic of locally dominant species.

Patches of sedge-grass vegetation in mountain swamps and bogs form unmapped inclusions in grassland. Between 1500 and 2500 m the mid-height sedge *Machaerina rubiginosa* often dominates. At higher altitudes the community consists of low cushion plants including *Astelia papuana* and the sedge *Carpha alpina*.

(g) *Pioneer Vegetation*

Pioneer vegetation comprises a range of communities from scattered club mosses and ferns to forest, pioneering on newly formed ground that has never been vegetated and on terrain where the original vegetation has been destroyed. Most pioneer vegetation occurs in the lowlands, growing on sites that range from swampy to excessively dry. Many small areas of pioneer vegetation have had to be included in other mapping categories, and where pioneer vegetation is shown on the map it has not been subdivided into types. For the purpose of description the various seres have been divided into coastal, riverine, stream-bed and volcanic blast area successions.

(i) *Coastal Successions* (Plate 17, Fig. 2).—From just above high-water mark the first beach ridge behind the beach is covered with creeping, sand-binding herbs and low grasses and sedges. On the seaward slope pantropic *Ipomoea pes-caprae* and *Canavalia maritima* are dominant, whereas grasses and sedges are more prominent on the crest. In places *Casuarina equisetifolia* forms narrow strips of forest on aggrading sandy coasts and offshore sand bars above high-water mark.

In tidal lagoons and river mouths, scrub-like, often pure stands of the mangroves *Avicennia*, *Sonneratia* and *Ceriops* colonize sites that are protected from wave action. At a later stage such scrub becomes mixed with other mangrove species and eventually develops into mangrove forest.

(ii) *Riverine Successions*.—*Sonneratia*, *Pandanus* and *Phragmites* are the first plants to appear on coastal, low, silty river banks and scrolls that are frequently flooded by slightly brackish to fresh water. Upstream, *Saccharum robustum* commonly is the pioneer. *Artocarpus altilis*, *Octomeles sumatrana*, *Timonius*, *Althoffia* and, mainly on New Britain, *Eucalyptus deglupta* are among the first trees to appear on recently formed river banks and flats that are frequently flooded by fresh water, and commonly form pure stands. At a later stage other tree species form lower storeys, and the emerging original pioneers no longer regenerate.

(iii) *Stream-bed Successions* (Plate 4, Fig. 1; Plate 19, Fig. 2).—Coarse stream deposits in upper river courses and outwash fans are commonly colonized by grasses such as *Saccharum spontaneum* on well-drained sites and *Phragmites karka* on poorly drained sites, and by the trees *Casuarina cunninghamiana* and, mainly on New Britain, *Eucalyptus deglupta*. *Casuarina cunninghamiana* pioneers on the very bouldery banks and bars of braided streams as well as on sandy, poorly drained to swampy outwash fans. *Eucalyptus deglupta* colonizes mixed loamy, sandy and coarser deposits that, though frequently flooded, are porous and well drained. Initially the pioneers form pure stands with little or no undergrowth, but gradually a herb layer and a shrub layer develop. When the stream changes course away from such stands, the habitat becomes more stable as a result of less frequent flooding, and broad-leaved species appear. Conversely, increased flooding may retard or reverse the succession. Once closed lower storeys are established the pioneers no longer regenerate and the forest eventually reaches the mixed, broad-leaved climax.

*Terminalia brassii*, commonly in association with *Camposperma*, forms seral forest mainly in the south-west of Bougainville. Such forest occurs on low-lying and frequently flooded sandy river tracts and in peat swamps with flowing water.

(iv) *Volcanic Blast Area Successions* (Plate 18; Plate 19, Fig. 1).—Eruption deposits on and near the cones and craters of volcanoes are colonized by club mosses, ferns, grasses, trees and occasionally tree ferns, which may all appear more or less at the same time. Trees are either scattered or form monospecific stands of such species as *Casuarina cunninghamiana*, *C. papuana*, *Albizia falcata*, *Rhus taitensis*, *Timonius timon*, *Neonauclea* sp., *Trema* sp. and, on New Britain, *Eucalyptus deglupta*. Eventually the pioneers are replaced by mixed forest.

#### (h) *Mangrove Vegetation*

Mangroves occupy sheltered, mostly muddy shores, tidal flats and estuaries, and grow on peat, clay, sand and coral detritus, providing the environment is tidal. They fringe the coast in discontinuous mostly narrow bands that widen in river deltas and around coastal lagoons (Plates 3 and 13; Plate 14, Fig. 1; Plate 20, Fig. 1).

Mangroves are very sensitive to changes in flooding regime and salinity of the water, and as a result commonly grow in distinct zones. Depending on the interacting factors of age, flooding, salinity, climate and soil, mangrove vegetation ranges from a low scrub to a tall forest of trees over 30 m high and over 1.5 m in girth.

Towards land and away from aggrading coasts mangrove forest is older and taller. Tallest is mature mangrove forest in areas of low seasonality in rainfall and on sites that are daily flooded by brackish water from nearby creeks. By contrast, mangroves are only shrubby on poorly drained centres of tidal flats away from creeks, on sandy shores and coral detritus, and, in monsoonal areas, in strongly saline, spring-tidal environment.

