Lands of the Kerema–Vailala Area, Territory of Papua and New Guinea

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PART I. INTRODUCTION

By B. P. RUXTON*

I. INTRODUCTION

The Kerema–Vailala area covers 3272 sq miles in the Gulf district of Papua and 44 sq miles in the Morobe district of New Guinea. It lies to the north-west of the Port Moresby–Kairuku area, previously surveyed by the Division of Land Research in 1962 (Mabbutt *et al.* 1965), and it is bounded by long. 145° 05′ E. and 146° 25′ E. and lat. 7° 30′ S. and 8° 15′ S. (Fig. 1). High hill and mountain chains in

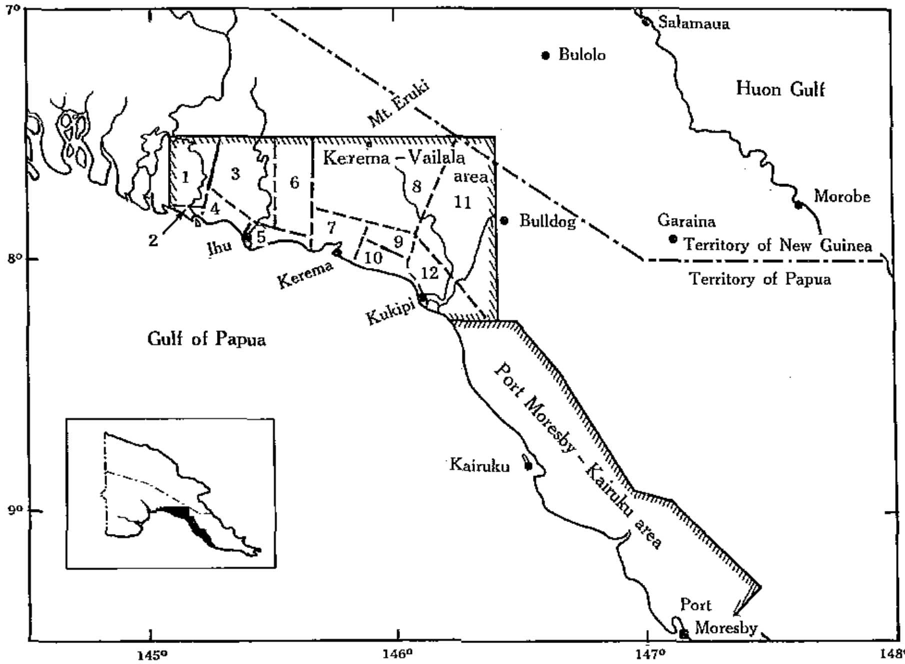

Fig. 1.—Locality map and census divisions of the Kerema–Vailala area (1965). Census boundaries are dashed and divisions are shown by numbers. 1, Iari; 2, Maipua; 3, Upper Vailala; 4, Vailala West; 5, Vailala East; 6, Dewe; 7, Kerema Bay; 8, Kovimoni; 9, Inland Kukukuku; 10, Kaipi; 11, Kovio; 12, Toaripi.

the centre of the area descend to the coast near Kerema and separate the coastal plains of the Purari delta west of Ihu from those crossed by the Tauri and Lakekamu Rivers inland from Kukipi (physical features map).

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Survey procedure was similar to that of previous surveys carried out by the Division in New Guinea (Haantjens 1965). The survey team consisted of a geologist/geomorphologist, a pedologist, a plant ecologist, a forest botanist, and an agronomist, who with the assistance of a transport officer traversed the area by boats near the coast and by helicopter inland between January 21 and March 26, 1966. The inclusion of an agronomist in the team was a novelty in New Guinea surveys and enabled a detailed assessment of the land capability to be made. Only one member of the team, Mr. R. Pullen (forest botanist), had experience of the adjacent Port Moresby–Kairuku survey area.

Aerial photographs taken by Adastra Airways Pty. Ltd. between 1956 and 1963 at a scale of 1:50,000 at sea level were available for most of the area. In the extreme west and north-west, aerial photographs taken in 1939 at a scale of about 1:30,000 at sea level by the Australasian Petroleum Company Pty. Ltd. (A.P.C.) completed the coverage. The Adastra aerial photographs are of poor quality in the middle reaches of the Vailala River and are partly obscured by cloud near the Purari River. The A.P.C. photographs are of very variable quality and their larger scale leads to difficulties in mapping the land patterns recognized on the smaller-scale photographs. The base map at a scale of 1:250,000 used in this report has been prepared by the Division of National Mapping, Department of National Development, Canberra.

The first stage of the work consisted of aerial photograph interpretation carried out in Canberra from April to June 1965. This resulted in the establishment of 35 preliminary mapping units. The boundaries of these units were transferred onto the aerial-photo mosaics for sample planning in the field. About 250 sites were examined in detail in the field by all scientific members of the team together, and on return to Canberra a further interpretation and remapping of the aerial photographs led to the definition of 28 land systems and one land system complex. The sites were distributed fairly evenly over most of the area, with a concentration in areas of land likely to have a high agricultural or forestry potential and with a dearth of observations in the very rugged mountainous country especially in the north-east.

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PART II. REGIONAL DESCRIPTION OF THE KEREMA–VAILALA AREA*

By B. P. RUXTON†

I. CLIMATE

Most of the Kerema–Vailala area has a wet tropical climate, but in the south-east there is a transitional zone grading to a subhumid tropical climate.

In the wet tropical portion the rainfall shows little seasonality, and this is probably due to the southerly projection of the mountains and hills of the Kukukuku lobe across the directions of the prevailing seasonal winds. The mean annual rainfall ranges from 127 in. at Ihu, through 142 in. at Kerema (both on the coast), to 189 in. at Kaintiba, some 40 miles inland. The mean annual temperature at Kerema at sea level is 79·1°F, with little variation through the year. With increasing elevation above sea level the mean annual temperature is expected to decline at the rate of 3 degF per 1000 ft. Mean monthly relative humidity likewise shows little variation, throughout the year averaging 83% at 9 a.m. and 74% at 3 p.m.

In the smaller subhumid tropical area adjacent to the previously surveyed Port Moresby–Kairuku area (Fitzpatrick 1965), there is a marked dry season between June and mid October and the greater part of the 46 in. mean annual rainfall at Kukipi on the coast falls in the "north-west season" between December and April.

II. GEOLOGICAL SETTING

Thick marine deposition of greywacke and mudstone in the Aure trough of the Papuan Geosyncline from near Kerema northwards in early and mid Miocene time was followed at the end of mid Miocene time by meridional folding and later by emergence to form the embryonic core of the central mountains of the Kukukuku lobe.

Complementary subsidence around the central core led to further thick deposition of mudstone and greywacke in the late Miocene and early Pliocene. These beds grade from marine through freshwater to terrestrial towards the core, and to the east where intermediate and basic volcanism also occurred. They were folded and uplifted in about mid Pliocene and reverse faulting along NNW.–SSE. lines took place in the west. This gave rise to a broad sinuous belt of low hills which now skirt around the centre of the Kukukuku lobe and swing inland to frame the Delta and Lakekamu embayments.

Quaternary history has involved the rapid denudation of the uprising Kukukuku lobe and its fringing foothills with complementary aggradation of the two subsiding embayments to form large deltas on and across which alluvium and alluvial lobes are being added.

* This Part has been compiled from data brought together by all members of the team, and J. R. McAlpine contributed to the sections on climate, population, and land use.

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III. Geomorphic Framework

The Kerema–Vailala area forms part of the "southern littoral" physiographic province of Papua and New Guinea and was subdivided by Carey (1938) into the Delta and Lakekamu embayments and the Kukukuku lobe (see map of physical features).

(a) *Delta Embayment*

From the mouth of the Purari River, brackish and freshwater tidal flats extend inland for over 20 miles and merge into alluvial flats only slightly above high water level. Austen (1938) noted "freshwater mangroves" on the inland tidal flats and also the abundant cross-connecting tidal channels between the distributaries. At the coast the normal tidal range is about 7 ft but four times a year the range exceeds $8\frac{1}{2}$ ft, reaching a maximum of 9 ft. The general gradient of the tidal flats normal to the coast is 1 in 20,000.

Although this part of the Gulf coast is actively subsiding (Carey 1938), the sediment supply from the Purari River is so great that the coast is extending rapidly seawards (Austen 1938). As along other parts of the Gulf coast there are no coral reefs.

(b) *Lakekamu Embayment*

The Tauri and Lakekamu Rivers flowing down the axes of alluvial lobes are margined by very large seasonal freshwater swamps which make up the major portion of the Lakekamu embayment. Unlike the Delta embayment river gradients are steeper, probably between 1 in 400 and 1 in 2000, and tidal influences only extend from 7 to 10 miles inland. In the east, two long narrow prongs of low hills aligned north-north-west, the Kurai and Palipala hills, jut out across the alluvial plains and swamps.

(c) *Kukukuku Lobe*

The rugged mountainous area in the core of the Kukukuku lobe includes the Nabo and Albert ranges and reaches a maximum of 7325 ft at Mt. Eruki. They form a great southward-projecting lobe separating the lowlands of the Delta and Lakekamu embayments. The outlying members form rocky headlands at the strand at The Bluff and Cape Cupola.

The lower mountains in the west are arranged as long strike ridges which are aligned north-north-west and curved concavely towards the north-east.

Low hills in a wide belt fringe the mountains of the Kukukuku lobe and extend around the head of the embayments. The hills are intricately dissected, with low relief, and are seldom higher than 500 ft. The harder rocks form prominent strike ridges parallel to the trend of the hill belt, and one such curved ridge running for 30 miles from near Murua to beyond the Tauri River near Hauta has been named "Rim Ridge".

Several partly enclosed basins occur within the foothills and are most common between the Vailala and Purari Rivers.

IV. The Major Environments

As a result of the geological and geomorphic history four major environments have been formed: littoral plains, alluvial plains, foothills, and the hills and mountains of the Kukukuku lobe (see map of physical features). Each of these environments is described below in terms of its geology, geomorphology, soils, and vegetation. Reference is made to all land systems within each environment and this section should be read in conjunction with the land system map, the plates, and Part VI.

(*a*) *Littoral Plains* (*349 sq miles*)

Outgrowing deltas and bay infillings are built from the bed loads of the rivers and are veneered by sediments deposited in the intertidal zone to form littoral plains. As the beach ridge barriers grow seawards their inland margins are degraded by tidal creek scour and are converted into tidal flats on which there is slow deposition of fine silt and clay and very slow peat accumulation. The tidal creeks tend to be interconnected with a rectilinear pattern separating interchannel flats of oblong shapes with raised rims. The raised rims are accentuated by an abundance of crab mounds adjacent to channels and may be built up above normal high-tide level.

The salt-water tidal flats (Alele land system; Plate 1, Fig. 1) with undifferentiated fine-textured "soft" alluvial swamp soils and mostly mid-height *Rhizophora–Bruguiera* forest, and the brackish tidal flats (Nipa land system; Plate 1, Fig. 2) with similar soils and *Nypa* palm occur close to the coast. Inland they merge into freshwater tidal flats just below high-tide level, with organic soils with either mid-height swamp forest (Purari land system) or swamp woodland (Murva land system; Plate 2, Fig. 1). Further inland the uppermost freshwater tidal flats merge into and are being replaced by accreting alluvial plains, and this transitional zone with undifferentiated fine-textured "soft" alluvial swamp soils and sago palm under a very open canopy of mid-height trees is mapped as Ebala land system.

Beach ridge barriers graded to sea level along the coast form Araimiri land system (Plate 2, Fig. 2). They have strongly gleyed undifferentiated sandy soils, locally with neutral thick dark topsoils, and littoral woodland largely replaced by coconuts and gardens. Sago, *Phragmites*, and *Nypa* palms occupy the swales. Inland remnants of degraded beach ridge barriers and raised beach plains are distinguished as Malalaua land system (Plate 3, Fig. 1), with undifferentiated neutral to weakly acid sandy soils, locally with thick dark topsoils, and minor undifferentiated alluvial soils. Tall large-crowned forest is locally replaced by coconuts, gardens, and mid-height grassland.

(*b*) *Alluvial Plains* (*857 sq miles*)

Above the highest tidal levels surface deposition on the plains and in the valleys is almost wholly derived from the suspended sediments of rivers forming alluvial plains and meander tracts that extend far inland. Wherever land gradients and drainage outlets are inadequate to disperse the rain and run-on water, freshwater swamps are maintained. Accretion from the run-on water gradually forms better-drained alluviated basin plains; while near the larger rivers and in confined valleys rapid alluviation has formed higher-lying flood-plain tracts.

The non-tidal freshwater swamps are floored by very heavy clay, occasionally interstratified with peat layers, except near the coast where newly formed portions are developed on degraded beach ridges. They are classified on their vegetation into five land systems. Tall mixed swamp forest and *Campnosperma* swamp forest occur in permanent stagnant swamps with organic soils (Campnosperma land system; Plate 4, Fig. 1). *Thoracostachyum–Hanguana* in the west and tall *Phragmites* grassland in the east occupy permanent and semi-permanent deep-water herbaceous swamps with undifferentiated fine-textured "soft" alluvial swamp soils (Waigani land system; Plate 3, Fig. 2) and organic soils. In the south-east of the survey area *Melaleuca leucadendron* swamp savannah (Melaleuca land system; Plate 4, Fig. 2), with undifferentiated fine-textured "soft" alluvial swamp soils and undifferentiated strongly gleyed alluvial soils, dries out and is burnt in the north-west season. Pure sago palm (Karama land system) is common, especially on the intake zones of swamp margins on undifferentiated fine-textured "soft" alluvial swamp soils and near the coast on organic soils developed on sands. Swamp woodland (Movori land system; Plate 3, Fig. 2) occurring on similar soils is scattered throughout the area.

The alluviated basin plains (Vailala land system; Plate 6, Fig. 2) are mostly infilled tectonic depressions with drainage outlets or with antecedent through-going drainage as on the Vailala River. They have undifferentiated fine-textured strongly gleyed alluvial soils and mid-height basin forest.

The flood-plains were differentiated on their vegetation and land form, which in turn reflect their drainage and stability. In most areas silty levees merge into clay-mantled back plains: the scrolls are built of fine sand, overlain by coarse silt, and prior meanders and oxbows are being infilled with heavy clay. The rapidly growing ends of the meander tracts of the Tauri and Lakekamu Rivers are very unstable, with undifferentiated fine- to medium-textured strongly gleyed alluvial soils and freshwater swamp woodland transitional to tall large-crowned open canopy forest (Terapo land system; Plate 5, Fig. 1). A tall large-crowned open canopy forest occurs on poorly drained unstable alluvial plains with undifferentiated fine-textured moderately to strongly gleyed alluvial soils (Tauri land system; Plate 5, Fig. 2). On alluvial terraces, flood-plain terraces, and better-drained back plains with non-gleyed undifferentiated fine- to medium-textured weakly acid alluvial soils, the forest is tall and large-crowned with moderately closed canopy (Hepea land system; Plate 6, Fig. 1).

(*c*) *Foothills* (*580 sq miles*)

The high hills and mountains of the Kukukuku lobe are generally separated from the plains by a belt of low foothills developed on soft mudstone and greywacke of Upper Miocene and Pliocene age.

Partly dissected benches with strongly weathered acid to strongly acid soils and mid-height hill forest (Olipai land system) are scattered along the outer edge of the foothills, particularly around the Lakekamu embayment. In places, with increasing dissection, these merge into low undulating concavo–convex hills with moderate slopes and uniform-textured acid to strongly acid soils and strongly weathered acid to strongly acid soils (Hauta land system; Plate 7, Fig. 1). The hill forest is mid-height and small- to medium-crowned except in the south-east where it is very small-crowned.

Where the rocks are more tightly folded and more steeply dipping, usually on the inner part of the foothills, the hill ridges have very steep slopes with uniform-textured strongly acid and undifferentiated colluvial soils and mid-height hill forest (Maipora land system; Plate 7, Fig. 2). In the west between the Purari and Vailala Rivers similar land associations differ only in having the linear ridges separated by a maze of alluvial flats with undifferentiated fine-textured acid soils and mid-height basin forest (Aro land system).

(*d*) *Hills and Mountains of the Kukukuku Lobe* (*1479 sq miles*)

The central part of the Kerema–Vailala area, between the embayments and reaching to the coast at The Bluff and Cape Cupola, is the Kukukuku lobe, most of which is composed of high hills and mountains developed mainly on Lower and Middle Miocene greywacke, mudstone, and subordinate limestone. The nine land systems are distinguished on land form and lithological characters. There is a wide variety of soils and vegetation varies mainly with altitude and slope. Above about 3000 ft large areas of the forests are secondary.

In the Wenna valley, a tributary of the Tauri, between 4000 and 5500 ft, a series of low hill ridges with benched spurs have uniform-textured acid soils with secondary *Castanopsis* forest and garden regrowth (Kwambega land system; Plate 8, Fig. 1). At lower altitude (about 900 ft) a series of parallel accordant low ridges and dissected alluvial benches between the Ivori and Lohiki Rivers, with uniform medium- to fine-textured acid soils and strongly weathered acid to strongly acid soils have dense mid-height hill forest (Bananu land system).

In the east, on the Saw Mountains and north of Putei, flat-lying Miocene limestone forms hilly plateaux rising from 2500 ft in the south to 5500 ft in the north. The steep-sided low hills and enclosed depressions have undifferentiated shallow stony colluvial soils and mid-height lower montane and upland forest with mixed *Casuarina* forest on the upper slopes and crests (Saw land system; Plate 8, Fig. 2).

Around the Saw Mountains and near Putei a group of high hills with smooth steep and moderate slopes, partly developed on limestone, has uniform medium-textured shallow soils and undifferentiated soils with mid-height hill and upland forest and many deciduous trees (Putei land system). Further east on gently folded Upper Miocene and Pliocene greywacke, conglomerate, and subordinate volcanics, the high hills have well-developed scarps and dip slopes with uniform medium-textured acid shallow soils and mid-height hill forest (Kurai land system; Plate 9, Fig.1).

Most of the high hills of the Kukukuku lobe are developed on Lower and Middle Miocene greywacke, mudstone, and subordinate limestone. Where structural control is not evident and small benches occur on the moderate to very steep slopes, they are mapped as Lohiki land system (Plate 9, Fig. 2). This has undifferentiated medium- to fine-textured acid soils with mid-height small- to medium-crowned hill forest, and minor tall medium- to large-crowned hill forest. In contrast high parallel subaccordant ridges with very steep upper slopes and very broad dissected foot slopes with U-shaped valleys and prominent structural control are distinguished as Nabo land system (Plate 10, Fig. 1). This has uniform medium-textured weakly acid soils and undifferentiated colluvial soils and mid-height small- to medium-crowned hill and upland forest.

The core of the Kukukuku lobe, centred on Mt. Eruki (7325 ft), is made up of high subparallel mountain ridges with very steep slopes and uniform medium-textured acid soils (Eruki land system; Plate 10, Fig. 2). The vegetation shows an altitudinal zonation from minor mid-height hill forest through mid-height small-crowned upland forest to largely secondary mid-height lower montane forest. East of the Kapau River, limestone, conglomerate, and volcanics occur in the greywacke–mudstone succession, and the landscape is a complex of hill and mountain ridges, scarps, dip slopes, and structural benches (Kapau Complex land system; Plate 11, Fig. 1). From limited ground data the soils are undifferentiated medium-textured soils and uniform medium-textured acid to strongly acid soils, and the vegetation, as in Eruki land system, ranges from hill to lower montane forest.

V. Forest Resources

The forest potential of the littoral plains is very low. Tall forest on the raised beach plains is of good quality but, due to human interference, economically exploitable areas are very rare and most of its occurrence is in pockets only. The main genera are *Pometia*, *Octomeles*, *Dracontomelum*, and *Terminalia*. Mangrove forest has a potential for the cutch industry and, particularly in the Kerema estuary, is a possible source of raw material for the production of kraft pulp. Access to the mixed swamp forest is difficult, and it is very poor in timber of marketable species and dimensions.

The well-drained alluvial plains have a moderately high forest potential. Highest in terms of timber volume are the forests along the Tauri River, with *Dracontomelum mangiferum* as the most frequent timber species. The alluviated basin plains of Vailala land system have a lower timber volume and present access difficulties because of generally poor drainage. *Campnosperma* occurs in more or less pure but scattered stands near the coast as well as inland.

The forest potential of the foothills is moderate to low. Marketable genera such as *Pometia*, *Homalium*, and *Terminalia* occur throughout but are nowhere very frequent. *Terminalia* is more frequent in the east. *Koompassia*, generally of scattered occurrence, is very locally rather common.

The forests of the hills and mountains are very difficult to impossible of access as regards timber haulage, and also they have been greatly disturbed by shifting cultivation.

VI. Agricultural Capability

Some 500 sq miles of the land of the Kerema–Vailala area has a moderate or high capability and is distributed around the inland margins of the embayments, in the basins of the fringing foothills, and, to a lesser extent, near the coast mainly west of Kerema. No large areas of land have a very high agricultural potential.

Much of this potentially usable land is concentrated in three main areas: on the alluvial plains of the Vailala River; on a belt of undulating hills, terraces, and alluvial plains bordering the south side of Rim Ridge and passing through Hauta on the seasonally navigable Tauri River; and on scattered areas of undulating hills, terraces, alluvial plains, beach ridges, and beach plains close to the coast from near Kerema west to Muro.

The largest contiguous area of good land of about 50 sq miles, with high potential for arable crops or rice, occupies the lower Vailala basin close to the growing town of Ihu. This area would, however, require drainage improvement of the heavy clay soils before development.

The largest areas of almost entirely well-drained land, best suited to tree crops, occur on low hills west of Hauta (13,000 acres) and around Epo near Kerema (8000 acres). On the other hand, the better-drained parts of the beach ridges and beach plains should probably be more fully utilized for coconuts.

Other than the plains and less rugged low hills there is very little potential for agricultural development, owing to swampy conditions and inundation in tidal or seasonal swamps or severe erosion hazards with problems of accessibility in steeply sloping hills or mountains.

Improvement of alluvial plains and beach plains by drainage appears feasible, but reclamation of the large swamps of the Delta and Lakekamu embayments would be extremely difficult and involve very large engineering works.

VII. Population and Land Use

The total population is estimated at about 32,000 indigenes and 70 Europeans, most of whom live near the coast. In fact 60% of the population, the Elema people, live on less than 1% of the survey area on the beach ridges and beach plains of Araimiri and Malalaua land systems.

Sago gathered from the swampy swales is the chief source of food for the Elema people. This is supplemented partly by fishing, particularly in the drier eastern area, and partly by gardening. Garden crops include sweet potatoes, yam, taro, bananas, cassava, edible pit-pit, papaw, pineapple, cucurbits, maize, tomatoes, and peanuts. Gardens are shifted regularly on the bush fallow system with a rotation cycle of less than 10 years in the densely populated areas, e.g. in the coastal strip from Orokolo to Harevavo where population density exceeds 600 persons per sq mile.

The coastal beach ridges and beach plains also contain nearly all the cash cropping activity of the area, with 644 tons of copra per annum from six European-managed plantations and 1582 tons of copra from numerous indigenous small holdings. Most of this production is from the area between Muro and Araimiri. The rapidly growing town of Ihu, with an all-weather airstrip, near the mouth of the Vailala River acts as an administrative and commercial centre for the area.

In the east the populated coastal beach ridges are separated from the unpopulated inland beach plains at Malalaua by tidal swamps, and the administrative centre at Kukipi is being moved inland to Malalaua with its large all-weather airstrip in an attempt to encourage the coastal people to move inland onto better land.

The Kerema estuary with its excellent natural harbour is the site of the main administrative centre, and the seasonal airstrip at Kerema town is supplemented by an all-weather airstrip at Murua. The established rubber plantation at Epo nearby produces about 700,000 lb per annum, and production of rubber and coffee is just commencing from the Murua settlement scheme which when fully developed will occupy 7207 acres.

Little use has yet been made of the levee banks of the navigable rivers, particularly along the Purari, Vailala, Tauri, and Lakekamu Rivers. At present there is a steady increase of settlement along the rivers as the distrust between the mountain Kukukuku tribes and the coastal peoples diminishes. Thus a dryland rice scheme has been established at Terapo on the Tauri River and this settlement is serviced by an all-weather airstrip. Small dryland rice holdings are also being established several miles further up the Tauri River (Plate 5, Fig. 2).

The Namau people numbering about 1000 and living on the tidal flats of the Purari delta subsist mainly on sago supplemented by hunting and fishing. For luxuries they depend on the vagaries of growth of bananas, sweet potatoes, sugarcane, and coconuts planted individually on the tops of crab mounds all but submerged daily by the tide (Plate 1, Fig. 2).

Inland the estimated 3000 Kukukuku people are concentrated around Moiwari and subsist from shifting cultivation growing chiefly sweet potato, bananas, and taro. Their gardening practice is unusual in that they fell the trees after, not before, planting and do not burn the felled timber (Plate 11, Fig. 2).

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PART III. LAND SYSTEMS OF THE KEREMA–VAILALA AREA

By B. P. RUXTON,* K. PAIJMANS,* P. BLEEKER,* and B. J. LEACH†

I. INTRODUCTION

The land system is a composite mapping unit defined by Christian and Stewart (1953) as "an area, or group of areas, throughout which there is a recurring pattern of topography, soils, and vegetation". Land systems have a characteristic recurring, catenary, or irregular pattern on aerial photographs (Haantjens 1965) and their boundaries are mapped by photo-interpretation of the land form and vegetation (Mabbutt and Stewart 1963).

The land system is made up of several land units which are not individually mappable at the scale of working but which are visited at representative sites in the field, and the observations made of the land form, soil, vegetation, and land use limitations are held to be characteristic of these units over the entire land system.

In the tabular descriptions of land systems, as well as on the land system map, the land systems are grouped morphogenetically in order of increasing altitude and relief and this sequence also corresponds roughly with the order of occurrence of land systems inland from the coast.

II. CORRELATION WITH PORT MORESBY–KAIRUKU AREA

Some of the distinctive aerial photograph patterns mapped as land systems in the Port Moresby–Kairuku area (Mabbutt *et al.* 1965) continue across lat. 8°15′S. into the Kerema–Vailala area with little or no apparent change, for example Nipa and Waigani land systems. The land characteristics of each photo pattern may vary from south-east (Port Moresby–Kairuku area) to north-west (Kerema–Vailala area) and descriptions, i.e. tabulated land systems, may be slightly different as a result. Thus in the Kerema–Vailala area, Nipa land system is confined to pure *Nypa* or mixed *Nypa*–mangrove associations and includes both medium- and coarse-textured soils in the Kerema estuary. Waigani land system has two distinct photo patterns in the Kerema–Vailala area and the name is retained for that part correlated with herbaceous swamp whereas the fringing swamp savannah is separated as Melaleuca land system.

Several land systems (Lesewalai, Galley Reach, Hisiu, and Palipala) are characteristic of the relatively low seasonal rainfall area and these terminate adjacent to the wetter relatively non-seasonal climate towards Kerema. Though mapped, these are left uncoloured in the south-eastern part of the Kerema–Vailala land system

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map and are not redescribed in this report. Some of the land characteristics of these land systems are a little different from those previously described and these differences are enumerated below.

Lesewalai land system of high-lying tidal flats with open low mangrove forest and local bare salt flats extends to close to the mouth of the Lakekamu River. In the Kerema–Vailala area, however, unit 5 of inner tidal flats with *Avicennia* forest occurs on degraded beach plains with undifferentiated sandy alkaline soils.

Galley Reach land system of broad tidal flats with dense mangrove extends to about 8 miles east of Kerema. In the Kerema–Vailala area, land unit 4 consists of uppermost tidal flats with undifferentiated "soft" alluvial swamp soils and low to mid-height mangrove forest, and also includes large areas of mangrove woodland transitional to freshwater swamp woodland with abundant crab mounds and undifferentiated fine- to medium-textured soils.

Hisiu land system of sandy beach ridges also extends to within 10 miles of Kerema, but unit 2 of beach ridge complexes and sand plains is better considered as two units in the Kerema–Vailala area. A major unit of beach ridges has neutral sandy strongly gleyed soils with thick dark topsoils and mid-height *Imperata* grassland or *Lumnitzera* scrub or coconut plantations; and a minor unit of very poorly drained swales has undifferentiated sandy strongly alkaline soils and low grassland or low *Avicennia* forest.

Although Palipala land system extends only a few miles into the Kerema–Vailala area, the character of the soil and vegetation is different from that described further south-east. Thus eucalypts are absent. In unit 1 (on ridges) the soils are neutral to weakly acid, not alkaline, and the vegetation is mostly mid-height grassland, *Imperata* with *Coelorachis* locally co-dominant and no *Ophiuros*. The main valley plains (unit 3) have undifferentiated fine-textured neutral strongly gleyed alluvial soils with mid-height *Imperata–Saccharum spontaneum* grassland, and the foot slopes (unit 6) have weakly acid medium-textured soils with very thick dark topsoils and mid-height *Imperata* grassland with *Coelorachis* co-dominant and no *Ophiuros*. Finally, a narrow fringing level plain of alluvium over degraded beach ridges formerly mapped in with the main valley plains (unit 3) is now mapped as unit 5 of Hepea land system.

Two of the Port Moresby–Kairuku land systems, Nipa and Waigani, continue throughout the Kerema–Vailala area and are accordingly redefined. Nipa land system is confined to pure *Nypa* or mixed *Nypa*–mangrove associations and includes both medium- and coarse-textured soils in the Kerema estuary. Waigani land system is redefined as herbaceous swamp and the fringing swamp savannah is separated as Melaleuca land system.

III. Explanation of Tabular Land System Descriptions

(*a*) *Terrain Parameters*

The terrain parameters used in this report are the same as those defined by Speight (1967) for the Bougainville–Buka Islands area, and the plan-profile classification is that of van Lopik and Kolb (1959).

(*b*) *Block Diagrams and Plans*

The block diagrams and plans are composites made from a combination of typical forms or patterns in each land system and the land units are not necessarily shown in their correct proportion. They are drawn to different scales and each block diagram has both the horizontal and vertical scale indicated on it. A small map shows the distribution of the land system.

(*c*) *Land Units*

The land unit description below the block diagram or plan gives a systematic correlation between land forms, soils, vegetation, and land use limitations. Areas of land units are subjective estimates from inspection of the aerial photographs and may be in error by up to 20%.

(i) *Land Form.*—The standard set of parameters defined by Speight (1967) for Bougainville and Buka Islands is used in this report.

(ii) *Soils.*—The brief soil descriptions are given in terms similar to those used in the 7th Approximation (United States Soil Conservation Service 1960). The number in brackets refers to the great soil group and family which are described in more detail in Part VI. For each land unit soil families are described in the order of their abundance.

(iii) *Limitations.*—Land characteristics that impose limitations on the potential land utilization are here presented by a letter denoting the nature of each limiting characteristic, together with a number denoting the estimated degree of severity. These are presented in Appendix I. Permeability ratings are also presented as this factor has an important bearing on drainage and irrigation.

The degree of difficulty in providing irrigation water for rice is also presented for each land unit where applicable.

(*d*) *Inclusions*

The scale of mapping prevented the delineation of small but significant areas of other land systems within the boundaries of the land system described and these are mentioned here.

(*e*) *Population and Land Use*

The population of a land system is given as the total of the populations of the villages that occur on it. Where the population of one land system uses land of an adjoining land system to any large degree, this is stated. There is no census as yet of the mountain Kukukuku people hence land systems in the Kukukuku lobe have no population figures.

Areas of the various land use types per land system are stated but it is not possible to measure riverine land use or sago areas that are harvested. Areas "used for cultivation" are those areas of current cultivation together with resulting secondary growth under 50–80 years old but mostly under 25 years.

IV. References

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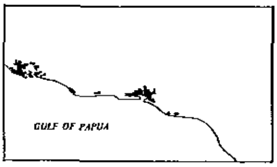
(1) Alele Land System (62 sq miles)

Tidal mangrove swamps.

Geology.—Recent estuarine and lagoonal mud, silt, and sand with local peat.

Geomorphology.—Open-ended tidal channels surround inter-channel flats with raised rims and depressed centres. Crab mounds are abundant on the raised rims and rapidly decrease in abundance away from the channels. Newly formed tidal flats include emerging mud banks in estuaries, lagoons behind off-shore sand bars, and degraded beach plains.

Terrain Parameters.—Altitude: av., $2\frac{1}{2}$ ft; min., −5 ft in channels; max., 6 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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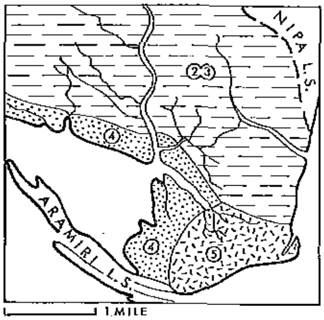
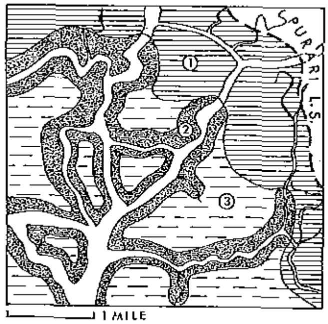




Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	12	**Upper tidal flat:** transitional to fresh water about $4\frac{1}{2}$ ft above mean sea level; up to 4000 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured weakly acid over alkaline, with moderate to high amounts of organic matter (2*a*)	Mid-height forest: *Rhizophora–Bruguiera*. Transitional to mid-height fresh-water swamp forest	i5, w4, p2, a1, c1, I3
2	13	**Raised margins:** of inter-channel tidal flats $2\frac{1}{2}$–4 ft above mean sea level; up to 1200 ft wide		Mid-height forest: *Rhizophora–Bruguiera*	i6, w4, p4, t1, a1, c1, I3
3	33	**Central depressions:** of inter-channel tidal flats 1–$2\frac{1}{2}$ ft above mean sea level; up to 4000 ft wide		Mid-height forest: *Rhizophora–Bruguiera*, lower in height	i6, w4, p2, a3, c1, I3
4	1	**Coastal lagoons:** 1–$2\frac{1}{2}$ ft above mean sea level; up to 2500 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, fine- over coarse-textured, alkaline (2*c*)	Colonizing low forest: *Avicennia*, minor *Sonneratia*	i6, w4, p2, m1, a6, c2
5	3	**Lower tidal flats:** about mean sea level; scattered small crab mounds; up to 2000 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, weakly acid over alkaline (2*a*)	Mid-height forest: *Rhizophora–Bruguiera*. Minor low forest: *Sonneratia–Avicennia*	i6, w4, p4, t1, a4, c1, I3

Agricultural Capability.—Complete empoldering would be required before this land system could be of any agricultural value.

Population and Land Use.—Population 440. Some gardening on unit 2; subsistence chiefly from sago, crabs, and fish.

Forest Potential.—Low-yielding. Locally (unit 2) high-yielding, particularly in Kerema estuary.

Observations.—5.

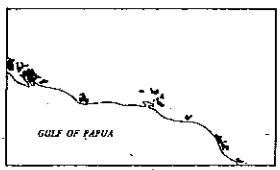
(2) Nipa Land System (45 sq miles)

Tidal swamps with *Nypa* palms (continuation of Nipa land system of Port Moresby–Kairuku area).

Geology.—Recent estuarine mud, silt, sand, and gravel.

Geomorphology.—Inter-channel tidal flats with raised rims and depressed centres, crab mounds becoming abundant near channel margins. In places crab mounds coalesce to form crab islands, generally 12×6 ft, separated by tidal channels. Newly formed tidal flats include emerging mud banks in estuaries, alluvial scrolls on meander bends, and degraded beach plains.

Terrain Parameters.—Altitude: av., 2½ ft; min., −4 ft in tidal channels; max., 6 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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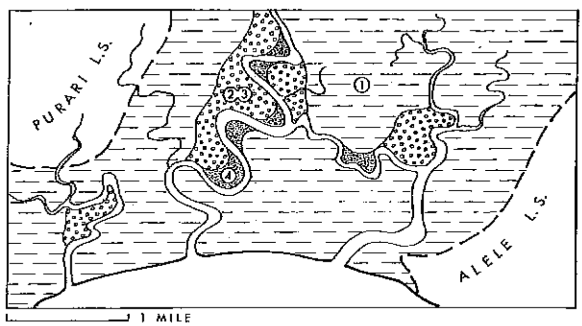


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	35	Upper tidal flat: 2–3 ft above mean sea level; abundant crab mounds near channel margins; up to 4000 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, medium-textured, weakly acid (2*b*)	Palm vegetation: *Nypa*, pure or mixed mainly with *Bruguiera*, locally with *Heritiera*, particularly along creeks	i6, w4, p2, c1, I3
2	6	Crab island: 4–5 ft above mean sea level; generally 12×6 ft	Undifferentiated alluvial soils: strongly gleyed, fine- to medium-textured, acid (3*a*)	*Acrostichum* fern	i1, w2, p4, a2, n2, I3
3	3	Tidal channels: between crab islands from below to about 3 ft above mean sea level; 6–12 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, with neutral to weakly acid topsoils over alkaline subsoils (2*a*)	Palm vegetation: *Nypa*, mixed with minor young mangrove	i6, w4, p4, a4, c1, I3
4	1	Scrolls: on meander bends of tidal channels and rivers; about 3 ft above mean sea level; up to 300 ft wide and 1000 ft long		Low forest: *Sonneratia*	i5, w4, p4, a3, c1, I3

Agricultural Capability.—Apart from unit 2, which can be used for gardens and some tree crops, this land system is of no agricultural value without empoldering and drainage.

Population and Land Use.—Population nil. Some gardening on unit 2 by people living in surrounding land systems.

Observations.—4.

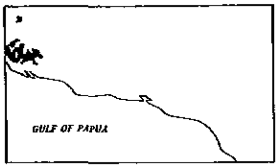
(3) Purari Land System (48 sq miles)

Freshwater tidal swamp forest.

Geology.—Recent paludal silt, clay, and peat.

Geomorphology.—Inter-channel tidal flats with raised margins and depressed centres separated by open-ended tidal channels. The channels are straight, sinuous, and sharp-pointed with silty beds between 100 and 1000 ft wide. Crab mounds are abundant on the raised margins of the flats.

Terrain Parameters.—Altitude: av., 4 ft; min., −3 ft in channels; max., 6 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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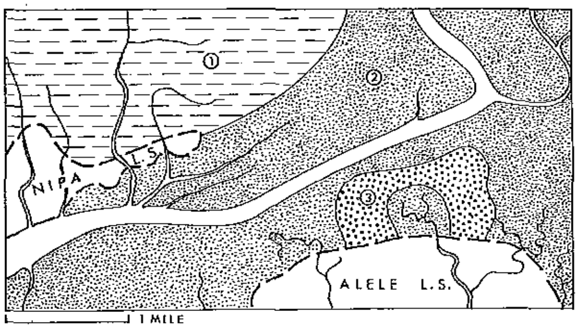


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	18	**Uppermost tidal flats:** 4 ft above mean sea level; up to 5000 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, weakly acid (*2b*)	Mid-height small-crowned mixed swamp forest, with increasing sago to landward. In the north tall medium- to large-crowned mixed swamp forest	i5, w4, p4, I1
2	27	**Upper tidal flats:** 3 ft above mean sea level; up to 5000 ft wide	Peaty mucks developed on clays (*1a*)		i6, w4, p4, a2, I1
3	2	**Upper tidal flats:** permanent stagnant swamp; 4–5 ft above mean sea level; up to 3000 ft wide		Mid-height small-crowned swamp forest: *Calophyllum* and *Campnosperma*	i5, w4, p2, I1

Agricultural Capability.—Use of this land would be dependent on complete empoldering to prevent tidal inundation.

Population and Land Use.—Population 50. Some gardening on unit 2; subsistence chiefly from sago, crabs, and fish.

Observations.—3.

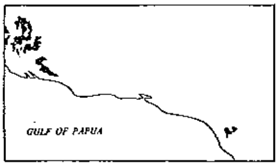
(4) Murva Land System (60 sq miles)

Freshwater tidal swamp woodland.

Geology.—Recent paludal silt, clay, and peat.

Geomorphology.—Inter-channel tidal flats with raised margins and depressed centres separated by open-ended tidal channels. The channels are straight, sinuous, and sharp-pointed with silty beds between 100 and 1000 ft wide. Crab mounds are abundant on the raised margins of the flats. Mainly near Muro the tidal flats are developed on degraded beach plains.

Terrain Parameters.—Altitude: av., 4½ ft; min., −3 ft in channels; max., 7 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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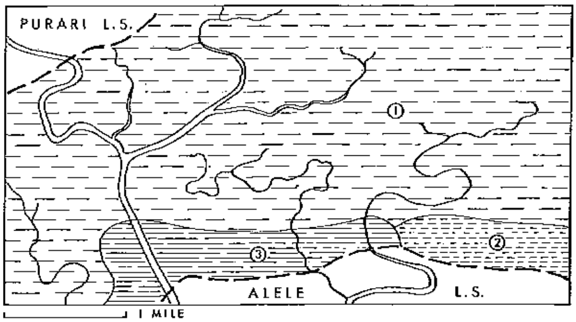


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	54	**Uppermost tidal flats:** about 4 ft above mean sea level; up to 5000 ft wide	Peaty mucks developed on clays (1*a*)	Freshwater swamp woodland with sago	i5, w4, p4, a2, T1
2	3	**Degraded beach plain:** just below high-water mark; up to 4000 ft wide with discernible pattern of ridges and swales	Peats developed on sands (1*b*)	As in unit 1, but *Nypa* occurs in some swales close to tidal creeks	i5, w4, p1, m3, a1, n2
3	3	**Alluvial flats with tidal channels:** at about high-water mark, up to 1000 ft wide	As unit 1 and undifferentiated alluvial soils; strongly gleyed, fine-textured acid over coarse-textured alkaline (3*b*)	Freshwater swamp woodland and mixed mangrove swamp woodland	i4, w4, p2, a2, c1, n2, T1

Agricultural Capability.—No agricultural value unless completely empoldered to prevent tidal inundation.

Population and Land Use.—Population 440. Some gardening on unit 2; subsistence chiefly from sago, crabs, and fish.

Observations.—3.

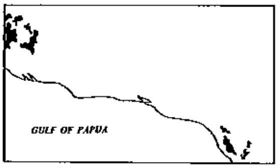
(5) Ebala Land System (55 sq miles)

Freshwater tidal swamps with sago.

Geology.—Recent paludal clay and peat, and alluvial silt.