Mangrove vegetation commonly has only one tree layer, forming a dense, small-crowned canopy. The ground layer is either absent or consists of mangrove tree seedlings, dense *Acrostichum* and *Acanthus* where the tree canopy is open, or sparse herbs, sedges and grasses in monsoonal areas in the spring-tidal zone. Climbers and epiphytes are either absent or rare, but become more frequent inland. Arched and branching stilt roots of *Rhizophora* and breathing roots, which are peg-like in *Avicennia* and knobby and knee-like in *Bruguiera*, abound.

The main tree genera are *Rhizophora*, *Bruguiera*, *Avicennia*, *Sonneratia*, *Ceriops*, *Lumnitzera* and *Excoecaria*. *Rhizophora* grows nearest the ocean, followed inland by *Bruguiera*. Both trees form tall forest. *Avicennia* forms woodland and scrub on the seaward side of mangrove vegetation and also on saline inner tidal flats, and is often associated with *Lumnitzera* and *Ceriops*. *Excoecaria* is a low tree that favours a brackish environment and is most common in monsoonal areas. Species of *Sonneratia* are present on muddy shores together with *Rhizophora*, on tidal flats, and on the landward side of mangroves where *Sonneratia* grows into a large tree. Included in mangrove vegetation is nypa palm, which is characteristic of areas subject to daily tidal flooding with brackish water.

#### (i) Garden

This category comprises areas of current food cropping, plantations of cash crops, plantings of *Casuarina*, sago palm, cane grass and other plants, weed regrowth and woody regrowth. Cultivation is by shifting agriculture, with fallow periods ranging from 3 to 25 years and more. Only in the densely populated Highlands of Papua New Guinea are permanent cultivation and conversion of grassland back to garden practised on a large scale (Plate 20, Fig. 2). Cold conditions put the upper gardening limit at about 2600 m. The indigenous population gardens well above the frost limit, with periodic catastrophic results, and does not shun very steep terrain, very low, frequently flooded river banks, and mangrove environment (Plate 13; Plate 14, Fig. 1).

#### V. ACKNOWLEDGMENTS

I wish to thank E. Mobbs who has played a large part in the preparation of stereo mosaics and has painstakingly transferred the vegetation boundaries from the mosaics onto the base map.

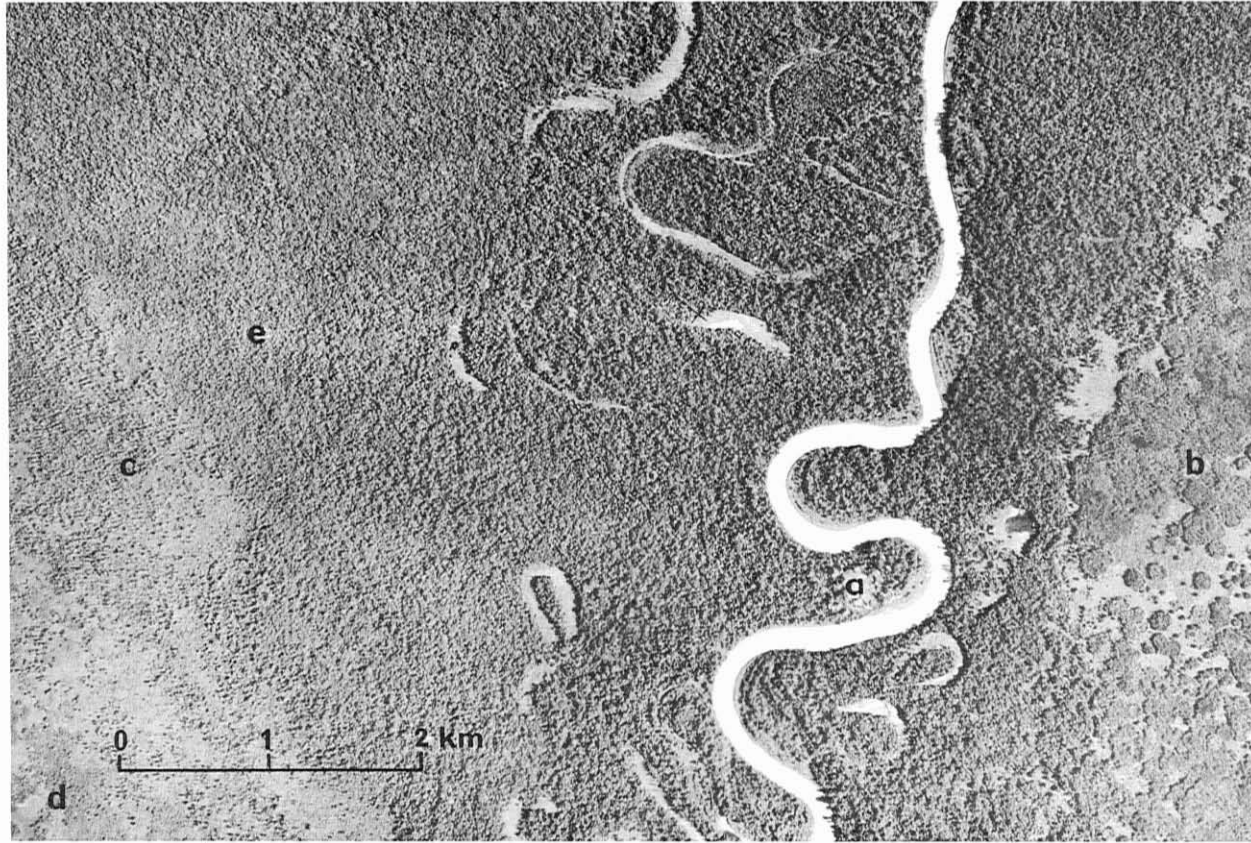
Plates 2, 3, 4, 5 Fig. 1, 6 Fig. 1, 7, 10, 11 Fig. 2, 13 and 18 are Crown Copyright Reserved; aerial photographs reproduced from material supplied by the Department of Minerals and Energy, Canberra, A.C.T.