Geomorphology.—Uppermost freshwater tidal flats, with raised margins and scattered crab mounds adjacent to tidal channels and low levee banks adjacent to rivers. The tidal channels become very narrow and dendritic and die out in the interior of the flats.

Terrain Parameters.—Altitude: av., 4½ ft; min., −2 ft in tidal channels; max., 8 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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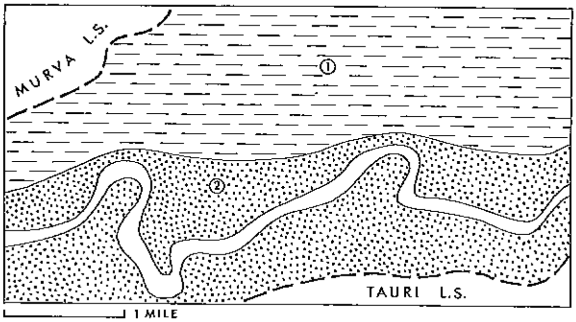


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	44	**Uppermost tidal flats:** 4 ft above mean sea level; up to 15,000 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, weakly acid to neutral, locally with thin inter-bedded organic layers (*2a*, *2b*)	Palm vegetation: sago, under a very open canopy of mid-height trees; in the south-east sago lower and poorer	i5, w4, p5, t1, I2
2	11	**Low levees and adjacent back plains:** above mean high-water mark; up to 800 ft wide			w4, p4, a1, I2

Agricultural Capability.—Low suitability for rice only. Complete empoldering would be required to prevent freshwater tidal inundation.

Population and Land Use.—Population nil. Source of sago for people on surrounding land systems.

Observations.—3.

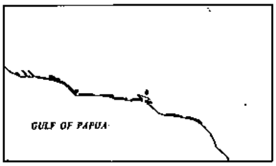
(6) Araimiri Land System (23 sq miles)

Beach ridge barriers.

Geology.—Recent littoral sand with local silt and clay in swales.

Geomorphology.—Prograding beach ridges, including spits and off-shore bars, becoming narrower and degraded inland. Swampy depressions include narrow linear swales between ridges and flats of sinuous tidal creeks oblique to the ridges.

Terrain Parameters.—Altitude: av., 5 ft; min., 0 ft; max., 6 ft. Characteristic slope: longitudinally level, transversely very gentle slopes. Plan-profile: no pronounced highs or lows (7).



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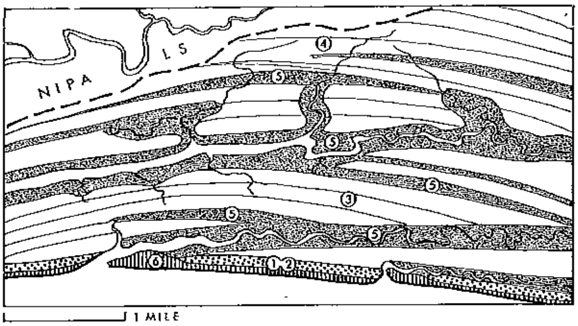


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	1	**Present active beach ridge:** 300 ft wide sloping ½° inland; up to 6 ft above mean sea level	Undifferentiated sandy soils: alkaline to strongly alkaline (5*b*)	Mixed herbaceous vegetation: *Ipomoea–Canavalia* above high-water mark	p3, m3, a6, c1, n3, I4
2	2	**Present stable beach ridge:** 400 ft wide sloping up to 1°; up to 6 ft above mean sea level	Undifferentiated sandy acid soils (5*a*)	Scrub: *Hibiscus–Desmodium*	w1, p3, m3, a2, n3, I4
3	4	**Inland beach ridges:** 800 ft wide, up to 1°; 5–6 ft above mean sea level	Undifferentiated sandy acid soils, locally with mottled subsoils (6*c*, 7*b*)	Littoral woodland, largely converted to coconut plantations	w2, p1, m3, a2, n3, I4
4	5	**Degraded beach ridges:** 100 ft wide, up to ½°; 5–6 ft above mean sea level	Weakly acid sandy soils with thick dark topsoils (18*a*). Undifferentiated sandy weakly acid soils (4*a*)	Littoral woodland, mostly converted to coconut, gardens, and regrowth	w2, p1, m3, n3, I4
5	10	**Swales between ridges and flats adjacent to sinuous tidal creeks:** of variable width; 1–5 ft above mean sea level	Undifferentiated sandy soils: where tidal or newly formed, alkaline (4*b*); otherwise weakly acid (4*a*)	*Phragmites* and *Nypa* palm where tidal; sago, littoral woodland, and garden regrowth where non-tidal	w3, p1, m3, a4, c1, n3, I4
6	1	**Present beach** up to 100 ft wide, concave; between low-water mark and high-water mark **Spits and off-shore bars:** of variable size; up to 5 ft above mean sea level	Undifferentiated sandy weakly alkaline soils (4*b*)	Bare	i5, w3, p3, m3, a3, c2, n4, I4

Agricultural Capability.—Generally of very low potential for arable crops and most tree crops, but of moderate potential for improved pastures. Coconuts should be well suited to stable beach ridges (unit 2) and inland beach ridges (unit 3).

Population and Land Use.—Population 12,100. Village sites, gardens, and coconuts occupy 1·6 sq miles of units 1 and 2. 4·8 sq miles of units 3 and 4 are planted to coconuts or used for subsistence cultivation. Unit 5 is the chief source of sago for this population. Non-indigenously owned plantations occupy 0·6 sq mile (coconuts).

Observations.—6.

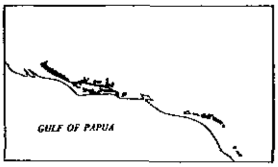
(7) Malalaua Land System (56 sq miles)

Beach plains.

Geology.—Recent littoral sand with minor alluvial silt and clay.

Geomorphology.—Mostly raised beach ridge barriers with ridges and swales in various stages of degradation to flat plains. Local alluvial flats adjacent to stream courses.

Terrain Parameters.—Altitude: av., 12 ft; min., 5 ft; max., 25 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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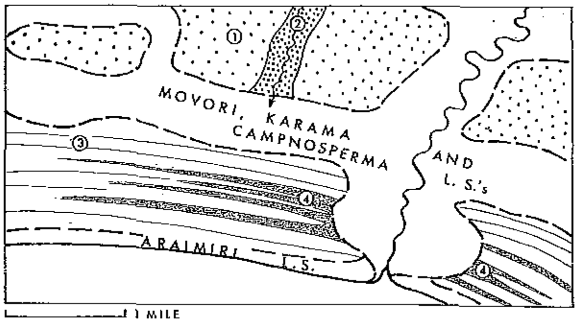


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	26	**Flat beach plain:** 10–20 ft *above mean sea level sloping* up to 1° on margins, otherwise level; up to 10,000 ft wide	Weakly acid sandy soils with *thick dark topsoils (16a).* Undifferentiated alluvial soils; medium- over coarse-textured, neutral to weakly acid (*6c*), and locally with mottled subsoils (*7b*). Undifferentiated sandy neutral to weakly acid soils (*5a*)	Tall large-crowned forest; *locally mid-height Themeda* grassland and coconut plantations	p1, m2, n2, I4
2	3	**Alluvial flats:** on beach plain; up to 600 ft wide; adjacent to sinuous channels; level	Undifferentiated alluvial soils; medium- over coarse-textured, neutral to weakly acid (*6c*)	Tall large-crowned forest	p2, m2, n2, I3
			Undifferentiated alluvial soils; strongly gleyed, fine-textured, acid (*3a*)	Fringing mid-height semi-deciduous forest in the east	e1, w2, p4, a2, I4
3	18	**Degraded beach ridges:** up to *800 ft wide; up to 15 ft above* mean sea level; slopes up to 1°	Undifferentiated alluvial *soils; medium- over coarse-*textured, weakly acid (*6c*). Undifferentiated sandy neutral to weakly acid soils (*5a*). Locally, sandy soils with neutral or acid thick dark topsoils (*16a*, *14a*), mostly on grassland	Tall large-crowned forest; *locally mid-height Imperata* grassland and coconut plantations	w1, p1, m3, n2, I4 *Locally, p1, m3,* a2, n3, I4
4	9	Swales: between ridges of unit 3; up to 400 ft wide, margins locally up to 4°, otherwise level	Undifferentiated alluvial soils: strongly gleyed, fine-textured, neutral (*3a*). Undifferentiated sandy weakly acid to acid soils (*4a*)	Open tall large-crowned forest	i2, w3, p5, m1, t1, a1, n2, I3 w4, p2, m2, a1, n2, I3

Inclusion.—Movori land system.

Agricultural Potential.—Highly suited to arable and tree crops and improved pastures, with low potential for irrigated rice as suitability of irrigation is limited to parts of units 2 and 4. Potential for tree crops is low in the seasonally dry eastern parts. General improvement could be achieved by drainage in unit 4 and parts of unit 3. Soils appear to be generally only moderately fertile.

Population and Land Use.—Population 1900. The area used for cultivation occupies 11·7 sq miles of units 1–3, almost wholly in those occurrences of the land system to the west of Kerema. Sago is gathered and processed from surrounding land systems. Non-indigenously owned plantations (coconuts) occupy 2·3 sq miles of units 1–3.

Forest Potential.—Scattered, high-yielding remnants of tall forest are generally easy of access but useful only for local consumption.

Observations.—20.

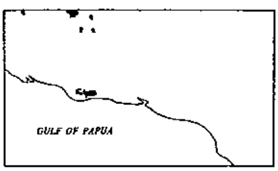
(8) Campnosperma Land System (16 sq miles)

Permanent, stagnant, freshwater, non-tidal swamps with swamp forest.

Geology.—Recent paludal clay and peat, and beach sand.

Geomorphology.—Stagnant swamps with active peat accumulation, mostly in basins, partly on inland margins of degraded beach ridge plains.

Terrain Parameters.—Altitude: av., 40 ft; min., 5 ft; max., 200 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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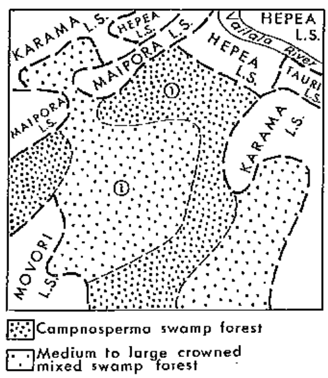
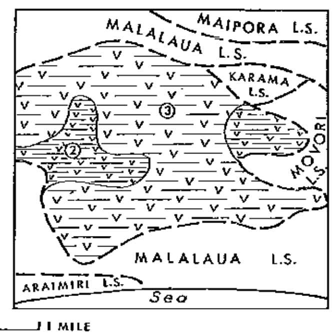




Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	8	Non-tidal, permanent, freshwater swamps: level; up to 10,000 ft wide	Peaty mucks developed on clays (1*a*)	Tall forest: *Campnosperma* swamp forest and medium- to large-crowned mixed swamp forest	w4, p4, a2, I2
2	2	Non-tidal, permanent, peat swamp: over degraded beach ridges, 5–6 ft above mean sea level; up to 12,000 ft wide; level	Peats developed on sands (1*b*)		w4, p1, n2, I4
3	6	Degraded beach ridges: now permanent swamp, 5–6 ft above mean sea level; up to 10,000 ft wide; level	Undifferentiated, gleyed, sandy, acid to weakly acid soils (4*a*)	Tall forest: medium- to large-crowned mixed swamp forest	w4, p1, m3, a2, n3, I4

Agricultural Capability.—Unit 1 is highly suitable for rice.

Population and Land Use.—Population nil. Source of sago for people on surrounding land systems.

Forest Potential.—Low-yielding. Scattered areas of *Campnosperma* forest cover about 10 sq miles in the west and north-west.

Observations.—5.

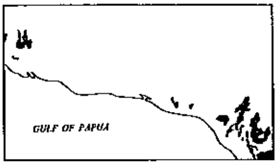
(9) Waigani Land System (98 sq miles)

Permanent and semi-permanent freshwater mostly non-tidal swamps with herbaceous vegetation (continuation of Waigani land system of Port Moresby–Kairuku area).

Geology.—Recent paludal clay and peat, locally beach sand.

Geomorphology.—Permanent swamps which in the Purari delta have marginal tidal fringes, and semi-permanent swamps in the Lakekamu embayment which occasionally dry out and are burned.

Terrain Parameters.—Altitude: av., 15 ft; min., 5 ft; max., 100 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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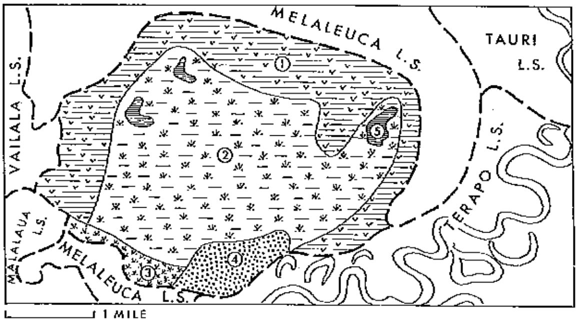


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	22	Semi-permanent swamps: with variable depth of standing water; occasional drying out and burning; level; up to 15,000 ft wide; in south-east of area	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, acid, with inter-bedded organic layers (*2b*). Peaty mucks developed on clay (*1a*)	Tall grassland: *Phragmites*	i5, w4, p4, a2, n2, I2
2	68	Permanent swamps: variable depth of standing water over paludal clay; level; up to 10,000 ft wide	No data	Mixed herbaceous vegetation: *Thoracostachyum–Hanguana;* minor pure *Hanguana*	i6, w4, p4, a2, I2
3	3	Permanent swamps: variable depth of standing water, over degraded beach ridges; level; up to 3000 ft wide	Peats developed on sands (*1b*)	Mixed herbaceous vegetation: *Hanguana*	i6, w4, p1, m3, a2, n3
4	5	Swamp margins: uppermost freshwater tidal flats in the west; level; up to 2000 ft wide	As in unit 1	Low sago and *Hanguana*	w4, p5, a2, n2, I2
5	<1	Lakes: deep standing water; up to 1000 ft wide		Bare	

Agricultural Capability.—Without extensive and difficult reclamation this land is of no agricultural value.

Population and Land Use.—Population nil. Source of sago for people on surrounding land systems.

Observations.—2.

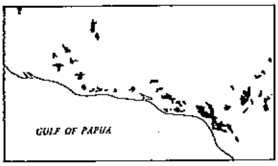
(10) Movori Land System (68 sq miles)

Freshwater non-tidal swamps with swamp woodland.

Geology.—Recent paludal clay or littoral sand.

Geomorphology.—Swamps on back plains, in basins, and on the inland margin of degraded beach plains.

Terrain Parameters.—Altitude: av., 25 ft; min., 5 ft; max., 150 ft. Characteristic slope: level. Plan-profile: no pronounced highs or lows (7).



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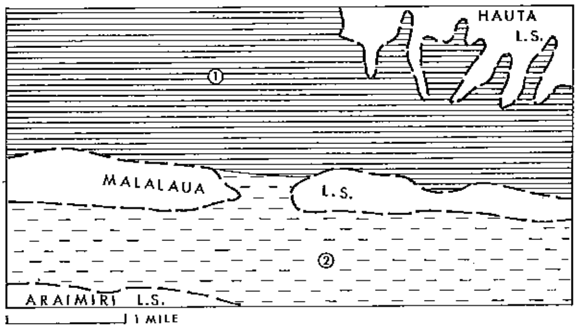


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	41	Back plains and basins: level; up to 10,000 ft wide	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, acid (2*b*)	Freshwater swamp woodland: locally sago, *Hanguana*, *Thoracostachyum*, *Pandanus*	In east: i2, w4, p5, t1, a2, n2, I2 In west: w4, p4, n2, I2
2	27	Degraded beach ridges: permanent standing water; about 6 ft above mean sea level; level; up to 6000 ft wide	Peats developed on sands (1*b*)	Freshwater swamp woodland: undergrowth mainly *Hanguana*	w4, p1, m3, n3, I4

Inclusions.—Waigani and Tauri land systems.

Agricultural Capability.—Unit 1 has moderate to low suitability for rice only. Prevention of seasonal inundation in the east would depend on control of large rivers and drainage in all areas would be very difficult.

Population and Land Use.—Population of 270 resides on an inclusion of Tauri land system. Source of sago for people of surrounding land systems.

Observations.—2.

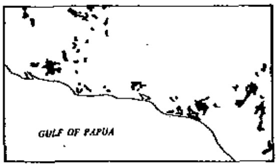
(11) Karama Land System (84 sq miles)

Freshwater non-tidal swamps with sago.

Geology.—Recent alluvial clay and silt, and littoral sand.

Geomorphology.—Mainly back plains and small basins, and partly the inland margins of degraded beach ridge plains.

Terrain Parameters.—Altitude: av., 40 ft; min., 6 ft; max., 200 ft. Characteristic slope: very low gradient. Plan-profile: no pronounced highs or lows (7).



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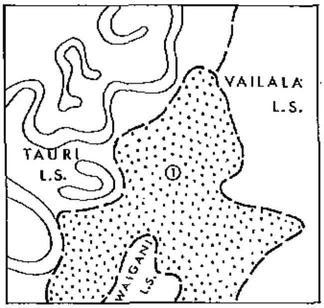

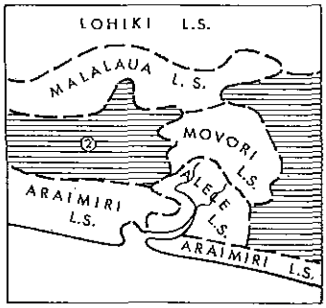

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Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	50	**Back plains and small basins:** mainly intake areas of freshwater swamp; up to 8000 ft wide; very low gradient; level	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, acid (2*b*)	Palm vegetation: sago, pure or with very scattered mid-height trees; in the south-east seasonal drying out and burning	In west: w4, p5, t1, a2, n2, I2 In east: i2, w4, p5, t1, a2, n2, I2
2	34	**Degraded beach ridges:** semi-permanent standing water; about 6 ft above mean sea level; up to 6000 ft wide; level	Peats developed on sands (1*b*)		w4, p1, m3, n3, I4

Inclusion.—Tauri land system.

Agricultural Capability.—In its present state this land is useful only for sago production.

Population and Land Use.—Population of 820 resides on an inclusion of Tauri land system within this land system in the Kerema Bay area. Source of sago for population on surrounding land systems.

Observations.—2.

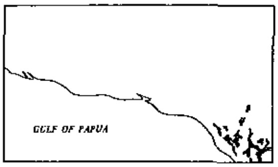
(12) Melaleuca Land System (77 sq miles)

Strongly seasonal freshwater non-tidal swamps with *Melaleuca leucodendron.*

Geology.—Recent paludal clay and silt, and littoral sand.

Geomorphology.—Strongly seasonal swamps in the south-east of the area, either marginal to permanent swamps or on recently degraded beach ridge plains.

Terrain Parameters.—Altitude: av., 10 ft; min., 3 ft; max., 30 ft. Characteristic slope: very low gradient Plan-profile: no pronounced highs or lows (7).



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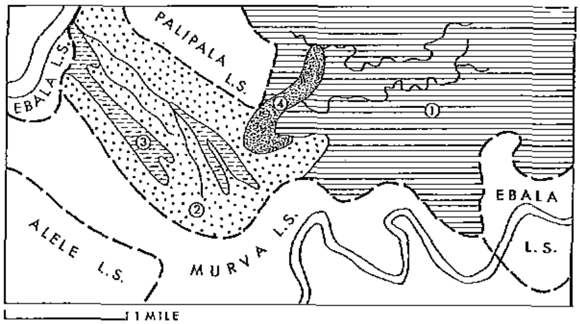


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	46	Back plains and swamp margins: very low gradient 6–20 ft above mean sea level	Undifferentiated alluvial soils: strongly gleyed, fine-textured, weakly acid (3*a*, 2*a*)	*Melaleuca* swamp savannah: locally with undergrowth of scattered sago annually burnt. Locally, tall grassland: *Phragmites*	i3, w3, p5, t1, n2, I2
2	28	Degraded beach plain: generally level; about 6 ft above mean sea level	Undifferentiated mostly soft alluvial soils: strongly gleyed, fine-textured, weakly acid overlying strongly alkaline to alkaline sands (2*c*)		i4, w4, p4, a1, n2, I3
3	1	Degraded beach ridges: up to 300 ft wide; about 6 ft above mean sea level; level	Undifferentiated alluvial soils: medium- over coarse-textured, weakly alkaline with mottled subsoils (7*b*)	*Melaleuca* swamp savannah and mid-height grassland of *Imperata*	i1, w2, p4, m3, t1, a3, n2, I2
4	1	Swales and creek bottoms: up to 400 ft wide; 3–5 ft above mean sea level; level	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, alkaline (2*c*)	Mixed herbaceous vegetation: *Leersia–Nymphaea*	i5, w4, p4, m1, a3, n2, I2

Agricultural Capability.—In its unimproved state this land is moderately suitable only for irrigated rice and only in unit 1.

Population and Land Use.—Population nil. Unit 2 used as a source of sago for people on surrounding land systems.

Observations.—4.

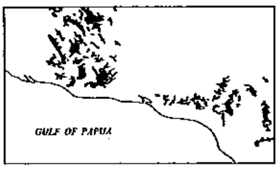
(13) Vailala Land System (212 sq miles)

Stable alluvial plains with mid-height basin forest.

Geology.—Recent alluvial clay and silt, with local sand and gravel.

Geomorphology.—Alluviated basins, on the one hand merging into the back plains of the larger rivers, and on the other merging into re-entrants in the hills with marginal terraces. Locally, small widely spaced channels have muddy beds between 6 and 20 ft wide with rectangular cross-sections and very low gradients.

Terrain Parameters.—Altitude: av., 50 ft; min., 10 ft; max., 500 ft. Characteristic slope: very low gradient. Plan-profile: no pronounced highs or lows (7).



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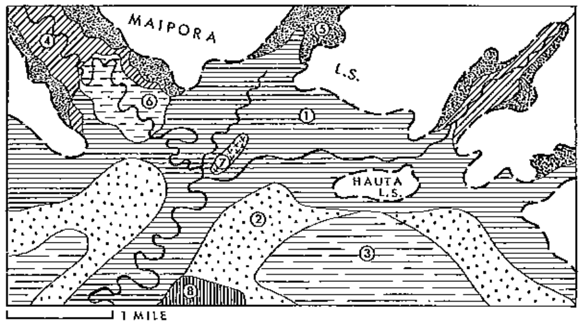


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	53	**Stable alluvial plains:** very low gradient; up to 6000 ft wide **Alluvial flats:** low gradient; up to 800 ft wide	Undifferentiated alluvial soils: fine-textured, acid, with mottled and/or gleyed subsoils (*7a*)	Mid-height small- to medium-crowned basin forest; taller forest on narrow alluvial flats	w1, p4, a2, n2, I2
2	53	**Unchannelled back plains and basin margins:** very low gradient; up to 4000 ft wide	As in unit 1 but strongly gleyed (*3a*). Locally strongly gleyed, neutral, fine-textured soils with thick dark topsoils (*18b*)	Mid-height small- to medium-crowned basin forest	Back plain: f2, w3, p4, a2, n2, I2 Basin margin: w2, p5, t1, a1, I2
3	53	**Basin centres:** very low gradient; local very shallow wash courses; up to 8000 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine-textured, weakly acid (*3a*). In eastern part, with alkaline subsoils (*3b*)		f1, w2, p4, I2
4	15	**Alluvial terraces:** very high gradient; 8–20 ft above nearby stream channels; up to 800 ft wide	Undifferentiated alluvial soils: medium-textured, acid (*6b*). Neutral medium-textured soils with thick dark topsoils (*16b*)		e1, p2, a2, n2, I2 Locally, e1, p2, m2, n2, I2
5	21	**Dissected terraces:** very short; gentle to moderate slopes	Uniform, medium-textured, acid soils with mottled subsoils and altered B horizons (*9a*)		e1, w1, p2, a2, n2, I3
6	4	**Dissected stable alluvial plain:** short; gentle smooth straight slopes	As in unit 1		e1, w1, p4, a2, n2, I3
7	6	**Swamps:** very low gradient; alluviated flats up to 800 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine-textured, acid to strongly acid, locally with interbedded organic layers (*2a*)	Freshwater swamp woodland: sago, *Pandanus*	w4, p5, a5, I2
8	6	**Alluviated beach plains:** very low gradient; linear pattern of buried beach ridges discernible on aerial photographs; up to 8000 ft wide	As in unit 3 but weakly alkaline in east (*3c*). Locally, neutral fine-textured soils with very thick dark topsoils and mottled subsoils (*17a*)	Mid-height small- to medium-crowned basin forest with many deciduous trees. In the east, locally, mid-height *Melaleuca argentea* savannah	w2, p5, m1, t1, a1, I3

Agricultural Capability.—Generally highly suited to pastures and rice and moderately suited to arable and tree crops. Drainage improvement would change suitability for tree crops and pastures to very high and arable crops to high. Tree crops would be less suitable in the east (notably north of Malalaua) because of seasonal drought. Rice could be irrigated from rivers or streams using weirs or pumps.

Population and Land Use.—Population 410. Some gardening on unit 4 in the west.

Forest Potential.—Moderately high-yielding. *Dracontomelum*, *Homalium*, *Pterocarpus*, *Vitex*, and *Pometia* are relatively common, but a large percentage of *Pterocarpus* and *Vitex* would be rejects.

Observations.—20.

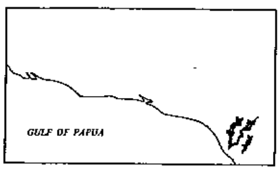
(14) Terapo Land System (33 sq miles)

Very unstable alluvial flood-plains with freshwater swamp woodland transitional to tall, large-crowned, open-canopy forest.

Geology.—Recent alluvial silt and clay, very rapid alluviation.

Geomorphology.—Lacine meander plains with abundant small scroll plains with point bars and intervening sloughs: mostly the distal ends of the alluvial lobes of the Tauri and Lakekamu Rivers.

Terrain Parameters.—Altitude: av., 10 ft; min., 6 ft; max., 20 ft. Characteristic slope: longitudinally very low gradient, transversely high gradient. Plan-profile: no pronounced highs or lows (7).



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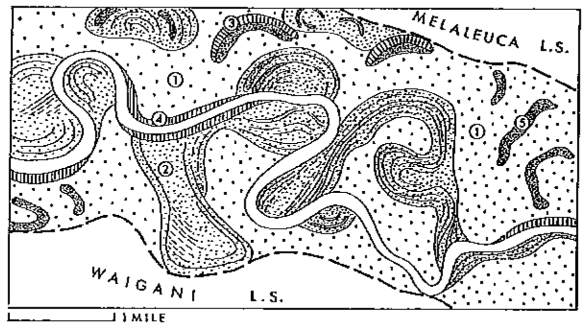


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	8	Back plain: covered plain; very low gradient; up to 2500 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine-textured, alkaline (3*c*)	Freshwater swamp woodland, transitional to open, tall, large-crowned forest	f1, w3, p4, a4, n2, I2
2	13	Scroll plains: up to 4000 ft wide and 1 mile long with point bars separated by swampy swales or sloughs; longitudinally very low gradient, transversely high gradient	Undifferentiated alluvial soils: medium- over fine-textured, acid with mottled and/or gleyed subsoils (7*a*); in swales as above but strongly gleyed (3*a*)	Succession from tall grass (*Saccharum robustum*) through lines of mid-height *Octomeles–Artocarpus* forest, interspersed with low grasses in swales and sloughs, to open, tall, large-crowned forest	f6, w2, p2, m1, n2 In swales and sloughs: f6, w4, p2, m1, n2
3	2	Prior levees: about 200 ft wide; low gradient	Undifferentiated alluvial soils: medium- over fine-textured, neutral, with mottled and/or gleyed subsoils (7*a*)	As in unit 1	f1, w2, p4, a1, n2, I2
4	1	Present embryonic levees: strip 50 ft wide adjacent to main channel; low gradient	Probably as in unit 3, but alkaline over neutral (?7*a*)	Mid-height *Octomeles–Artocarpus* forest, much disturbed	f4, w2, p2, a1, n2, I2
5	9	Prior meanders and oxbows: up to 800 ft wide and 1 mile long; level	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, weakly acid (2*a*)	Succession from open water through mixed herbaceous vegetation (*Nymphaea–Lemna*) and mid-height grassland (? *Hymenachne*) to tall grassland (*Saccharum robustum* and *Phragmites*)	i5, w4, p4, m1, n2

Agricultural Capability.—Potential is low for irrigated rice and very low for improved pastures only.

Population and Land Use.—Population 580. Some gardening on units 3 and 4.

Observations.—4.

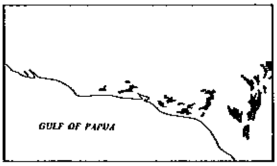
(15) Tauri Land System (117 sq miles)

Unstable alluvial flood-plains with tall, large-crowned, open-canopy forest.

Geology.—Recent alluvial clay and silt with local paludal clay, locally over deltaic sand.

Geomorphology.—Unstable covered lacine meander plains.

Terrain Parameters.—Altitude: av., 40 ft; min., 15 ft; max., 250 ft. Characteristic slope: very low gradient. Plan-profile: no pronounced highs or lows (7).



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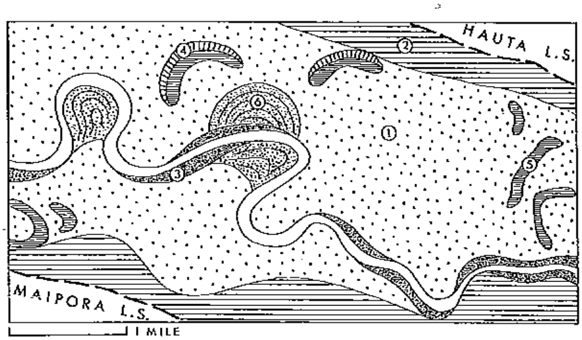


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	77	**Back plain:** covered plain, very low gradient; locally channelled; up to 4000 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine-textured, weakly acid (3*a*)	Open tall, large-crowned forest	f3, w2, p4, m1, n2, I2
2	5	**Flood-plain terrace:** covered plain adjacent to hills; low gradient; up to 800 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine-textured, acid (3*a*)	Mid-height small- to medium-crowned basin forest	w1, p4, a2, n2, I2
3	6	**Levee banks:** 3 ft above back plain; 200–300 ft wide; locally channelled; low gradient	Undifferentiated alluvial soils: medium- over fine-textured, weakly acid (7*a*)	As in unit 1	f3, w1, p4, m1, n2, I2
4	6	**Prior levees:** about 200 ft wide; low gradient	Probably as in unit 3 but fine-textured (?7*a*)		f1, w1, p4, m1, n2, I2
5	14	**Prior meanders and oxbows:** up to 600 ft wide and 1 mile long; level	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, weakly acid (2*a*)	Open water, mixed herbaceous vegetation, tall grassland, and *Pandanus*	i5, w4, p4, m1, n2
6	9	**Scrolls:** bundles of point bars up to 1000 ft wide and 4000 ft long; linear microrelief; very low gradient	Undifferentiated alluvial soils: medium- over coarse-textured, weakly acid, locally with mottled subsoils (6*c*)	Tall grass: *Saccharum robustum*. Mid-height forest: *Octomeles–Artocarpus*	f6, w1, p1, m1, n3

Agricultural Capability.—Suitability is moderate for pastures, low for arable crops and rice, and very low for tree crops.

Population and Land Use.—Population 450. Some gardening on units 3 and 6.

Forest Potential.—Moderate-yielding. *Dracontomelum*, *Vitex*, and *Pometia* are relatively common; *Octomeles* is locally common.

Observations.—5.

(16) Hepea Land System (154 sq miles)

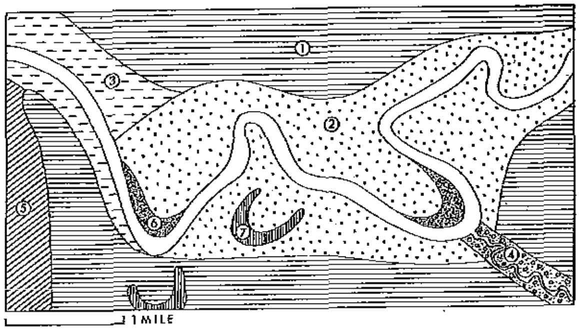
Stable alluvial plains with tall, large-crowned, closed-canopy forest.

Geology.—Recent alluvial sand, silt, and clay.

Geomorphology.—Stable levees, flood-plain terraces, and back plains mostly covered with a thick layer of alluvial silt and clay. Stream courses are sinuous, of low gradient with sandy beds between 100 and 1000 ft wide with rectangular and triangular cross-sections.

Terrain Parameters.—Altitude: av., 40 ft; min., 10 ft; max., 150 ft. Characteristic slope: low gradient. Plan-profile: no pronounced highs or lows (7).

Distribution



Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	69	Back plains: low gradient, locally channelled; up to 6000 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine-textured, acid to weakly acid (3*a*). Locally, medium- over fine-textured weakly acid, with gleyed and/or mottled subsoils (7*a*)	Tall large-crowned forest, locally with open canopy	w2, p5, t1, n2, I2 Locally w2, p2, n2, I2
2	51	High flood-plain terraces: several feet above general level of present flood-plain; low gradient; up to 3000 ft wide	Undifferentiated alluvial soils: medium-textured, weakly acid, partly with gleyed and/or mottled subsoils (6*b*, 7*b*). Locally with sandy subsoils (6*c*)	Tall large-crowned forest; locally mid-height small- to medium-crowned basin forest	p2, m1, n2, I2 Locally f2, w1, p2, m2, a1, n2, I2
3	9	Low flood-plain terraces: slightly above general level of flood-plain; low gradient; up to 2000 ft wide	Undifferentiated alluvial soils: strongly gleyed and mottled, fine-textured, weakly acid (3*a*)	Tall large-crowned forest	w2, p2, n2, I2 Locally I3
4	14	Levee banks: up to 6 ft above back plain; moderate to low gradient; up to 800 ft wide	As in unit 3 and undifferentiated alluvial soils; fine-textured, weakly acid, with mottled subsoils (6*c*)		t2, p4, I2
5	5	Alluviated beach plains: very low gradient; linear pattern of buried beach ridges discernible on aerial photographs; up to 1000 ft wide	As in unit 3 and undifferentiated alluvial soils: medium- over fine-textured, weakly acid, with gleyed and/or mottled subsoils (7*a*)	As in unit 1. In the east, fringing mid-height semi-deciduous forest	w2, p5, t1, a1, n2, I3
6	3	Scrolls: groups of point bars up to 1000 ft wide and 4000 ft long; linear microrelief	Undifferentiated alluvial soils: medium- over coarse-textured, weakly acid (6*c*)	Tall grass: *Saccharum robustum* and mid-height *Octomeles–Artocarpus* forest	t6, p1, m2, n3
7	3	Prior meanders and oxbows: up to 800 ft wide and 4000 ft long	Undifferentiated soft alluvial soils: strongly gleyed, fine-textured, weakly acid (2*a*)	Open water, mixed herbaceous vegetation, tall grass, *Pandanus*	i5, w4, p4, m1, n2

Agricultural Capability.—Suitability is high for pastures and rice and moderate for arable and tree crops; it would become high for the last two following drainage improvement and, locally, flood control by construction of levees. Seasonal drought imposes further limitations on tree crops on the well-drained land of units 2 and 4 in the eastern area, making suitability moderate to low. Rice could be irrigated from weirs or dams in some areas and by low-lift pumping in others.

Population and Land Use.—Population 1530. Some gardening on units 2–4. Non-indigenously owned plantations (coconuts) occupy 0·2 sq mile of units 2 and 4. Murua resettlement scheme occupies approximately 6·4 sq miles of units 2 and 4.

Forest Potential.—High-yielding, particularly along the middle reaches of Tauri River. Generally, *Octomeles*, *Dracontomelum*, and *Pometia* together form about 30% of the total timber volume. Along Tauri River, *Octomeles* of large girth and *Dracontomelum* together account for over 30% of the timber volume. The main areas have ready access from the major rivers.

Observations.—19.

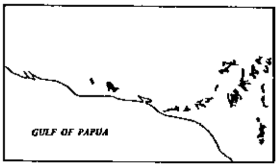
(17) Olipai Land System (50 sq miles)

Partly dissected benches with mid-height small- to medium-crowned hill forest.

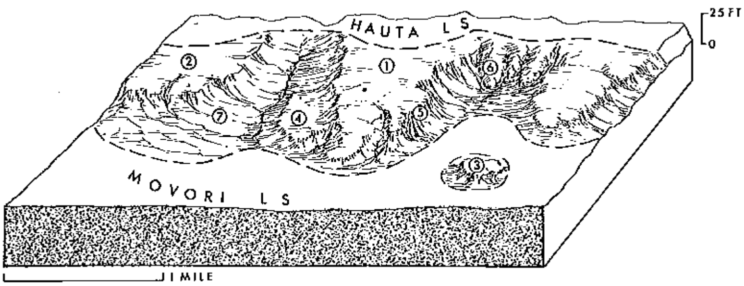
Geology.—Late Pleistocene to Recent littoral sand and alluvial gravel, silt, and clay over Upper Miocene and Pliocene mudstone, greywacke, and subordinate limestone.

Geomorphology.—Raised aggradational surfaces with veneer of alluvial or littoral deposits in varying stages of dissection. Severe to extreme subsurface erosion near margins of benches bearing alluvial silt over gravel. Minor ephemeral stream courses, low-gradient silty clay bed between 6 and 15 ft wide, and rectangular cross-sections.

Terrain Parameters.—Altitude: av., 75 ft; min., 0 ft; max., 200 ft. Relief: ultra-low (40 ft). Grain: coarse (3000 ft). Characteristic slope: high gradient (1:200). Plan-profile: flat-topped highs occupy more than 60% of area and are non-linear and random (1).



Distribution



Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	17	**High benches:** 60–100 ft above nearby streams; high to very high gradient; 2000–5000 ft wide; with alluvial deposits	Acid to strongly acid soils with textural B horizons and strong brown and/or reddish plastic clayey subsoils (22*a*, 22*b*). Locally with thick dark topsoils and reddish plastic clayey subsoils (24*b*)	Mid-height, small- to medium-crowned hill forest. Locally, mid-height grassland: *Imperata*	p2, a2, n2, I4 Locally, w2, p4, a2, n2, I4
2	3	As in unit 1; low gradient; with beach deposits	As in unit 1, but with red mottled plastic clayey subsoils (23) and partly with thick dark topsoils (25*b*)		p2, a5, n2, I4
3	<1	**Low plateaux:** 50–60 ft above beach plain; slightly dissected with gentle slopes	Undifferentiated alluvial soils: fine-textured, acid, with mottled and/or gleyed subsoil (7*a*)	Tall, medium- to large-crowned hill forest	e1, w1, p5, a2, I4
4	10	**Low benches:** 15–25 ft above nearby streams; low to high gradient. Veneered with alluvium inland and beach sand near coast	As in unit 3, but medium-textured, neutral (6*a*). Near coast, sandy weakly acid soils (5*a*)	Mid-height small- to medium-crowned hill forest. Near coast, locally, coconut plantation	p2, a1, n2, I2 Near coast p2, m2, n3, I3
5	5	**Steep slopes:** very short and ultra-short; concavo-convex	Acid to strongly acid soils with textural B horizons and reddish plastic clayey subsoils (22*a*)	Mid-height small- to medium-crowned hill forest; locally, mid-height very small-crowned hill forest	e5, p2, a2, n2
6	10	**Moderate slopes:** very short; concavo-convex	As in unit 5; and uniform medium-textured acid to strongly acid soils (9*a*)		e3, p2, d1, m2, a2, n3
7	5	**Gentle slopes:** short and very short; straight or concave	As in unit 5		e2, p5, n2

Agricultural Capability.—Generally good land with high potential for tree crops and improved pastures and moderate potential for arable crops. Potential for rice is low owing to the impracticability of irrigation in most areas.

Population and Land Use.—Population nil. Some gardening near Kerema on unit 2.

Forest Potential.—Moderate-yielding, in the east low-yielding. *Calophyllum* is relatively common near Kerema.

Observations.—16.

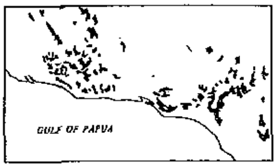
(18) Hauta Land System (121 sq miles)

Low hills with moderate slopes and mid-height small- to medium-crowned hill forest.

Geology.—Upper Miocene and Pliocene mudstone, siltstone, greywacke, sandstone, and subordinate limestone.

Geomorphology.—Low rolling mostly concave–convex hills. Stream courses have low gradients with silty gravelly beds between 10 and 30 ft wide and rectangular cross-sections.

Terrain Parameters.—Altitude: av., 150 ft; min., 10 ft; max., 500 ft. Relief: very low (100 ft). Grain: very fine to ultra-fine (250 ft). Characteristic slope: high-moderate. Plan-profile: crested highs occupy more than 60% of area and are non-linear and random (4).