Fig. 1.—Interior of large-crowned forest on plains and fans, rich in palms and climbers; many trees have buttresses.



Fig. 2.—Wet aspect of open forest on plains and fans. Sago palms are abundant in the understorey. As inundation becomes more prolonged trees become sparser and the type grades into swamp woodland.



Open forest (*a*) near the river is flanked to the right by sago palm vegetation (*b*) and to the left by *Melaleuca* swamp savanna (*c*) merging into herbaceous swamp vegetation (*d*) at bottom left. A zone of swamp woodland (*e*) is transitional between forest and savanna. Rainfall is relatively low, c. 1170 mm, and markedly seasonal.



Mangrove vegetation (a) in tidal swamp, readily distinguished by its dark tones, changes via a narrow zone of brackish swamp woodland (b) into open forest on plains and fans (c). Small areas of garden and secondary forest (d) occur locally on the alluvial plain. *Melaleuca* savanna (e) is the main vegetation type on fans which are seasonally waterlogged due to the presence of very slowly permeable, clayey subsoils; the type cannot be distinguished from eucalypt savanna on air-photo pattern. Forest (f) on the hills backing the plain and fans has been mapped as medium-crowned, though in many places the canopy is small-crowned due to the predominance of *Hopea*. Rainfall is c. 2500 mm and weakly seasonal.



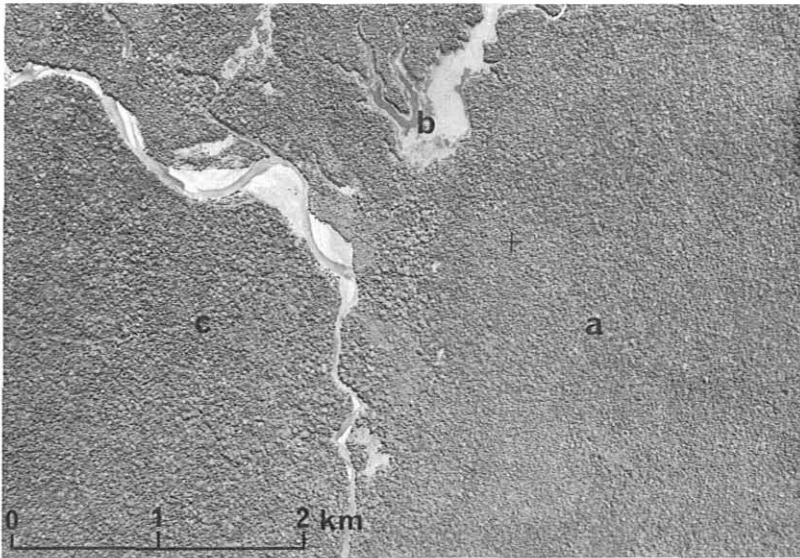


Fig. 1.—Small-crowned forest on plains and fans (*a*) is the main vegetation type to the right, where soils are rich in gravelly lateritic iron concretions. Drowned valleys with swamp grassland and herbaceous swamp vegetation (*b*) are a feature of this type of terrain. Tall forest on plains and fans (*c*) occurs to the left on moderately to well-drained, deep alluvial clays. *Saccharum spontaneum* colonizes the higher parts of sand and gravel bars in the river channel. Vegetated parts show up in grey tones; the frequently flooded and non-vegetated parts are bright white.