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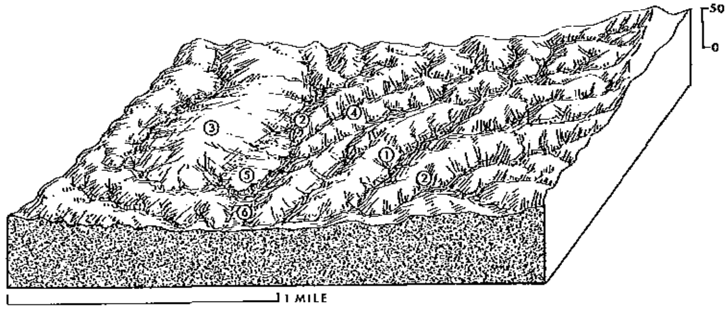


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	73	Moderate slopes: very short and ultra-short; concave–convex; locally dip slopes and valley heads	Acid to strongly acid soils with textural B horizons and reddish and yellowish brown, partly strongly mottled, plastic clayey subsoils (22*a*, 22*b*, 23); also with thick dark topsoils (25*a*, 24*a*). Uniform fine-textured acid to strongly acid yellowish brown soils with altered B horizons (9*b*) and minor strongly acid friable red clay soils (26*a*)	Mid-height small- to medium-crowned hill forest. In the east, mid-height very small-crowned hill forest and low *Melaleuca argentea* savannah. Near Kerema, tall medium- to large-crowned hill forest	e2, p4, d1, m1, a2, n2
2	18	Steep and very steep slopes: straight and concave; ultra-short	Uniform medium- to fine-textured weakly acid to neutral olive-brown soils with altered B horizons, and uniform fine-textured acid reddish soils with altered B horizons (9*d*)		e5, p2, m1, a2, n2; very steep, e6, p2, m2, n2
3	7	Broad to very broad ridge crests: gentle and very gentle slopes; marginally convex	Acid to strongly acid soils with textural B horizons, thick dark topsoils, and yellowish brown or strongly red mottled subsoils (24*a*, 25*a*). Locally, strongly acid soils with textural B horizons and gleyed and red mottled subsoils (21), and uniform medium-textured acid yellowish brown soils with altered B horizons (9*a*)	Mid-height small- to medium-crowned hill forest; minor tall medium- to large-crowned hill forest	e1, p4, m1, a2, n2, I4
4	2	Narrow ridge crests: gentle to moderate slopes; convex	Uniform medium-textured acid partly shallow soils with altered B horizons (9*a*, 12)		e1, p2, d1, m2, a2, n2, I4
5	2	Terraces: 10–40 ft above nearby streams; high to very high gradient	Uniform medium-textured strongly acid locally stony and gravelly soils with altered B horizons (9*a*)	Tall medium- to large-crowned hill forest and mid-height, small- to medium-crowned hill forest; minor mid-height small- to medium-crowned basin forest	p2, m1, a5, n2, I3
6	18	Gentle foot slopes: very short and ultra-short; usually concave; local severe subsurface erosion	Uniform medium-textured gleyed acid soils with altered B horizons (13); locally, fine-textured with thick dark topsoils (14*b*)		e2, w1, p4, a2, n2

Agricultural Potential.—Generally high potential for tree crops and improved pastures, with low potential for arable crops. In the seasonally dry areas of the east, potential for tree crops and improved pastures is low and moderate respectively. Arable crops could be grown only in small areas mainly on units 6 and 5 and on the gentler slopes of unit 1.

Population and Land Use.—Population nil. Some gardening on units 1, 3, 5, and 6. 1·1 sq miles of non-indigenously owned plantation (rubber). Murua resettlement scheme occupies 4·9 sq miles mainly on units 1, 3, 5, and 6.

Forest Potential.—Generally low-yielding, high-yielding east of Kerema.

Observations.—23.

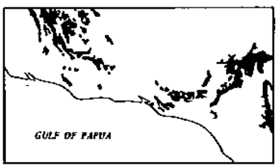
(19) Maipora Land System (342 sq miles)

Low hills with very steep straight slopes and mid-height small- to medium-crowned hill forest.

Geology.—Upper Miocene and Pliocene mudstone, siltstone, greywacke, sandstone, and subordinate limestone.

Geomorphology.—Ridge and ravine land forms with low relief and only local structural control. Stream courses have high gradients with sandy cobbly beds between 12 and 40 ft wide with rectangular cross-sections. The cobbles are softened by weathering.

Terrain Parameters.—Altitude: av., 350 ft; min., 0 ft; max., 1000 ft. Relief: low (200 ft). Grain: very fine (400 ft). Characteristic slope: very steep. Plan-profile: crested highs occupy more than 60% of area and are non-linear and random (4).



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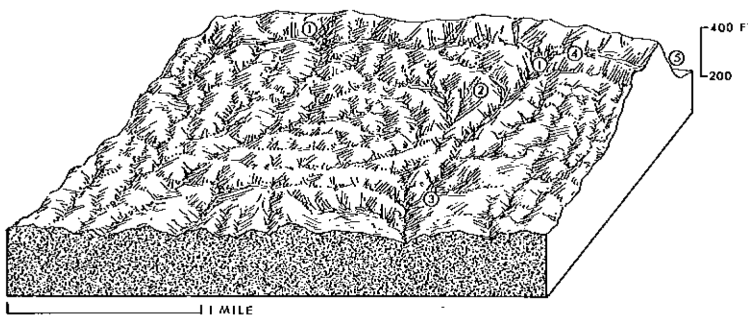


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	270	Very steep and steep straight slopes: short to ultra-short; locally convex or uneven; 25–45°	On mudstone, siltstone, and greywacke: uniform fine- to locally medium-textured acid to strongly acid soils, with reddish or yellowish brown subsoils and altered B horizons (*9d*, *9a*, *9b*). On sandstone: undifferentiated medium- and coarse-textured acid colluvial soils (*6a*). Uniform coarse-textured strongly acid soils with yellowish brown subsoils and altered B horizons (*9c*)	Mid-height small- to medium-crowned hill forest; locally, tall medium- to large-crowned hill forest	e6, p2, d1, m2, a5, n2
2	34	High-moderate and steep slopes: short to ultra-short; concave; straight and convex	Uniform fine- to locally medium-textured acid to weakly acid soils, with altered B horizons and partly with mottled and gleyed subsoils (*9a*, *9b*, 11). Uniform fine-textured strongly acid soils with thick dark topsoils, yellowish red to strong brown subsoils, and altered B horizons (*14c*). Strongly acid soils with textural B horizons and yellowish red to red plastic clayey subsoils (*22a*)		e3, p4, a5, n2; steep slopes, e5, p4, d1, m1, a2, n2
3	17	Gentle to low-moderate slopes: very short to ultra-short; mostly concave foot slopes; locally severe subsurface erosion	On moderate slopes: undifferentiated medium-textured gravelly acid soils (*6a*). On gentle slopes; uniform medium- to coarse-textured acid soils, with thick dark topsoils and altered B horizons (*14a*)	Tall medium- to large-crowned hill forest	e2, p2, m2, a2, n2
4	17	Narrow ridge crest: 20–150 ft wide; 0–10°; convex	Uniform medium-textured acid yellowish brown soils with altered B horizons (*9a*)	As in unit 1	e2, p4, a2, n2
5	3	Precipitous slopes: 45–65°; straight or uneven; mostly scarp of Rim Ridge	Undifferentiated shallow stony soils (8) and rock outcrops	Mid-height small- to medium-crowned hill forest with very open canopy	e6, r1, p2, d4, m4, a2, n3

Agricultural Capability.—Very low suitability for tree crops and improved pastures. Parts of the eastern area are totally unsuited to tree crops owing to the severe dry season.

Population and Land Use.—Population 1040 using 0·8 sq mile for cultivation, mainly on units 2–4. Land use adjacent to the sea or main rivers. Non-indigenously owned plantations occupy 0·2 sq mile (rubber).

Forest Potential.—Low- to moderate-yielding. *Koompassia* has scattered occurrence.

Observations.—14.

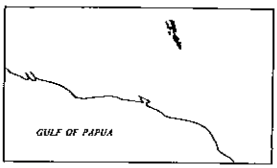
(20) Kwambega Land System (11 sq miles)

Moderate and low hills with benched spurs and narrow alluvial terraces at high altitude.

Geology.—Middle and Lower Miocene greywacke, mudstone, and minor limestone.

Geomorphology.—Complete leaf litter cover on all slopes (except cliffs) and soil flow, subsurface erosion, and probably subsurface corrasion are the dominant erosion processes.

Terrain Parameters.—Altitude: av., 4500 ft; min., 3750 ft; max., 5250 ft. Relief: moderately high (400 ft). Grain: fine (750 ft). Characteristic slope: steep. Plan-profile: crested highs occupy more than 60% of area and are linear and random (4L).



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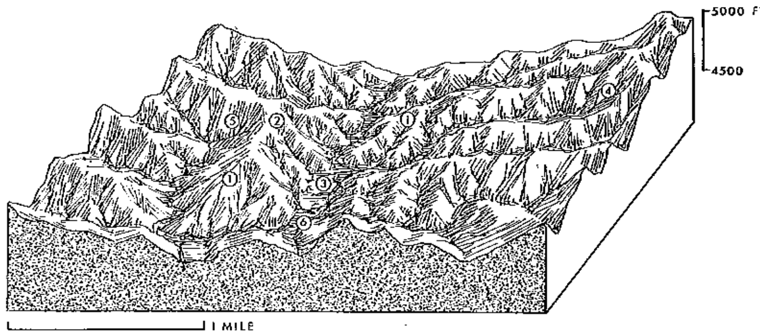


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	2	Benched spurs: gentle to low-moderate slopes; 2–10°; mostly convex	Acid soils with textural B horizons and strong brown and reddish plastic clayey subsoils (22*b*)	Largely secondary; mid-height lower montane forest: *Castanopsis;* also gardens, regrowth, and minor mid-height *Imperata* grassland	l3, e2, p4, a2, n2
2	3	High-moderate to steep slopes: 10–25°; mostly convex	Uniform fine-textured acid to strongly acid soils with strong brown to reddish subsoils, altered B horizons, and, locally, thin hardpans (9*e*)		l3, e4, p4, d1, m1, a2, n2
3	1	Alluvial terraces: 10–100 ft above stream; up to 300 ft wide and 1000 ft long; high to very high gradient	Uniform medium-textured acid gravelly yellowish brown soils with altered B horizons (9*a*)	Mid-height *Imperata* grassland and garden regrowth	l3, e1, p2, m2, a2, n2
4	3	Very steep and steep slopes: 25–45°; medium to very short; mostly straight	Uniform fine- and, locally, medium- to coarse-textured gravelly acid soils with altered B horizons (9*a*, 9*c*, 9*d*). Locally, undifferentiated medium- to fine-textured gravelly and stony acid colluvial soils (6*a*, 6*d*)	Garden regrowth and remnants of lower montane forest: *Castanopsis*	l3, e6, p2, a2, n2
5	1	Precipitous slopes and cliffs: short to ultra-short; generally straight; locally bare rock	Undifferentiated medium-textured shallow, gravelly, and stony colluvial soils (3)	Probably lower montane forest: *Castanopsis*, with open canopy, locally bare	l3, e6, r2, p2, d2, m4, a2, n3
6	1	Present stream channel and flood-plain: high-gradient streams with bouldery gravelly beds 30–100 ft wide with rectangular cross-sections, banks up to 12 ft high, flood-plains up to 300 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine- to medium-textured, acid (3*a*)	Probably tall and mid-height grassland, garden regrowth	f6, w2, p2, m2, a2, n2

Agricultural Capability.—Low potential for tree crops and improved pastures only. Tree crops would be limited to those suited to moderately high altitude.

Population and Land Use.—8·4 sq miles used for cultivation mainly on unit 1, less on units 2 and 3.

Observations.—4.

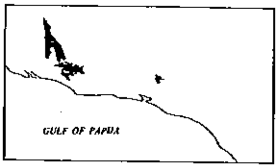
(21) Aro Land System (65 sq miles)

Low hills with very steep slopes and tall and mid-height hill forest, and local alluvial flats with basin forest.

Geology.—Upper Miocene and Pliocene mudstone, siltstone, greywacke, sandstone, and subordinate limestone. Recent alluvial silt, clay, and local gravel on flats.

Geomorphology.—Prominent structural control. Earth flows are common on bentonitic patches of mudstone. Stream courses within the hills have high gradients with cobbly beds generally 8–12 ft wide, and most of the cobbles are softened by weathering.

Terrain Parameters.—Altitude: av., 100 ft; min., 20 ft; max., 400 ft. Relief: low (200 ft). Grain: fine (600 ft). Characteristic slope: very steep. Plan-profile: crested highs occupy more than 60% of area and are linear and parallel (4L//).



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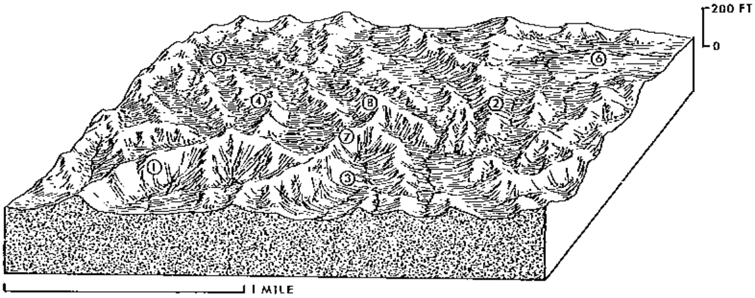


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	40	**Very steep and steep straight slopes:** short to ultra-short; locally convex or uneven; 25–45°; local earth flows	Uniform medium-textured strongly acid yellowish brown soils with altered B horizons (*9a*)	Mid-height small- to medium-crowned hill forest; minor tall medium- to large-crowned hill forest. Locally mixed herbaceous vegetation: Marantaceae	e6, p2, d1, m2, a5, n2
2	6	**High-moderate and steep slopes:** short to ultra-short; concave; straight and convex	Uniform fine- to, locally, medium-textured acid to weakly acid soils with altered B horizons and partly mottled and gleyed subsoils (*9a*, *9b*, 11); strongly acid and with thick dark topsoils and yellowish red to strong brown subsoils (*14c*); strongly acid soils with textural B horizons and yellowish red to red plastic clayey subsoils (*22a*)	Mid-height small- to medium-crowned hill forest; also tall medium- to large-crowned hill forest	Moderate slopes: e3, p4, a5, n2 Steep slopes: e5, p4, d1, m1, a2, n2
3	3	**Gentle to low-moderate slopes:** very short to ultra-short; mostly concave foot slopes; locally severe subsurface erosion	On moderate slopes: undifferentiated medium-textured gravelly acid soils (*6a*). On gentle slopes: uniform medium- to coarse-textured acid soils with thick dark topsoils and altered B horizons (*14a*)	Tall medium- to large-crowned hill forest	e2, p2, m2, a2, n2
4	3	**Low-moderate dip slopes:** short to ultra-short; straight; locally convex	Uniform fine-textured acid soils with altered B horizons and gleyed and mottled subsoils (11). Strongly acid soils with textural B horizons and plastic strongly red mottled subsoils (23)	Mid-height small- to medium-crowned hill forest	e3, p4, a5, n2
5	8	**Alluvial flats:** low to high gradient; up to 600 ft wide	Undifferentiated alluvial soils: strongly gleyed, fine-textured, acid (*3a*)	Mid-height small- to medium-crowned basin forest; locally with very open canopy and abundant *Pandanus*	w3, p5, a2, n2, 14
6	<1	**Alluvial terraces:** up to 20 ft above streams; up to 600 ft wide; very high gradient	Uniform coarse-textured gravelly acid yellowish brown soils, with altered B horizons (*9c*)	Tall medium- to large-crowned hill forest	p2, m2, a2, n2
7	3	**Narrow ridge crests:** 20–100 ft wide; 0–15°; convex	Uniform medium-textured shallow strongly acid soils with altered B horizons (12)	As in unit 2	e3, p2, d2, m3, a5, n3
8	<1	**Precipitous slopes and cliffs:** 45–65°, straight or uneven; mostly scarp slopes	Undifferentiated shallow stony soils (8) and rock outcrops	Mid-height small- to medium-crowned hill forest with very open canopy	e6, r1, p2, d4, m4, a2, n3

Agricultural Capability.—Very low suitability for tree crops and improved pastures only.
Population and Land Use.—0·6 sq mile used for cultivation, mostly on units 5 and 6.
Forest Potential.—Low- to moderate-yielding; *Homalium* and *Pometia*, locally *Parastemon*, are relatively common.
Observations.—5.

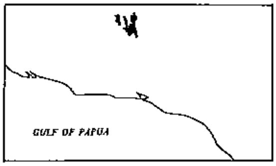
(22) Bananu Land System (23 sq miles)

Low parallel accordant hill ridges and dissected alluvial benches with dense mid-height small- to medium-crowned hill forest.

Geology.—Middle and Lower Miocene greywacke and mudstone with minor limestone.

Geomorphology.—Stream courses have low gradient with silty gravel beds between 10 and 40 ft wide and rectangular cross-sections.

Terrain Parameters.—Altitude: av., 600 ft; min., 400 ft; max., 900 ft. Relief: low (200 ft). Grain: medium (1750 ft). Characteristic slope: high-moderate. Plan-profile: crested highs occupy more than 60% of area and are linear and parallel (4L//).



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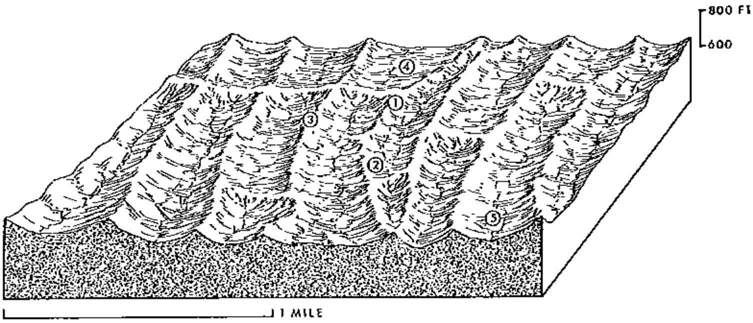


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	6	Very steep and steep slopes: medium to ultra-short; concave and straight	Uniform medium- to fine-textured, locally shallow and gravelly, acid yellowish brown soils with altered B horizons (*9a*, *9b*). Undifferentiated medium-textured shallow gravelly neutral colluvial soils (8)	Mid-height small- to medium-crowned hill forest	e5, s1, p2, d1, m2, n2
2	6	High-moderate and steep slopes: short to ultra-short; straight; concave or convex	Uniform fine-textured acid strong brown soils with altered B horizons (*9d*)		e5, p4, a2, n2
3	2	Narrow ridge crests: accordant, 50–300 ft wide; 0–15°, convex	Strongly acid soils with textural B horizons and strong brown and/or reddish plastic clayey subsoils (*22a*, *22b*)	As in unit 1, locally minor mid-height *Imperata* grassland	e2, p4, d1, m2, a5, n2
4	9	Dissected alluvial benches: up to 50 ft above streams; low to high-moderate concavo–convex; ultra-short slope	As in unit 3, but (*22c*)	As in unit 1	e3, p2, a5, n3
5	<1	Flood-plain terrace: up to 10 ft above stream; up to 600 ft wide; very high gradient	Uniform medium-textured acid soils with yellowish brown subsoils and altered B horizons (*9a*)	Mid-height small- to medium-crowned basin forest	c1, p2, a2, n2, I2

Agricultural Capability.—Low potential for tree crops and improved pastures.

Population and Land Use.—Minimal land use, on <0·2 sq mile.

Forest Potential.—Moderate- to high-yielding. *Koompassia* is locally common. Access is difficult because of remote situation.

Observations.—5.

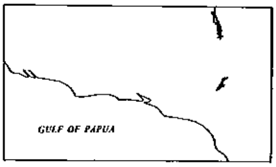
(23) Saw Land System (17 sq miles)

Karst plateaux with mid-height lower montane and upland forest.

Geology.—Miocene limestone.

Geomorphology.—Rectilinear patterns of enclosed depressions, including dolines, and steep-sided blade or cone-like hills (pyramid), with local cliffs, pinnacles, and towers. The plateaux are margined mostly by vertical cliffs. No surface drainage was observed.

Terrain Parameters.—Altitude: av., 4000 ft; min., 2000 ft; max., 5750 ft. Relief: moderately high (400 ft). Grain: fine (1800 ft). Characteristic slope: very steep. Plan-profile: crested highs occupy more than 60% of area and are non-linear and parallel (4L//).



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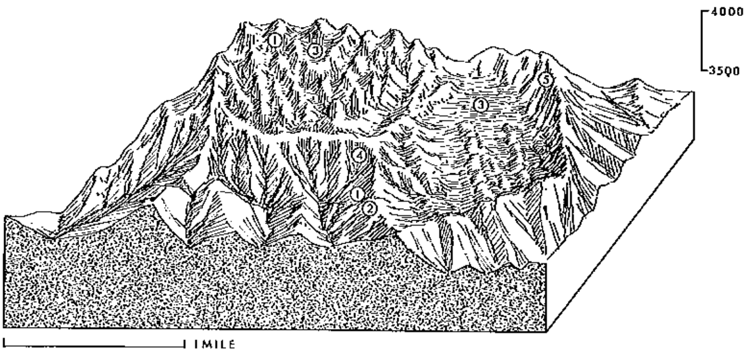


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	13	**Very steep and steep slopes:** short to ultra-short; straight and irregular; 25–45°; locally bouldery with large monoliths	Uniform fine- to medium-textured weakly acid to acid shallow stony soils with altered B horizons (12). Undifferentiated medium-textured shallow stony weakly acid colluvial soils (8) and rock outcrops	Mid-height small-crowned upland forest, canopy more open on rocky slopes; above 3000 ft, mid-height lower montane forest	l1, e5, s1, r4, p4, d4, m4, n2 l1, e6, s3, r5, p4, d5, m5, n3
2	2	**Steep upper slopes and summits:** very short and ultra-short; mostly convex; rocky with large monoliths	As in unit 1, and weakly acid medium- over fine-textured shallow stony soils with thick dark topsoils (19)	Mid-height mixed *Casuarina* forest	l1, e5, s1, r3, p4, d4, m5, n2
3	2	**Depressions and basins:** dolines with short to ultra-short concave slopes, 0–10°; locally rocky with large monoliths, and occasional caverns	Acid soils with textural B horizons and strong brown plastic clayey subsoils (22*c*). Uniform medium-textured shallow stony soils with altered B horizons (12) and rock outcrops	As in unit 1; above 3000 ft, mid-height lower montane forest	l1, e1, s1, r3, p4, d3, m4, a2, n2
4	<1	**Precipitous slopes:** short to ultra-short; irregular; abundant rock outcrops	Probably undifferentiated shallow stony colluvial soils (8) and rock outcrops	As in unit 1; canopy very open	l1, e6, r5, p4, d5, m5, n3
5	<1	**Cliffs, pinnacles, and towers:** short to ultra-short slopes, 72–90°; bare rock	Bare	Bare	

Agricultural Capability.—Very low suitability for tree crops only

Population and Land Use.—1·4 sq miles used for cultivation mostly on the northern occurrences of units 2 and 3.

Observations.—3.

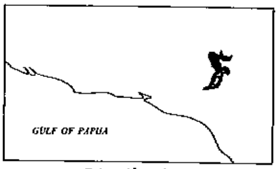
(24) Putei Land System (49 sq miles)

High hills with common limestone and mid-height hill and upland forest with many deciduous trees.

Geology.—Miocene greywacke, mudstone, and limestone.

Geomorphology.—Moderate and steep, mostly very even long straight or slightly curved slopes with local karstic features. Severe subsurface erosion occurs on the concave foot slopes where there is strong seepage. Stream courses have high gradient with cobbly sandy beds 20–60 ft wide with rectangular cross-sections.

Terrain Parameters.—Altitude: av., 600 ft; min., 125 ft; max., 2000 ft. Relief: high (900 ft). Grain: very coarse (4500 ft). Characteristic slope: high-moderate. Plan-profile: crested highs occupy more than 60% of area and are linear and random (4L).



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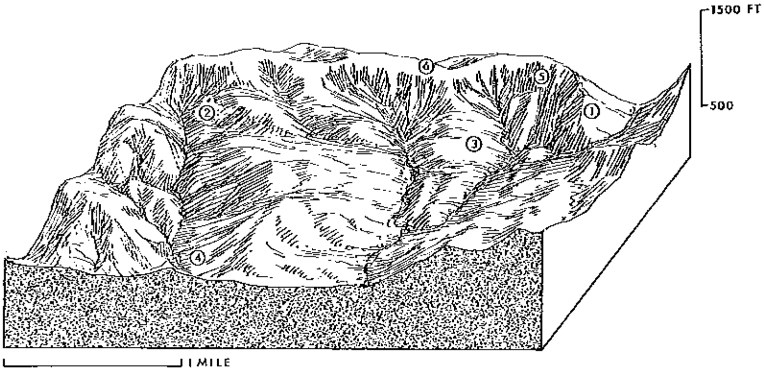


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	20	Steep straight slopes: short to long; locally dip slopes; clints and grikes on limestone	On limestone: weakly acid to neutral medium- over fine-textured shallow stony soils with dark topsoils (19). Uniform medium-textured locally gravelly and shallow, acid soils with altered B horizons (9*a*, locally 12) Undifferentiated medium-textured stony weakly acid colluvial soils (6*a*)	Mid-height small- to medium-crowned hill forest and mid-height small-crowned upland forest; locally, tall medium- to large-crowned hill forest	e5, s1, r3, p4, d4, m4, n2 e5, p2, d1, m2, a2, n2
2	5	Very steep straight slopes: short to ultra-short; on limestone bouldery, locally with monoliths	On limestone: undifferentiated medium-textured shallow stony acid colluvial soils (8) On greywacke-mudstone: undifferentiated medium-textured gravelly weakly acid colluvial soils (6*a*)	Mid-height small-crowned upland forest	e5, s4, r1, p2, d5, m5, a2, n2 e6, p2, d1, m2, a1, n2
3	20	Moderate slopes: mostly straight; medium to very short; locally concave	Uniform fine-textured acid olive-brown soils with altered B horizons (9*b*). Acid soils with textural B horizons and yellowish red to red plastic clayey subsoils (22*a*)	Mid-height small-crowned upland forest and mid-height, small- to medium-crowned hill forest	e3, p4, d1, m1, n2
4	2	Concave foot slopes: moderate to very gentle; medium to very short, with strong seepage at base	Uniform fine-textured acid soils with altered B horizons and strongly gleyed and mottled subsoils (13)	Tall medium- to large-crowned hill forest	e2, w2, p5, n2
5	<1	Precipitous slopes and cliffs: short to ultra-short; locally bare rock	Probably undifferentiated shallow colluvial soils (8) and rock outcrops	As in unit 1; canopy very open	e6, r5, p2, d5, m5, n3
6	1	Ridge crests: 0–15°; convex; usually narrow, 20–300 ft wide	Probably acid soils with textural B horizons and yellowish red to red plastic clayey subsoils (22*a*)	As in unit 1; commonly burnt	e2, p4, d1, m2, a2, n2

Agricultural Capability.—Potential is very low for arable cropping as this is limited to small areas on units 3 and 4; low to moderate for tree crops and moderate for improved pastures.

Population and Land Use.—2·3 sq miles used for cultivation mostly on unit 4 and small river terrace inclusions.

Forest Potential.—Moderate-yielding. *Terminalia* is common.

Observations.—12.

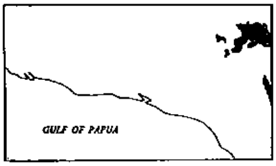
(25) Kurai Land System (122 sq miles)

High hills with very steep slopes and dip slopes and medium-textured shallow soils.

Geology.—Upper Miocene and Pliocene marine and terrestrial greywacke, mudstone, conglomerate, agglomerate, and local andesitic and basaltic volcanic rocks.

Geomorphology.—Intricately dissected with pronounced structural control. The upraised anticline of the Kurai hills is an example of tectonic relief. Stream courses are of high gradient, bouldery and gravelly between 20 and 100 ft wide, with rectangular cross-sections.

Terrain Parameters.—Altitude: av., 500 ft; min., 100 ft; max., 2000 ft. Relief: high (600 ft). Grain: coarse (2500 ft). Characteristic slope: steep. Plan-profile: crested highs occupy more than 60% of area and are linear and random (4L).



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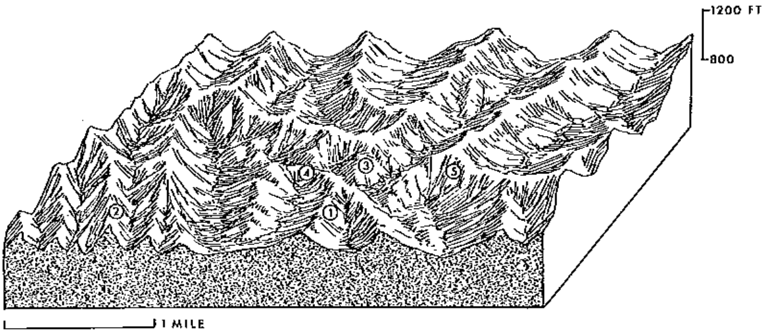


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	60	Steep and high-moderate slopes: 15–25°, short to medium length; straight or locally convex; locally dip slopes	Uniform medium-textured acid yellowish brown soils with altered B horizons (9*a*)	Mid-height small- to medium-crowned hill forest with open and irregular canopy; minor mid-height small-crowned upland forest	e5, p2, d1, m1 a2, n2
2	49	Very steep slopes: mostly straight; short to very short; locally scarp slopes	Uniform medium-textured shallow gravelly and stony acid soils with altered B horizons (12). Probably also undifferentiated medium-textured shallow gravelly and stony weakly acid colluvial soils (8)		e6, s1, p2, d4, m4, a2, n2
3	6	Structural benches: gentle and very gentle short straight slopes	Strongly acid soils with textural B horizons and yellowish red to red plastic clayey subsoils (22*a*). Uniform fine-textured acid yellowish brown soils with altered B horizons (9*b*)	Mid-height small- to medium-crowned hill forest	e1, p2, d1, m1, a2, n2
4	6	Narrow ridge crests: 0–15°; convex; 20–200 ft wide	Strongly acid soils with textural B horizons and yellowish red to red plastic clayey subsoils (22*a*)		e3, p2, d2, m3, a5, n2
5	1	Precipitous slopes and cliffs: short to ultra-short; locally bare rock	Shallow stony colluvial soils (8) and rock outcrops	Very open forest, locally bare	e6, r5, p2, d5, m5, n3

Agricultural Capability.—Generally low potential for tree crops except in drier parts in the south-east which are rated very low. Potential for improved pastures is very low.

Population and Land Use.—Nil.

Forest Potential.—Moderate-yielding.

Observations.—5.

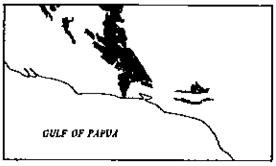
(26) Lohiki Land System (277 sq miles)

Densely forested high hills with high-moderate to very steep slopes and local benches and broad crests.

Geology.—Miocene greywacke, siltstone, and mudstone with subordinate limestone.

Geomorphology.—Near The Bluff, karstic features occur on flat-lying limestone. Stream courses have high gradients with cobbly sandy beds between 40 and 200 ft wide with rectangular cross-sections.

Terrain Parameters.—Altitude: av., 600 ft; min., 0 ft; max., 2000 ft. Relief: high (700 ft). Grain: medium (1800 ft). Characteristic slope: steep. Plan-profile: crested highs occupy more than 60% of area and are linear and random (4L).



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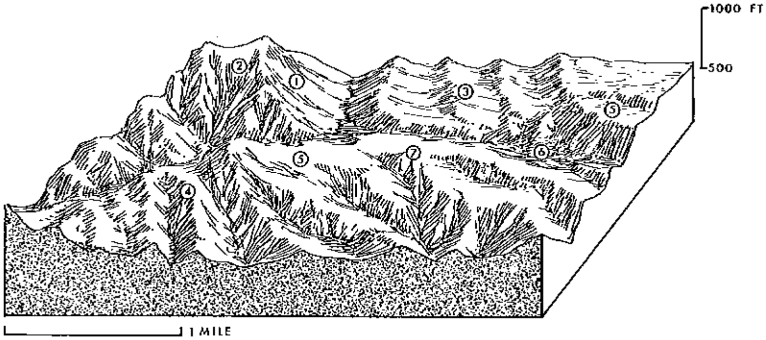


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	89	Steep and high-moderate slopes: 15–30°; short to long; straight; convex and uneven; locally spur slopes	Uniform medium- and fine-textured, locally gravelly, acid soils with altered B horizons (9*a*, 9*b*, 9*d*). Locally, strongly acid soils with textural B horizons and strongly red mottled plastic clayey subsoils (23) and undifferentiated gravelly weakly acid colluvial soils (6*d*)	Mid-height small- to medium-crowned hill forest and minor tall medium- to large-crowned hill forest; mid-height small-crowned upland forest above about 1000 ft	e5, p2, d1, m1, a2, n2
2	83	Very steep straight slopes: short to ultra-short	Uniform fine-textured acid olive-brown soils with altered B horizons (9*b*). Undifferentiated medium-textured, locally shallow and gravelly, weakly acid colluvial soils (6*a*)		e6, p2, d1, m2, a2, n3
3	42	Upper moderate slopes: mostly concave; short to ultra-short; 15–25°; locally steep	Uniform fine- and locally medium-textured acid yellowish brown soils with mottled subsoils and altered B horizons (9*b*, 9*a*). Locally, acid to strongly acid soils with textured B horizons and strong brown plastic clayey subsoils (22*c*)		e5, p4, a2, n2
4	17	Broad and narrow ridge crests: locally flat; generally convex	Uniform fine-textured acid grey mottled soils with altered B horizons (11). Uniform medium-textured acid yellowish brown soils with altered B horizons; minor, strongly acid reddish friable clay soils (26*a*, 26*b*)		e2, p4, a5, n2
5	17	Benches and flattened spurs: gentle and low-moderate medium to very short slopes; mostly convex	Uniform medium-textured, weakly acid yellowish brown soils with altered B horizons (9*a*)		e2, p4, n2
6	11	Concave foot slopes: short to ultra-short; moderate to gentle; strong seepage	Uniform medium-textured acid and neutral olive-brown to yellowish brown soils with altered B horizons (9*a*, 10)		e3, w1, p4, n2
7	19	Bench karst: on limestone; flats 100 by 200 ft; high-moderate to steep ultra-short side slopes; depressions up to 80 ft wide with gentle and very gentle slopes and local caverns	Uniform medium-textured shallow acid soils with altered B horizons (12); neutral shallow and stony soils with dark topsoils (19). Weakly acid to neutral soils with textural B horizons and thick dark topsoils (15)		e2, s2, r1, p2, d4, m4, a2, n2

Agricultural Capability.—Low potential for tree crops and improved pastures only.

Population and Land Use.—Minimal land use, <0·2 sq mile, mostly on occurrences of units 5 and 6 near Kerema Bay.

Forest Potential.—Moderate-yielding, but poorer towards Vailala River.

Observations.—24.

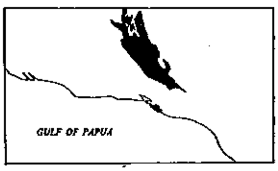
(27) NABO LAND SYSTEM (225 SQ MILES)

Low parallel mountain ridges and U-shaped valleys with mid-height hill and upland forest.

Geology.—Lower and Middle Miocene greywacke, siltstone, and mudstone with subordinate limestone.

Geomorphology.—Sub-accordant mountain ridges with dissected lower concave slopes. The axial streams are of high gradient with cobbly to sandy beds between 40 and 200 ft wide and rectangular cross-sections.

Terrain Parameters.—Altitude: av., 1500 ft; min., 100 ft; max., 3000 ft. Relief: high (900 ft). Grain: coarse (2500 ft). Characteristic slope: steep. Plan-profile: crested highs occupy more than 60% of area and are linear and parallel (4L//).



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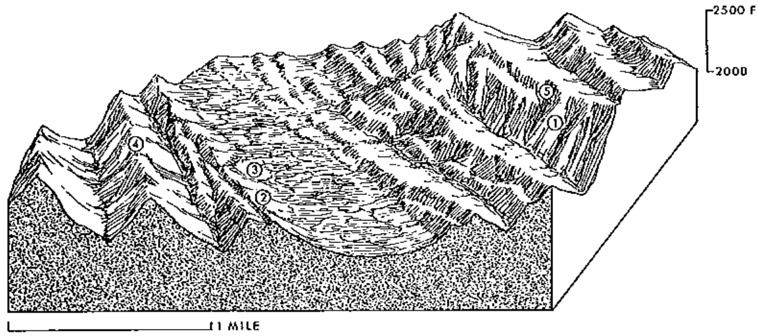


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	123	**Very steep and steep slopes:** medium to very short; concave and straight	Uniform medium- to fine-textured, locally gravelly, acid soils with altered B horizons (*9a*, *9b*). Locally, undifferentiated medium-textured partly shallow and gravelly colluvial soils (*6a*, 8)	Mid-height small- to medium-crowned hill forest and mid-height small-crowned upland forest, locally secondary	e5, s1, p2, d1, m2, n2
2	56	**High-moderate slopes:** mostly of concave valley head; short to very short; locally, severe subsurface erosion	Neutral medium-textured soils with thick dark topsoils (*16b*). Probably also uniform medium-textured acid soils with altered B horizons (*9a*)		e4, p2, a2, n2
3	33	**Dissected foot slopes:** of broad U-shaped valleys; concave-convex range 20–2°, average 10–12°; very short and ultra-short slopes	Uniform fine-textured acid to strongly acid soils with yellowish red subsoils and altered B horizons (*9d*)		e3, p4, a5, n2
4	10	**Narrow ridge crests:** 0–15°; convex; 30–200 ft wide	Strongly acid soils with textural B horizons and yellowish red to red plastic clayey subsoils (*22a*). Strongly acid reddish friable clay soils (*26b*)		e2, p2, a5, n2
5	2	**Precipitous slopes:** short to ultra-short	Undifferentiated medium-textured shallow gravelly colluvial soils (8)	As above, with more open canopy	e6, s1, p2, d2, m4, n3

Agricultural Capability.—Because of a high proportion of only moderate slopes this land system is moderately suitable for tree crops, is of low suitability for improved pastures, and of very low suitability for arable crops.

Population and Land Use.—4·8 sq miles used for cultivation, highly scattered, mostly on units 3 and 4. Non-indigenously owned plantations occupy 0·6 sq mile of units 1–4 (rubber).

Forest Potential.—Moderate-yielding. Patches of secondary forest are common.

Observations.—10.

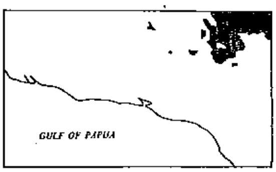
(28) Kapau Complex Land System (242 sq miles)

High hills to high mountains with mostly steep to very steep slopes and local karst.

Geology.—Miocene greywacke, mudstone, limestone, and conglomerate. In the north inliers of pre-mid-Tertiary and some basalt agglomerates of uncertain age.

Geomorphology.—Dip slopes, benches, and small plateaux are common. A group of conical hills with precipitous slopes occurs north-east of Putei. Scattered karst features, including furrowed hill slopes, dolines, and natural bridges, are developed on outcrops of limestone. Stream courses have high to very high gradient with cobbly and bouldery beds of variable width.

Terrain Parameters.—Altitude: av., 2500 ft; min., 400 ft; max., 6500 ft. Relief: very high (1500 ft). Grain: coarse (3000 ft). Characteristic slope: very steep. Plan-profile: crested highs occupy more than 60% of area and are linear and random (4L).



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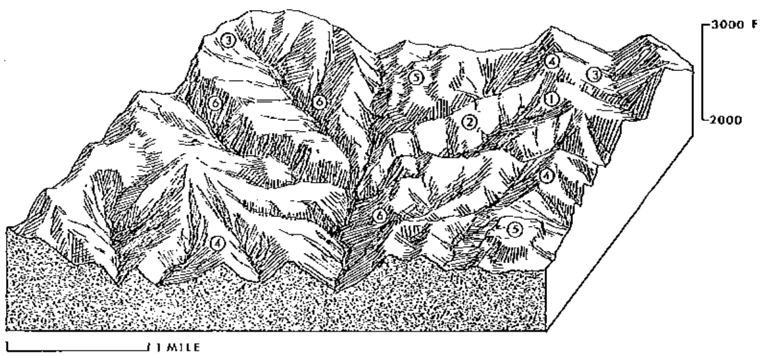


Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	121	Very steep slopes: short to very long; mostly straight	Undifferentiated medium-textured gravelly and stony acid colluvial soils (6*a*)	Largely secondary mid-height lower montane forest, also mid-height small-crowned upland forest and small- to medium-crowned hill forest	10–13, e6, p2, d2, m4, a2, n3
2	80	High-moderate and steep slopes: locally dip slopes; short to very long; mostly straight	Uniform fine- to medium-textured, locally gravelly and stony, strongly acid yellowish brown to strong brown soils with altered B horizons (9*a*, 9*b*, 9*d*)		10–13, e5, p2, a5, n2
3	10	Low-moderate and gentle slopes: locally dip slopes; short to very long; mostly straight	Probably uniform fine-textured strongly acid soils with altered B horizons (9*b*, 9*d*)		10–13, e2, p2, a2, n2
4	12	Ridge crest: mostly narrow; 0–15°; convex	Uniform fine-textured strongly acid yellowish red soils with altered B horizons (9*d*). Undifferentiated medium-textured gravelly acid colluvial soils (6*a*)		10–13, e2, p2, d1, m2, a5, n2
5	12	Benches and small plateaux: very gentle and gentle medium to very long slightly convex slopes	Probably uniform fine-textured strongly acid soils with altered B horizons (9*a*, 9*d*)	Probably lower montane forest	11–13, e2, p4, a5, n2
6	7	Precipitous slopes and cliffs: medium to ultra-short; local rock outcrop	Undifferentiated medium-textured shallow stony colluvial soils (8) and rock outcrops	As in unit 1; more open canopy; locally bare	10–13, e6, r2, p2, d2, m4, a2, n3

Agricultural Capability.—Generally low potential for tree crops and very low potential for improved pastures.
Population and Land Use.—5·2 sq miles used for cultivation in scattered occurrences mostly on units 3–5.
Observations.—5.

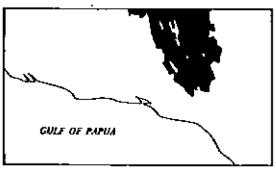
(29) Eruki Land System (513 sq miles)

High subparallel mountain ridges with very steep straight slopes and mid-height lower montane and upland forest.

Geology.—Middle and Lower Miocene greywacke, siltstone, and mudstone with subordinate limestone.

Geomorphology.—Above about 3000 ft there is a complete leaf litter cover on all slopes (except cliffs), and subsurface erosion, soil flow, and probably subsurface corrasion become the dominant agents of erosion. Stream courses have high gradient with cobbly beds and are generally 40–60 ft wide with rectangular cross-sections.

Terrain Parameters.—Altitude: av., 4000 ft; min., 250 ft; max., 7350 ft. Relief: very high (2000 ft). Grain: very coarse (5000 ft). Characteristic slope: very steep. Plan-profile: crested highs occupy more than 60% of area and are linear and parallel (4L//).