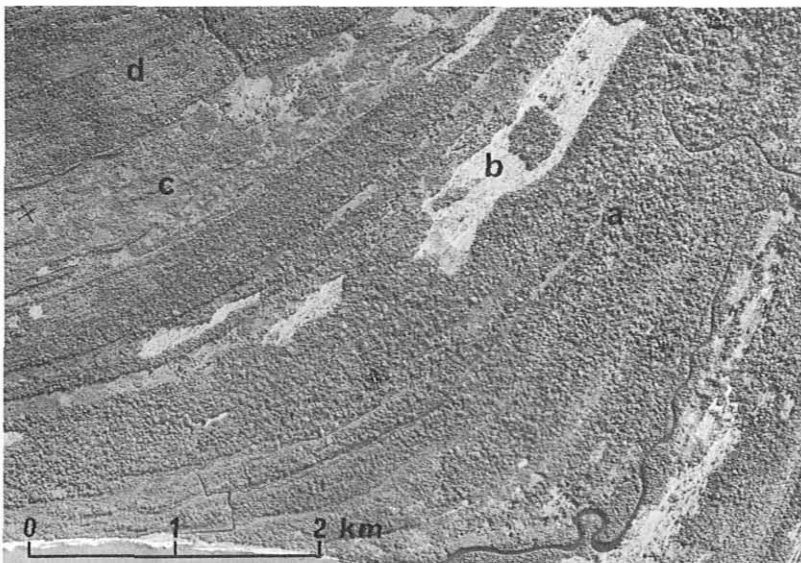


Fig. 2.—Littoral forest (*a*) and grassland (*b*) predominate on beach ridges and partly seasonally inundated outer beach plains. Sago palm vegetation and swamp woodland are present in a broad swale (*c*), and small-crowned *Melaleuca* swamp forest (*d*) covers low-lying inner beach plains. The seasonal annual rainfall is c. 2150 mm.

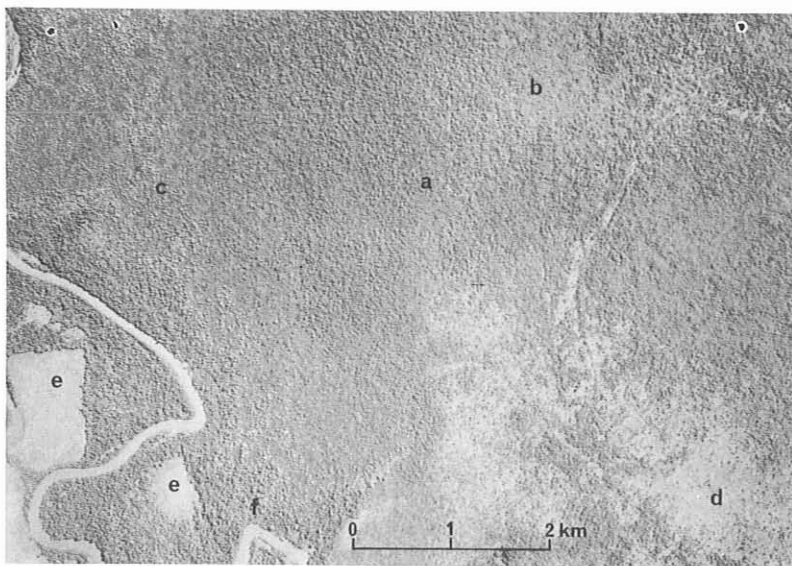


Fig. 1.—Swamp forest (*a*) is the main vegetation of the river back swamp. The forest has a smooth, light grey canopy where *Campnosperma* predominates (*b*). Towards the river swamp forest merges into swamp woodland with a dense understorey of sago (*c*); in stagnant water away from the river it merges into *Phragmites* swamp with scattered trees (*d*). Pure swamp grassland of *Phragmites* and *Saccharum robustum* (*e*) occurs in depressions near the river. Open forest on plains and fans (*f*) is locally present on levees.

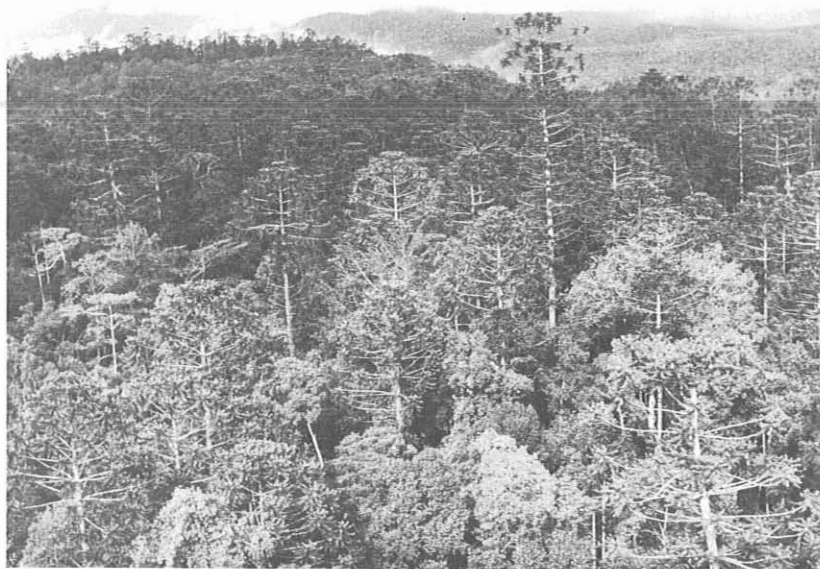


Fig. 2.—*Araucaria hunsteinii* (klinki pine) occurs scattered throughout the hills and mountains of Papua New Guinea, but locally forms a fairly dense upper storey towering some 20 m above a canopy of broad-leaved trees.