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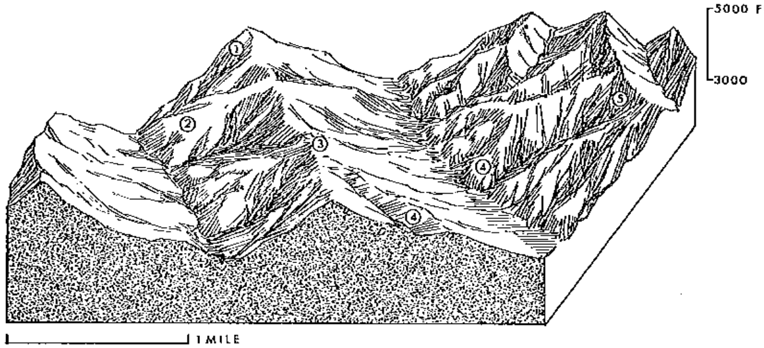

Land Unit	Area (sq miles)	Land Form	Soil	Vegetation	Limitations
1	308	**Very steep slopes**: mostly straight; medium to very long; locally bouldery; at higher altitudes active soil flow	Uniform fine- and, locally, coarse- to medium-textured gravelly acid soils with altered B horizons (9*a*, 9*c*, 9*d*). Undifferentiated medium- to fine-textured gravelly acid colluvial soils (6*a*, 6*d*). Locally, strongly acid soils with textural B horizons and strong brown plastic clayey subsoils (22*c*)	Mid-height small-crowned upland forest, largely secondary mid-height lower montane forest, minor mid-height small- to medium-crowned hill forest. Between 3000 and 4500 ft garden regrowth and tall grassland: *Imperata–Miscanthus*	Below 3500 ft: l1, e6, p2, d2, m2, a2, n2; locally a1, r3 Above 3500 ft: l3, e6, p2, a2, n2; locally s1, r3
2	169	**High-moderate and steep slopes**: straight and concave; medium to very long	Uniform fine-textured, locally gravelly, strongly acid strong brown soils with altered B horizons (9*d*). Strongly acid soils with textural B horizons and strong brown and reddish brown subsoils (22*b*)		e5, p2, d1, m1, a5, n2
3	15	**Ridge crests**: locally broad; mostly narrow; 0–15°; convex; strong subsurface erosion	Uniform fine-textured, locally gravelly, strongly acid soils with altered B horizons (9*d*, 9*e*). Strongly acid soils with textural B horizons and reddish plastic clayey subsoils (22*a*)		e3, p4, d1, m2, a5, n2
4	15	**Benches and spur flattenings**: short to ultra-short; slightly convex; high-moderate slopes	Uniform medium-textured acid yellowish brown soils with altered B horizons (9*a*)		e2, p2, m2, a2, n2; locally s1
5	5	**Precipitous slopes and cliffs**: short to ultra-short; generally straight; locally bare rock	Undifferentiated medium-textured shallow gravelly and stony colluvial soils (8) and rock outcrops	As above, with more open canopy; locally bare	e6, s1, p2, d2, m4, a2, n3

Agricultural Capability.—Generally of no value, but areas below 3500 ft have very low suitability for tree crops.

Population and Land Use.—101·5 sq miles used for cultivation mostly on units 2–4.

Observations.—10.

PART IV. CLIMATE OF THE KEREMA–VAILALA AREA

By J. R. McAlpine*

I. Principal Climatic Features and Controls

The climate of the area generally may be described by either Köppen (1931) or Thornthwaite (1931) classifications as tropical rain forest (Af) or wet tropical type (AA′r). The most south-easterly sector is, however, of the tropical savannah (Aw) or subhumid tropical type (CA′r). In the absence of climatic records, the zone of transition between these two climatic types has been inferred from changes in vegetation (see Part VIII) and is indicated in Figure 2. The transition zone is nowhere

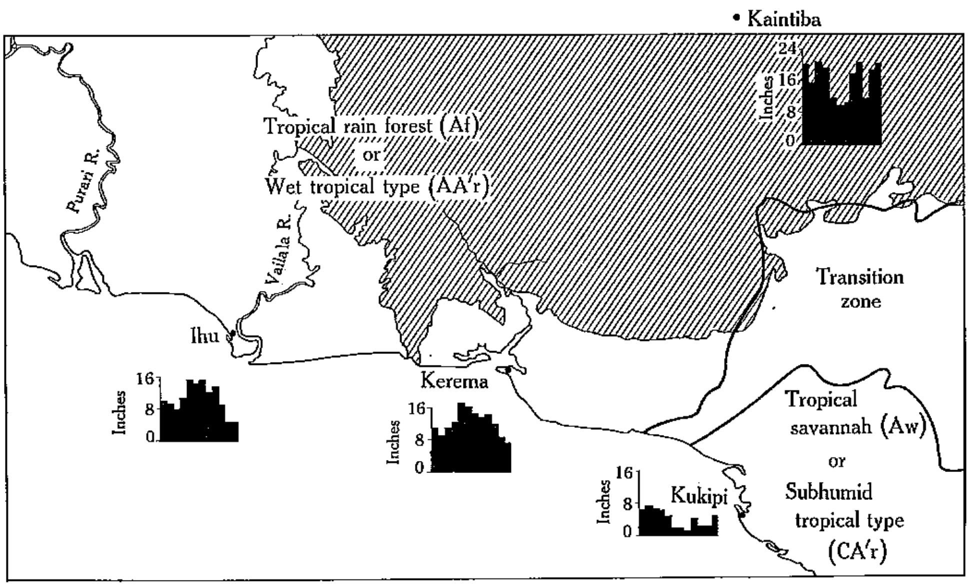

Fig. 2.—Climatic regions and histograms showing seasonal distribution of rainfall (January–December) for four stations. The extent of the Kukukuku lobe is shown by cross hatching.

wider than 20 miles. The south-easterly continuation of the tropical savannah sector forms a major part of the Port Moresby–Kairuku area previously described by Fitzpatrick (1965). Hence this Part should be read in conjunction with Fitzpatrick's work.

The major climatic controls of Papua and New Guinea are based on the seasonal wind systems and the aspect of terrain in relation to these systems. The north-west season occurs between December and April and the south-east (trade)

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wind season between June and mid October. Brief transitional doldrum periods occur between these two major seasons. For a fuller description of wind and other synoptic controls see Brookfield and Hart (1966), Glendinning (1959), Hogan (1940), and Hounam (1951).

II. General Climatic Characteristics

(*a*) *Rainfall*

The rainfall pattern in this area is placed in the general south-west Pacific setting by Brookfield and Hart (1966), and the broad regional rainfall seasonality pattern is discussed by Fitzpatrick, Hart, and Brookfield (1966).

The major control modifying the broad rainfall pattern in this particular region is the protrusion of the Kukukuku lobe (Fig. 2), a coastal extension of the central cordillera, across the otherwise parallel alignment of coast, ranges, and prevalent winds. The presence of this lobe in relation to the prevailing winds accounts for the sharp break in seasonality and amount of rainfall occurring on either side of it. This is a most distinguishing and dominant local climatic feature. Kerema occupies a central position on the coastal margin of this lobe and has the highest mean annual coastal rainfall in the area (142 in.). Although somewhat greater mean monthly falls occur at Kerema in the season of south-east winds, seasonality is not marked. To the north-west of the lobe seasonality increases and rainfall decreases slightly to 127 in. per annum at Ihu. By contrast, in the area to the south-east of the lobe mean annual rainfall decreases sharply to 46 in. per annum at Kukipi and seasonality becomes marked and reversed, the larger amount of rain falling in the north-west season. Inland from the coast, rainfall increases with distance and elevation. On the limited 3-yr record, mean annual rainfall at Kaintiba, on the ranges, is 189 in. Local experience indicates that most rainfall throughout the area occurs during the night (e.g. loss of work due to rain on plantations during the day is minimal despite the high annual rainfall). Thus daily variations in convection may also control the local rainfall pattern.

Monthly rainfall data for the four stations in the area are shown in Table 1, and the spatial distribution in Figure 2. Highest and lowest annual rainfalls on record are also given, since the record length is too short to provide a reliable measure of rainfall variability. Table 2 indicates the mean and longest observed periods without rain at Kerema and, in keeping with the high annual rainfall and lack of seasonality at this station, indicates the slight variation in these characteristics over the year. Records at Kukipi are too disjointed to make comparison of this aspect quantitatively reliable, but it can be qualitatively stated that mean rainless periods here are considerably longer, especially in the south-east season. Table 3 gives the frequency of daily rainfalls within specified limits for Kerema and indicates that heaviest falls are restricted to the south-east season.

(*b*) *Elements Other than Rainfall*

The only other elements for which data are available are temperature and relative humidity. Together with derived figures for evaporation, these are shown for Kerema in Table 4. Mean monthly temperatures (i.e. monthly mean of mean daily

TABLE 1

RAINFALL CHARACTERISTICS FOR FOUR STATIONS

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	Highest Annual	Lowest Annual
Kerema*															
Mean rainfall (in.)	9·37	8·40	10·40	11·54	16·70	15·72	14·08	13·39	13·89	11·94	8·62	7·76	141·81	177·38	76·89
Mean no. of rain days	15	17	17	16	20	19	20	21	21	16	14	13			
Kukipi (6 yr of records)															
Mean rainfall (in.)	6·49	7·23	6·67	5·50	3·83	1·56	1·50	1·18	3·73	2·03	2·07	4·36	46·15	52·16	38·91
Mean no. of rain days	19	10	5	6	4	4	4	3	6	4	5	5			
Ihu (11 yr of records)															
Mean rainfall (in.)	9·87	9·77	8·46	10·19	15·32	14·07	14·58	12·61	13·47	9·12	5·00	5·04	127·44	128·89	105·35
Mean no. of rain days	11	13	11	10	15	15	18	17	15	10	7	7			
Kaintiba (3 yr of records)															
Mean rainfall (in.)	19·75	14·00	20·11	18·73	11·41	9·06	10·06	17·38	19·77	11·51	18·15	18·87	188·80	199·16	183·09
Mean no. of rain days	26	22	25	25	25	23	26	27	27	27	23	29			

* Kerema rainfall tabulated from Brookfield and Hart (1966).

temperatures) vary little through the year, ranging from 77°F in August to 81°F in January. The average annual mean daily temperature is 79°F, mean minimum 73°F, and mean maximum 85°F. Thus diurnal temperature ranges, which vary from 10 to 14 degF, are greater than seasonal changes, but the greatest temperature variations occur with increasing ground elevation associated with a lapse rate of approximately 3 degF per 1000 ft.

TABLE 2

MEAN DURATION OF RAINLESS PERIODS AND LONGEST RAINLESS PERIODS (IN DAYS) AT KEREMA

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Average daily length of rainless period	2·3	2·8	2·1	2·1	2·1	2·1	2·0	1·9	1·9	2·9	3·2	2·6
Longest rainless period on record	11	11	8	10	9	13	9	7	7	13	14	10

Mean monthly relative humidity likewise shows little variation throughout the year, averaging 83% at 9 a.m. and 74% at 3 p.m.

TABLE 3

PERCENTAGE OF RAIN DAYS AT KEREMA WITH RAINFALLS WITHIN SPECIFIED LIMITS

Amount (in.)	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0·01–0·24	48	45	49	47	44	45	41	44	44	48	52	49
0·25–0·99	33	39	30	30	29	34	38	39	34	26	28	32
1·00–1·99	13	13	15	14	12	14	12	10	12	13	15	10
2·00–3·99	6	3	6	8	9	6	5	3	7	10	4	7
4·00–5·99				1	5	1	2	1	1	3	1	2
≥6·00					1		2	1	2			
Mean no. of rain days	*15*	*17*	*17*	*16*	*20*	*19*	*20*	*21*	*21*	*16*	*14*	*13*

III. Climate, Plant Growth, and Water Balance

Temperature and other climatic conditions in this area appear to be suitable for plant growth throughout the year. However, the tropical savannah climate of the south-easterly sector with its greater length and severity of dry season results in contrasting plant growth conditions, and hence vegetational characteristics, compared with the remainder of the area (see Part VIII). Climate and plant growth are here discussed solely through water balance relationships and these are presented at two levels. First, crudely, as a direct precipitation–evaporation relationship and secondly as a model based on changing soil moisture storage levels.

Figure 3 indicates the direct monthly relation for a number of years between precipitation and evaporation at Kerema and Kukipi. No direct evaporation data are available for Kerema but estimates related empirically to the standard Australian

TABLE 4

TEMPERATURE CHARACTERISTICS, MEAN MONTHLY RELATIVE HUMIDITY, AND EVAPORATION AT KEREMA

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Temperature (°F)													
Mean maximum	87·9	87·7	87·6	86·3	85·3	83·1	81·9	81·6	82·6	84·8	86·8	87·9	85·3
Mean	80·8	80·7	80·6	79·6	79·0	78·0	77·1	76·6	77·5	78·8	79·9	80·6	79·1
Mean minimum	73·7	73·7	73·5	72·8	72·6	73·0	72·3	71·7	72·4	72·9	73·0	73·2	72·9
Highest on record	95·0	96·7	94·2	95·8	93·0	90·2	90·0	89·7	89·2	90·7	92·7	94·7	
Lowest on record	69·1	69·1	61·3	57·9	58·0	67·9	65·5	61·3	66·8	64·0	67·0	67·9	
Relative humidity (%)													
0900 hr	81·0	83·0	81·0	82·0	85·0	88·0	90·0	88·0	88·0	82·0	78·0	77·0	
1500 hr	68·3	69·0	70·0	73·0	76·0	78·8	82·0	81·0	80·0	75·0	71·0	68·5	
Evaporation (in.)	5·1	5·0	4·8	4·3	4·1	4·0	3·7	3·7	3·6	4·3	4·9	5·6	53·1

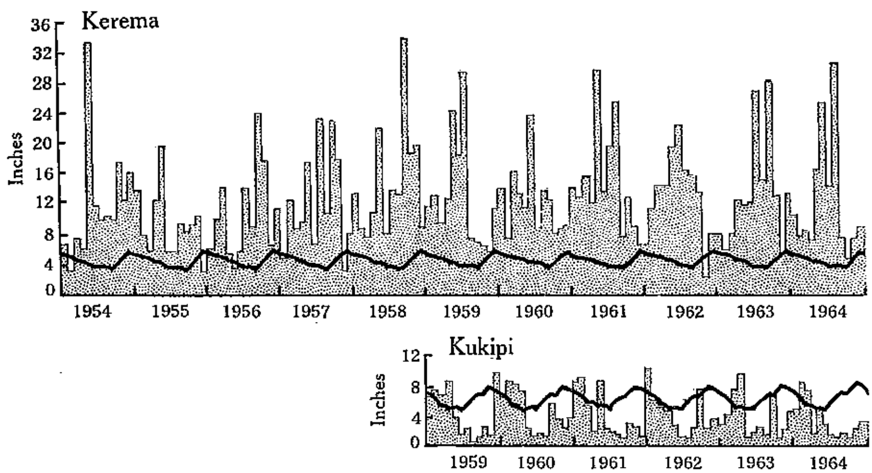

Fig. 3.—Mean monthly precipitation (histograms) and evaporation (graph) for Kerema and Kukipi. Evaporation data from Port Moresby have been applied to Kukipi.

TABLE 5

NUMBER OF WEEKS FOR SPECIFIED YEARS IN WHICH SOIL MOISTURE WAS DEPLETED BY SPECIFIED PERCENTAGE RANGES

Soil Moisture Depletion (%)	1957	1958	1959	1960	1961	1962	1963	1964	1965
					Kerema				
100	n.d.*	0	0	0	0	0	0	0	0
99–75	n.d.	0	0	0	0	0	1	0	0
74–50	n.d.	1	0	0	0	2	0	0	0
49–25	n.d.	2	3	6	0	4	4	0	3
24–1	n.d.	9	13	11	15	8	11	15	15
0	n.d.	40	36	35	37	38	36	37	34
					Ihu				
100	0	0	0	0	0	0	0	0	0
99–75	0	0	0	0	0	0	0	0	1
74–50	0	0	0	0	2	1	0	2	3
49–25	3	1	0	5	6	8	5	6	7
24–1	16	15	5	12	9	11	14	18	17
0	33	36	47	35	35	32	33	26	24
					Kukipi				
100	n.d.	n.d.	n.d.	6	4	10	5	6	n.d.
99–75	n.d.	n.d.	n.d.	2	10	7	4	4	n.d.
74–50	n.d.	n.d.	n.d.	15	8	3	4	9	n.d.
49–25	n.d.	n.d.	n.d.	13	7	15	9	7	n.d.
24–1	n.d.	n.d.	n.d.	10	12	6	17	9	n.d.
0	n.d.	n.d.	n.d.	6	11	11	13	17	n.d.

* No data.

tank have been obtained from monthly mean maximum temperatures, vapour pressures, and day length (Fitzpatrick 1963). These are given in Table 4. Evaporation records from the standard Australian tank at Port Moresby for the years 1957–62 have been averaged and applied to the Kukipi situation. A comparison of the two figures indicates strikingly the varying nature of the two stations and hence of the climatic regimes characteristic of the area.

TABLE 6

SUMMARIZED MEAN ANNUAL WATER SURPLUS DATA

		Annual Precipitation in Excess of Evapotranspiration ($P-ET$)	No. of Weeks in which Excess Occurred ($P>ET$)	Annual Precipitation in Excess of Evapotranspiration and Requirement to Replenish Storage ($P-(ET+\text{Storage})$)	No. of Weeks in which Excess Occurred ($P>(ET+\text{Storage})$)
Ihu	Mean	95·09	37	86·43	32
(10 yr)	Lowest	70·87	40	55·44	23
	Highest	135·59	47	134·34	47
Kerema	Mean	113·07	40	105·56	36
(9 yr)	Lowest	78·08	39	70·10	35
	Highest	139·11	41	133·87	37
Kukipi	Mean	20·14	19	7·84	6
	Lowest	16·67	15	5·30	6
	Highest	22·24	18	10·33	7

A more refined water balance model has also been applied using the previous evaporation data as withdrawal (evapotranspiration) and rainfall as input. The model is designed to indicate week-to-week changes in soil moisture levels and these have been assessed with the aid of computer processing. The assumptions in applying the model are that actual evapotranspiration (ET) is related to evaporation from a standard tank evaporimeter (E) by the relationship $ET=0\cdot8E$ for those weeks with storage plus rainfall exceeding 2·50 in. and by $ET=0\cdot4E$ below this level. The model may tend to underestimate evapotranspiration when the upper parts of an otherwise dry soil profile receive rains less than 2·50 in. and to overestimate it during weeks without rainfall when stored soil water in the upper profiles is nearing depletion. However, these variations are of little significance in a general assessment over a number of years. Maximum soil moisture storage is assumed to be 5·00 in. and run-off is assumed to occur only when maximum soil moisture storage is reached.

The results of this analysis are given in Table 5, which illustrates the number of weeks in a series of years in which given percentages of soil moisture depletion occurred. The table illustrates conclusively that water stress in plants is never likely to occur in the Kerema–Ihu sector. In fact, given poor drainage, land use capability is liable to be affected instead by frequent inundation resulting from excessive run-off. By contrast, in the Kukipi sector water stress will inhibit seasonal production for introduced tree and other crops.

These water balance figures have been further extended to give some indication of annual water surplus (i.e. run-off and infiltration). Table 6 indicates the mean annual run-off and infiltration situation at three stations and again clearly indicates the different climatic regimes occurring in the area.

IV. Acknowledgment

Data preparation and tabulations for this Part have been carried out by Miss P. Bridson.

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PART V. GEOLOGY OF THE KEREMA–VAILALA AREA

By B. P. RUXTON*

I. INTRODUCTION

Since oil seepages were discovered near the mouth of the Vailala River in 1911, a considerable amount of exploration for petroleum has been carried out in western Papua. This work has been fully documented by the Australasian Petroleum Company Proprietary (1961), and geological mapping has covered all but the extreme north-eastern corner of the Kerema–Vailala area (Fig. 4).

This chapter is for the most part a summary of this work as it refers to the survey area and as it is relevant to an understanding of the geomorphology and the land systems.

II. STRATIGRAPHY

(*a*) *Mesozoic*

Although there are no recorded outcrops of Mesozoic rocks, Mesozoic greywacke and mudstone have been encountered in deep bores and are probably present at varying depths across most of the area.

In the north-east near the New Guinea border a series of shales, cleaved greywackes, and low-grade phyllites are overlain unconformably by Upper Miocene sediments and may be of Mesozoic age (Australasian Petroleum Company Proprietary 1961).

(*b*) *Palaeogene*

There are no definite records of Palaeogene rock outcrops but siliceous rocks resembling the Eocene of Port Moresby district occur in the middle reaches of the Tauri River.

Evidence from deep bores and adjacent areas suggests that the Palaeogene formations are unconformable on the Mesozoic rocks and that marine deposition was intermittent during Eocene and Oligocene time.

(*c*) *Neogene*

The Upper Oligocene was a period of general emergence and Lower Miocene sediments are unconformable on Palaeogene rocks. In general the Neogene sediments are a monotonous sequence of greywacke of alternating argillaceous and arenaceous grade, and subordinate limestone. Macrofossils are extremely rare and subdivisions and correlation have been effected after the study of the microfossils.

Practically all the hills and mountains of the Kerema–Vailala area are made up of Neogene rocks and their nature and occurrence will be considered in more detail.