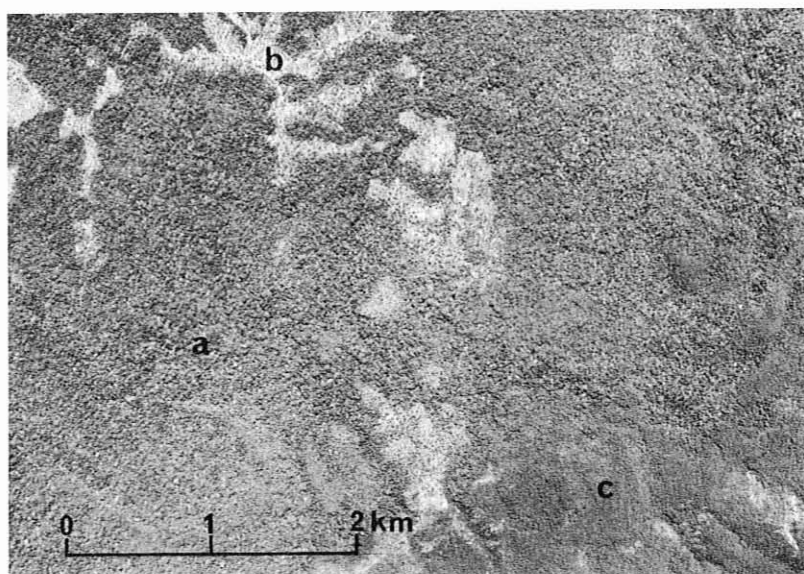
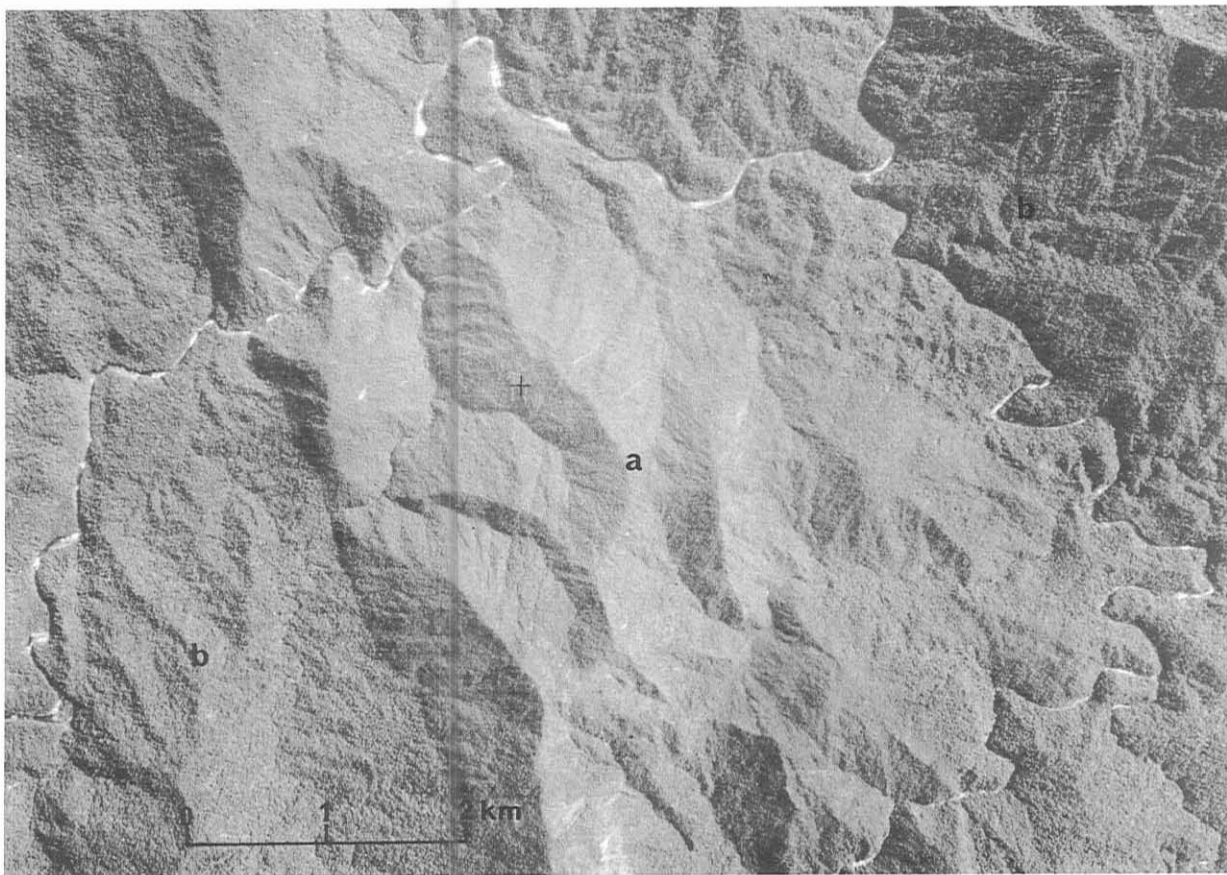


Fig. 1.—Inland rain-shadow area at 750 m with a relatively low and markedly seasonal annual rainfall of *c.* 1650 mm. Slightly deciduous medium-crowned hill forest (*a*) is the main vegetation type; the crowns of trees that have flushed new leaves show as white speckles. Eucalypt savanna (*b*) locally covers crests and upper slopes. *Casuarina papuana* forest (*c*), at bottom right, characterized by a smooth, dense, very small-crowned canopy, is probably secondary after the original forest had been severely damaged or destroyed by fire.



Fig. 2.—Small-crowned hill forest dominated by *Casuarina papuana*. At the skyline scattered araucarias emerge high above the canopy.



Rare example of strong correlation between forest type and rock type. Small-crowned hill forest (*a*) on a wedge of ultramafic rocks running diagonally across the photograph contrasts sharply with the adjacent medium-crowned hill forest (*b*) on mainly basic rocks.



Fig. 1.—Small-crowned, low, deciduous forest on coastal hills south-east of Port Moresby. The bare trees are mainly *Gyrocarpus americanus*. Grassland of *Themeda australis* (kangaroo grass) occurs in foreground.



Fig. 2.—The jagged forest boundary suggests that most of the tussock grassland covering this mountain valley at 2450 m is secondary after destruction of an original forest cover by fire. Grass fires and probably also frost prevent re-establishment of trees in the grassland. The surrounding lower montane forest is rich in conifers, particularly *Phyllocladus* and *Podocarpus*.





Interior of tall beech forest (*Nothofagus*). *Pandanus* and climbing bamboo form an understorey.



Mt Albert Edward region, 2800–3600 m. Grassland (*a*) covering the floor and lower slopes of an intermontane basin at top may be partly primary on the flat swampy basin floor, but is probably secondary on the slopes. A zone of tree-fern savanna present between the grassland and lower montane forest (*b*) on the higher slopes may indicate that tree-fern savanna is an intermediate stage in a gradual conversion of forest into grassland due to recurrent grass fires. Very dark-toned, small-crowned montane forest (*c*) occurs in mosaic with grassland above 3400 m on the summit plateau.



Fig. 1.—Montane forest at the edge of the summit plateau of Mt Albert Edward, 3350 m. The umbrella-shaped crowns of *Dacrycarpus compactus* form the canopy. A shrub zone between the forest and boggy grassland in foreground, mainly consisting of *Coprosma* and various *Ericaceae*, provides some measure of fire protection to the forest.

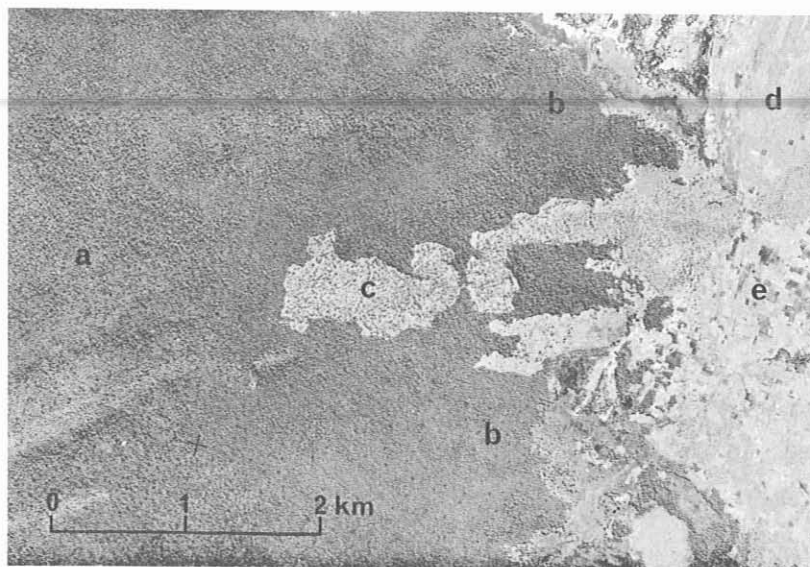


Fig. 2.—Low-rainfall coastal area north-west of Port Moresby. Woodland (*a*) grades into scrub (*b*) towards the coast. Patches of eucalypt savanna (*c*) are also present. Grassland (*d*) and gardens (*e*) cover the beach plain.





Fig. 1.—Herbaceous swamp vegetation consisting of tall ferns and *Hanguana malayana* in foreground is backed by swamp woodland of low, climber-covered trees.

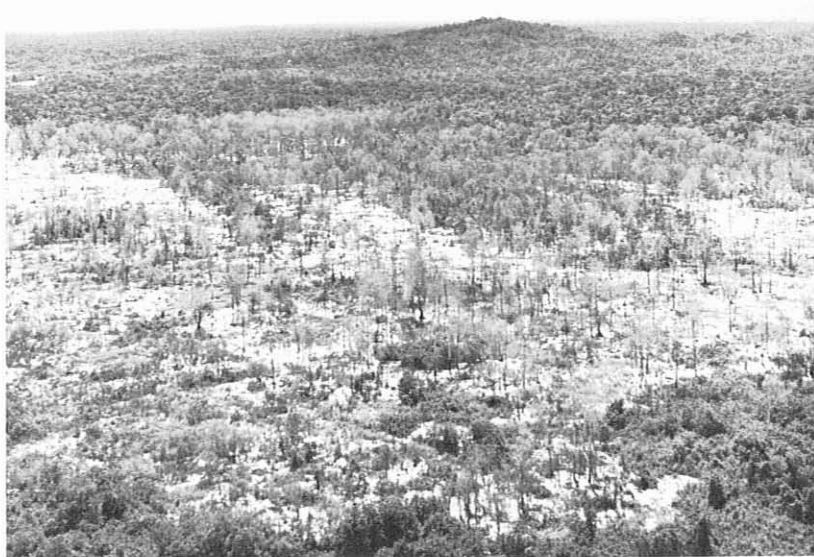
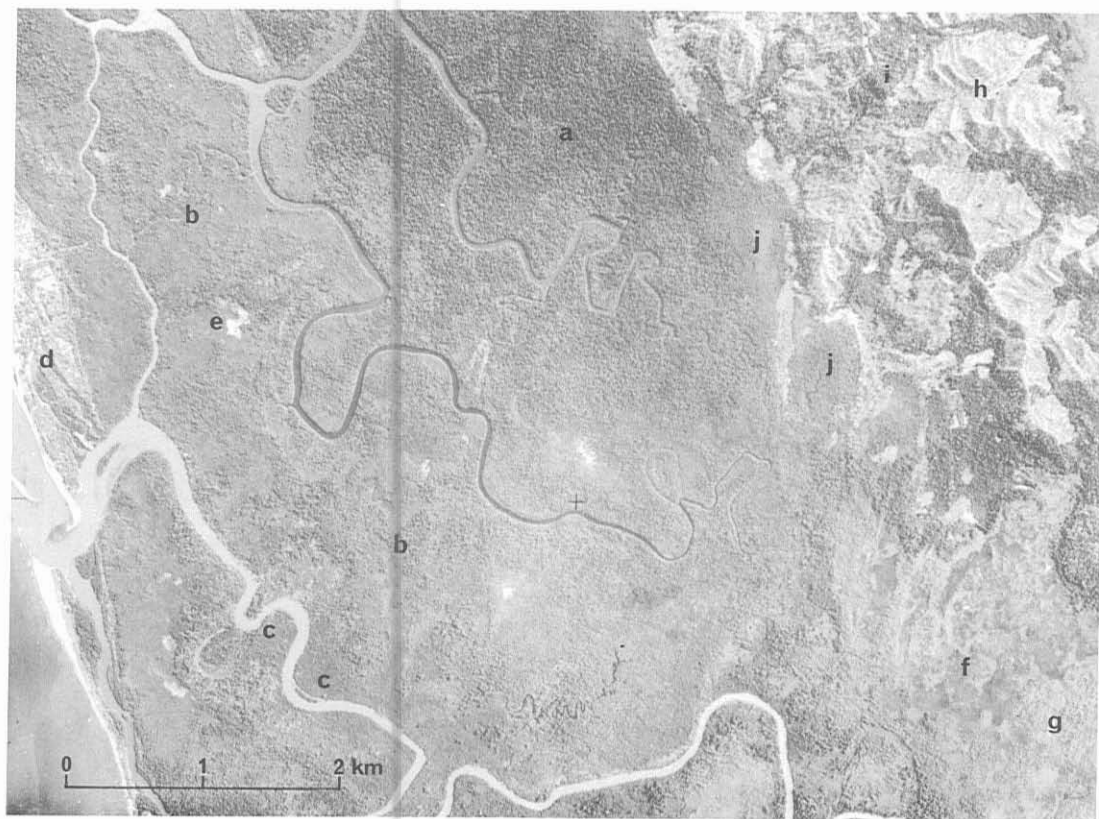


Fig. 2.—Aerial view of *Melaleuca* savanna, showing the blackened trunks of burnt trees inundated with at least 1 m of water, at the end of the wet season.



Dark-toned *Rhizophora-Bruguiera* forest (a) covers saline tidal swamp. Grey-toned nypa palm vegetation and scattered groups of mangrove trees (b) dominate a large area of brackish tidal swamp where sea water and fresh water from the larger river meet and mix. Darker-toned sago palm vegetation (c) is present along the river. The beach ridges are heavily gardened and planted with coconut trees (d); gardens also occur locally (e) within the nypa. Inland from the tidal swamps are mixed herbaceous vegetation (f) in permanent freshwater swamp, and patches of *Melaleuca* swamp savanna (g) on slightly higher ground, while eucalypt savanna (h) and remnants of forest and woodland (i) cover hilly terrain. Small areas of *Hibiscus-Pluchea* scrub (j) occur at the back of the mangroves in fluctuating swamp which dries out during the dry season but is occasionally flooded, probably during king tides, by brackish water.



Fig. 1.—Mixed nypa palm and mangrove vegetation on brackish tidal flat with abundant crab mounds. The man-made clearing is used as a garden, with coconut, banana, sugar-cane and sweet potato planted on the crab mounds. The photograph was taken at high tide.



Fig. 2.—Most eucalypt savanna is a fire disclimax. Mature trees are to a large extent fire-resistant, but their regeneration is usually badly damaged by recurrent grass fires.



Fig. 1.—Tall mixed savanna of south-west Papua New Guinea, consisting of various more or less fire-tolerant trees, is a disclimax resulting from repeated severe fire damage to dry evergreen forest. The most common trees in the picture are *Tristania*, with fissured, dark-coloured bark, and *Melaleuca*, with smooth, light-coloured trunks.

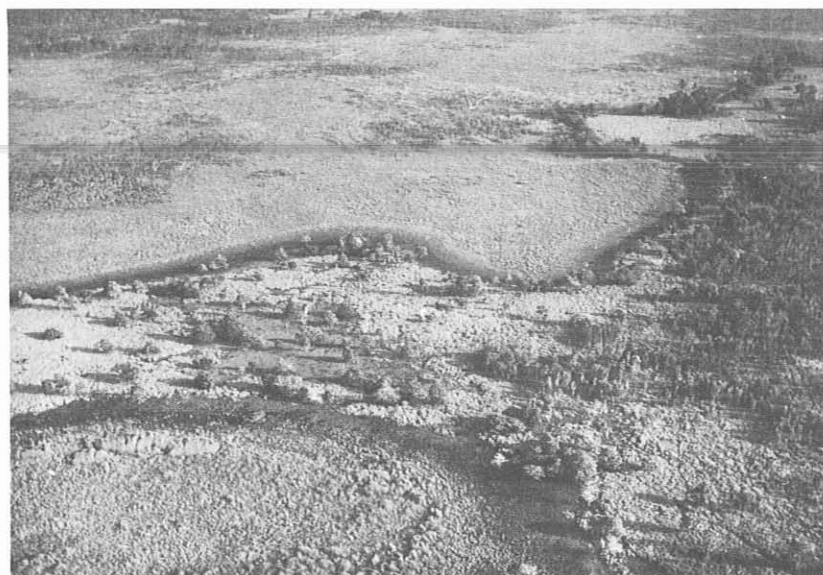


Fig. 2.—Inland edge of the coastal plain in south-west Papua New Guinea, showing the sharp, indented contact between tall sedge and reed swamp vegetation on the coastal plain, top and bottom left, and *Imperata* grassland and *Melaleuca* savanna on the slightly higher, seasonally dry inland plain to the right. The dark-toned margin is formed by a zone of low *Pseudoraphis* grassland.



Tree-fern savanna at 3200 m. Tree ferns (*Cyathea* spp.) typically occupy the relatively well-drained slopes and do not occur on the boggy valley floor and foot slopes.



Fig. 1.—Swamp grasses partly cover many shallow lake embayments, obstructing passage by canoe. Here a rim of *Melaleuca* trees marks the wet-dry transition to the surrounding forest on high ground.



Fig. 2.—*Ipomoea pes-caprae* and other pan-tropical herbaceous pioneers, backed by *Casuarina equisetifolia*, colonize the first beach ridge behind the sea shore from just above high-water mark. *Avicennia*, in the middle ground, colonizes an area within tidal reach.





Waiowa volcano and environs 11 years after its eruption in 1943. The main pioneers on the slopes of the volcano are *Casuarina* (a) and grasses (b), mainly *Saccharum spontaneum* and *Imperata cylindrica*. On the alluvial plain, right and top left, the extent of the devastation caused by the eruption is marked by the abrupt change from large-crowned forest (c) to *Octomeles*-dominated pioneer forest (d).



Fig. 1.—Crater of Waiowa volcano in 1969. A forest of *Casuarina cunninghamiana* and lower *Neonauclea* and *Timonius* has developed on the sides of the crater. Although there was little soil on the blocky slopes, some of the casuarinas had girths over 1·4 m and heights over 30 m.



Fig. 2.—Grasses, mainly *Saccharum spontaneum*, colonize the highest parts of bouldery river beds. Even-aged stands of *Casuarina cunninghamiana* have developed on sites that are above the level of frequent flooding.





Fig. 1.—*Nypa* palm fringes a brackish tidal creek, with mangrove forest in the background. A grove of coconut trees in the right foreground occurs above high-tide level.



Fig. 2.—Sweet potato, the staple crop of the Highlands, is cultivated in mounds of earth containing compost. The mounds shown are at different stages of maturity. At the right centre mounds are being prepared, and those in the right foreground have been composted. Sugar-cane, corn and planted *Casuarina* are also present.