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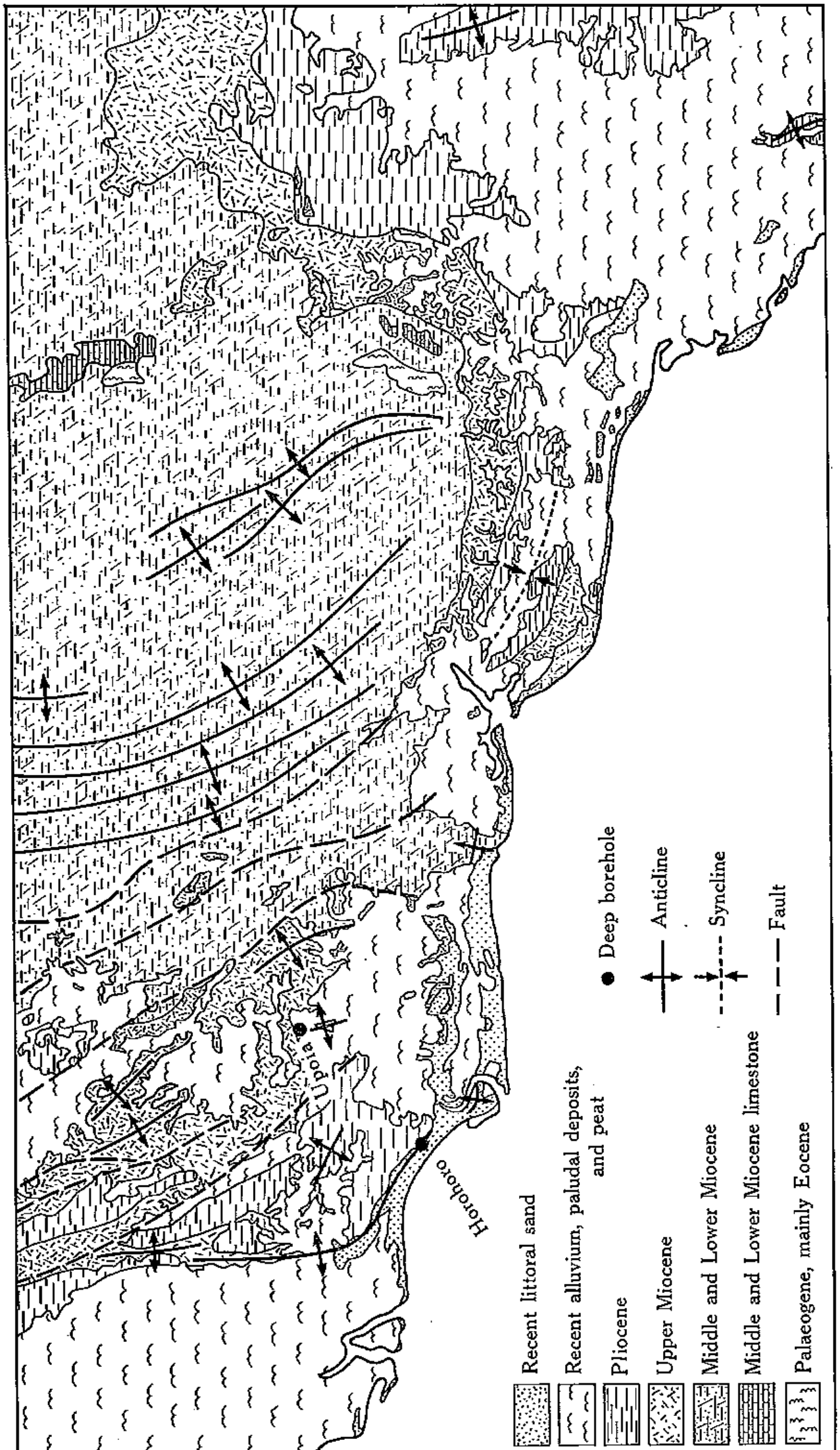

Fig. 4.—Geology of the Kerema-Vailala area.

(i) *Lower and Middle Miocene.*—Great thicknesses of alternating beds of mudstone and greywacke were deposited in a meridionally elongated marine basin in Early and Middle Miocene time. This basin is termed the Aure trough and is part of the larger Papuan Geosyncline.

In Lower Miocene time more than 15,000 ft of such sediment was deposited in the vicinity of Kerema and northwards, while in Middle Miocene time the axis of maximum sedimentation shifted westwards, over 6000 ft being deposited about the lower reaches of the Vailala River.

These beds have been called the Aure facies and though dominated by argillaceous and arenaceous greywacke and mudstone, subordinate beds of siltstone, sandstone, marl, calcareous grit, and conglomerate occur. The greywackes show graded bedding and are poorly sorted with 25 to 30% clay.

The Aure facies belt is now about 70 miles wide, being approximately bounded by the Purari River in the west, beyond which the sequence becomes highly calcareous, and by the Tauri–Kapau Rivers in the east. The eastern hinge-line to the Aure trough is marked by limestone reefs aligned meridionally along the Tauri–Kapau Rivers. East of here the sediments are thinner and coarser, including conglomerates, and terrestrial andesites and basaltic volcanics become important. The limestone is developed both in the Lower Miocene, e.g. north of Putei, and in the Middle Miocene, e.g. as a capping of the Saw Mountains.

(ii) *Upper Miocene and Pliocene.*—The Upper Miocene sediments are probably unconformable on the Middle and Lower Miocene beds. They are thickest northwards from between the mouths of the Purari and Vailala Rivers, where they exceed 9000 ft, and consist of dominant mudstone and greywacke with subordinate sandstone, conglomerate, limestone, and local slump reef breccias.

Between the Vailala and Purari Rivers, Upper Miocene mudstones are dominant and include members with a high bentonite content as well as fault zones altered to bentonite.

East of the Lakekamu River the Upper Miocene beds are mainly non-marine and in the Kurai hills they consist of conglomerates with basalt boulders overlain by massive sands and silts totalling some 2000 ft thick.

Little is known of the geology in the extreme north-east of the area, but during the survey gently dipping basalt agglomerates were noted near the Pade watershed (grid reference 410160) and they are tentatively correlated with the similar volcanics in the Kurai hills.

The Pliocene is generally conformable on the underlying Upper Miocene, and though it has been much disturbed by folding and erosion the thickest sedimentation of over 8000 ft appears to be in a NNW.-trending belt inland from the mouths of the Purari and Vailala Rivers. Here the rocks are mainly marine sandstone and mudstone with subordinate conglomerate, siltstone, and sandy and carbonaceous mudstones.

Pliocene sedimentation was in "two embayments (to the north) of a sea lying to the south of the present Papuan coast-line, with their adjacent maritime plains. The more westerly of the two embayments covers the present site of the deltas of the Kikori and Purari Rivers . . ., and may be called the 'Delta Embayment'; the more easterly covers the coastal country east of Kerema, through which the Lakekamu and

TABLE 7

CHEMICAL COMPOSITION OF THE AURE GREYWACKES AND MUDSTONES*

	As Analysed			Calculated free of $CaCO_3$ and Hygroscopic Water			Calculations of Daly (1933)		
	Greywacke	Gritty Greywacke	Mudstone	Greywacke	Gritty Greywacke	Mudstone†	Average Andesite	Average Augite Andesite	Average Hornblende Andesite
SiO_2	53·30	52·34	52·36	57·72	63·81	59·25	59·59	57·50	61·12
Al_2O_3	18·33	12·44	15·83	19·85	15·17	17·91	17·31	17·33	16·10
Fe_2O_3	2·41	1·23	1·96	2·61	1·50	2·22	3·33	3·78	2·89
FeO	2·36	3·02	3·74	2·55	3·68	4·23	3·13	3·62	2·40
MgO	2·62	2·54	3·00	2·83	3·10	3·40	2·75	2·86	2·44
CaO	5·88	12·80	5·91	5·39	5·88	3·25	5·80	5·83	5·80
Na_2O	2·18	2·04	2·18	2·36	2·49	2·47	3·58	3·53	3·83
K_2O	1·72	1·56	1·50	1·86	1·90	1·70	2·04	2·36	1·72
H_2O^+	3·14	0·96	3·62	3·40	1·17	4·09	1·26	1·88	1·43
H_2O^-	5·74	1·31	5·08	0	0	0	0	0	0
CO_2	1·00	8·78	3·34	0	0	0	0	0	0
TiO_2	0·84	0·62	0·91	0·91	0·75	1·03	0·77	0·79	0·42
P_2O_5	0·28	0·19	0·24	0·30	0·23	0·27	0·26	0·30	0·15
MnO	0·08	0·23	0·08	0·09	0·28	0·09	0·18	0·22	0·15
SO_3	0·08	tr	0·04	0·09	tr	0·05	—	—	—
Cl	0·03	0·03	0·03	0·03	0·04	0·03	—	—	—
Total	99·99	100·09	99·82						
$Na_2O:K_2O$				1·27	1·30	1·45	1·75	1·50	2·22

* From Edwards (1950*a*, p. 139). † Composite sample.

other rivers reach the sea, and has been called the 'Lakekamu Embayment'. At the heads of the embayments and on the flanks, the strata accumulated were largely terrestrial and, especially in the east, volcanic. In the centre of the embayments marine deposits are present, and these increase rapidly towards the south-east in the Delta Embayment, and to the south-west in the Lakekamu Embayment". (Australasian Petroleum Company Proprietary 1961, p. 105.)

(*d*) *Quaternary*

Most of the Pleistocene and Recent deposition has been in the two embayments and in isolated inland basins, particularly along the Vailala River. The deposits are rarely exposed and little work has been done on them. A bore at Wana in the delta embayment to the west of the survey area passed through 50 ft of unconsolidated silt presumed to be Recent alluvium and 850 ft of unconsolidated coarse sandstone and silty mudstone most of which was presumed to be Pleistocene. The beds are quite variable, reflecting several different terrestrial and littoral environments including alluvial lake, freshwater swamp, tidal flats, beach plain, etc.

On the coastal fringe of the Kukukuku lobe (see map of physical features) and along the inner margin of the Lakekamu embayment, a series of marine and alluvial terraces occurs up to 100 ft above nearby rivers with deposits of gravel, sand, and clay that have in most places been deeply and maturely weathered and reddened. In some instances the terraces appear to have been tilted since their formation.

III. Chemistry and Mineralogy of the Sediments

The greywacke and mudstone of the Aure facies of the Middle Miocene near Cape Cupola and Napere Creek were examined in detail by Edwards (1950*a*). The greywackes consist of angular grains of basic plagioclase, hornblende, and pyroxene, together with numerous rounded rock fragments in a prominent clay matrix. The rock fragments include a variety of andesite, schist, mudstone, and reef quartz. Most of the mineral and rock fragments are fresh. Angular grains of basic plagioclase were also found in the mudstone. Authigenic minerals include calcite, epidote, pyrite, and chlorite.

Three chemical analyses show that the chemical composition of the mudstone is similar to that of the greywacke and that both approximate to that of an average andesite (Table 7).

Edwards concluded that the Aure facies were derived from a mountainous terrain by erosion of andesitic tuffs under similar climatic conditions to those of today. In general the phenocrysts in the tuffs went to form the greywacke while the groundmass went to form the mudstone.

Results from the examination of Cretaceous greywackes from the Purari valley to the north of the survey area (Edwards 1950*b*) were very similar. It is therefore reasonable to expect that the character of most of the Neogene greywacke and mudstone in the Kerema–Vailala area is similar, though many of the terrestrial Pliocene sediments are probably secondarily derived from earlier Neogene rocks.

IV. Structure

The present structure is principally the result of folding, faulting, and uplift in about mid-Pliocene time (Smith 1965). Earlier precursory folding took place during the Upper and Middle Miocene and this had followed local disturbance and elevation in the Late Palaeogene.

Three structural zones are distinguished. A gently folded belt west of the Purari River, a strongly folded belt between the Purari and Vailala Rivers, and an imbricate zone east of the Vailala River. Most of the folds strike NNW.–SSE. The imbricate zone is a great series of subparallel fault slices striking NNW.–SSE. and dipping ENE. which repeat the same formations many times.

The reverse faults of the imbricate zone developed concurrently with the folding and are often traceable over considerable distances. Evidence from the Puri bore to the north-west of the survey area indicates that some of the thrusts are almost horizontal and that there is probably a sinistral transcurrent element in the total displacements.

V. Geology and Land Systems

In general the geology correlates only with groups of land systems that have rocks of the same general age and/or similar lithology.

(a) *Tertiary Rocks*

The mountain and high hill land systems are formed almost entirely on the strongly folded and faulted Lower to Middle Miocene strata. The proportion of limestone in the assemblage greywacke, mudstone, and limestone is one factor in the subdivisions of the land systems. Thus limestone is minor in Eruki land system, subordinate in Kapau Complex and Putei land systems, and dominant quasi-horizontal in Saw land system.

The less disturbed and less indurated Upper Miocene and Pliocene strata form low foothills and subdivision of land systems is partly based on lithological differences. Thus, where greywacke dominates, the topography tends to be more massive, as in parts of Lohiki land system. Where siltstone and greywacke co-dominate with mudstone the land forms tend to be of ridge and ravine type with very steep straight slopes, as in Maipora land system. When mudstone dominates, the slopes are less steep and often concavo–convex, as in the Hauta land system. In places, as between the Vailala and Purari Rivers, the mudstones are locally bentonitic, giving rise to unstable regoliths and numerous small earth flows characteristic of Aro land system.

The thinly interbedded sequence of greywacke, siltstone, mudstone, and subordinate limestone occurs in many of the hill and mountain land systems, and at the same general altitudes (below or above about 3000 ft) many slope characters are common to several land systems. Thus the range of soil types is the same and soil profiles on the same rock and slope in different land systems are very similar. Such detailed lithological variation also gives rise to a standard range of soil types on each land unit, and a particular land unit may be common to several land systems.

(*b*) *Quaternary Rocks*

The major changes of sediment type, as sand on beach ridges and plains, fine sandy silt on alluvial lobes, and heavy plastic clay in back plains and swamps, are reflected in the grouping of land systems on the alluvial and littoral plains. But within these different groups the land systems are classified on vegetation which reflects the drainage and relationships with sea or river levels rather than on the properties of the deposited sediments.

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PART VI. GEOMORPHOLOGY OF THE KEREMA–VAILALA AREA

By B. P. RUXTON*

I. GEOMORPHIC HISTORY

The physiographic division of the Kerema–Vailala area into the Delta and Lakekamu embayments and the Kukukuku lobe has been described in Part II (see also map of physical features).

(a) *Development of the Lobe and the Embayments*

Earth movements during and after the deposition of the Middle Miocene, although apparently not of much structural significance (Australasian Petroleum Company Proprietary 1961), had a profound effect on further geomorphological evolution and laid the foundations of the present landscape pattern.

Thus some folding of the Lower and Middle Miocene strata along NNW.–SSE. axes was followed by uplift, and probably emergence, to form the Kukukuku lobe. Later Upper Miocene and Lower Pliocene sediments were laid down around the margin of this lobe and the present outcrops form smooth sweeping curves into the heads of the Delta and Lakekamu embayments. Near the present coast east of Kerema, the axes of Upper Pliocene gentle folds are nearly east–west and are strongly discordant to the tight NNW.–SSE. fold axes and reverse faults of the Kukukuku lobe inland.

Towards the end of the Miocene the coastline was probably close to the present inland margin of Upper Miocene outcrops and its position corresponds closely with the present-day topographic discontinuity between the central mountains and the fringing foothills of the Kukukuku lobe.

During the Pliocene the Kukukuku lobe was further uplifted and denudation of it supplied considerable detritus to the embayments which, though subsiding rapidly in their seaward centres, were built up, or perhaps uplifted, inland to form gently sloping maritime plains as the sea receded southwards. At the end of the Pliocene these terrestrial, littoral, and marine sediments were gently folded and uplifted to form the broad belt of fringing foothills.

In the west the Pliocene earth movements were more severe and the Upper Miocene and Pliocene sediments were strongly folded concurrently with the formation of several NNW.-trending reverse faults.

(b) *Drainage Development*

(i) *Early Pliocene Superimposition.*—The radial drainage of the Ivori, Lohiki, Murua, and Tauri Rivers from the central core of the Kukukuku lobe was probably initiated in the early Pliocene, or a little earlier, by the superimposition of consequent

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streams through the up-domed, probably terrestrial, Upper Miocene strata onto often strongly discordant structures of the Lower and Middle Miocene strata beneath.

(ii) *Plio–Pleistocene Diversion and Antecedence*.—In the west the rate of warping during the Pliocene orogeny was often sufficiently rapid to divert the drainage around uprising hills with the complementary formation of basins. In the east, uplift was slower and most of the rivers were able to incise their beds more rapidly than local rates of uprise, and antecedent drainage has resulted. The presence of antecedence or of diversion depended partly on the size of the river and partly on the rate of uplift.

Thus in the west the Vailala River is antecedent in its mid reaches, crossing several transverse hill ranges and basins, whereas near the coast where its gradient is lower it is diverted to the west by the upwarped barrier of the Kira Hari hills. Other similar easterly-aligned upwarps, such as the Aro Aro hills, have formed enclosed basins, e.g. the Orovoi basin (see geomorphology map).

In the east the Murua, Karova, Maipora, Tauri, Fish, Olipai, and Tiveri are all antecedent streams and cut across the upwarped foothills, including in several instances the prominent Rim Ridge. On the other hand, the Lakekamu River has been diverted around Grim Point on the northern tip of the uprising Kurai hills which have cut off the Kunimaipa basin from the maritime plains. A small totally enclosed basin occurs north-west of Malalaua where large streams are absent.

Pliocene reverse faulting was probably responsible for further changes of stream course. Thus the southward swing of both the Ivori and Lohiki Rivers near long. 145° 44′ (at grid references 360164 and 358153 respectively) coincides with two large parallel reverse faults.

(*c*) *Upland Surfaces and Tectonic Relief*

The lack of tectonic relief and the subordinate degree of structural control of the higher mountains of the central core of the Kukukuku lobe (see map of physical features) reflect its early uplift and long period of denudation, which would probably exceed eight million years.

To the south-west of this central core the parallel series of lower mountain ridges show a remarkable accordance of level at about 3000 ft near the core and descending to about 1500 ft outwards (see map of physical features). This probably represents an erosion surface planed after the mid-Pliocene orogeny and before the great uplift at the end of Pliocene time.

A lower and later stage of planation is represented by accordant strike ridge crests at about 900 ft between the mid reaches of the Ivori and Lohiki Rivers.

Despite the recent uplift of the Upper Miocene and Pliocene strata, which commenced not more than about four million years ago and continued well into the Pleistocene, there is very little remaining of initial tectonic relief. The clearest examples are the breached anticlinal noses of the Kurai and Palipala hills. Elsewhere several tectonic basins are being infilled. In the extreme north-west at the headwaters of Merua Creek there is inversion of relief with synclinal Pliocene strata capping saddle-shaped high residual hills. The general absence of original tectonic relief forms in such very young landscapes suggests a very high rate of denudation.

II. Geomorphic Processes

Up-doming of the Kukukuku lobe and complementary subsidence of the adjacent embayments in the Plio–Pleistocene have led to denudation of decreasing severity outwards from the centre of the lobe and rapid aggradation in the embayments. The minor volcanism in the east (see Part V) has not built any separate land forms.

(a) *Denudational Processes*

(i) *Weathering*.—The high mean annual temperature, 79°F at sea level, and the high to very high rainfall, which is evenly distributed throughout the year over most of the area, provide optimal conditions for chemical weathering of the rocks and sediments.

The dominant rocks are greywacke and mudstone which have been derived from, and have the same chemical composition as, andesitic volcanics. Despite this they weather differently from andesitic volcanics to give much heavier textured weathering products and soils (cf. Haantjens 1967).

In general, shallow skeletal weathering is confined to precipitous slopes and Recent aggradational deposits, whereas deep mature weathering is found only on remnants of former erosion surfaces and on some dissected terraces. Otherwise the weathering appears to be shallow and immature over most of the area, and this is a reflection of the high rate of erosion.

The few natural sections seen in the foothills show a softening of the bed-rock to a considerable depth (50 ft or more) and this is probably a result of hydration and some leaching above the level of the permanent water-table indicating that chemical denudation, or the removal of material in solution, is a major part of total denudation. It is, of course, the dominant process in the limestone areas.

(ii) *Mass Movement*.—Superficial mass movement, including several types of creep and slow intermittent soil flow, and affecting only the soil layer, is probably the major process of denudation on the steep and very steep slopes of the hills and mountains. Tree fall is also important and gives rise to shallow pits and small linear mounds downslope.

Above about 3000 ft in the very-high-rainfall areas solifluction, as a slow but steady process, becomes more important. Some natural sections showed grooved and striated weathered sedentary bed-rock surfaces overlain by a breccia layer of weathered bed-rock fragments in turn overlain by soil. Subsurface corrasion (Berry and Ruxton 1961) is probably taking place at the base of the soliflual layer.

Deep rapid mass movement, displacing large quantities of weathered rock downslope, is uncommon in the survey area. Some debris slides and slumps occur on oversteepened slopes in the high hills and mountains but they are very rare on the low hills. Local earth flow is common on the very steep slopes on mudstone in the low hills, particularly where the mudstone is bentonitic. Where earth flow is very active the trees are removed, leaving gaps in the forest canopy clearly visible on the aerial photographs.

(iii) *Slope Wash*.—In periods of very heavy rain localized run-off from trunk trickle sweeps away the leaf litter cover and bares the soil surface to raindrop or waterdrop impact. Below 3000 ft the leaf litter cover on steep and very steep slopes is discontinuous, ranging mostly between a 70 and 90% cover, and slope wash is an important agent of erosion. Very severe slope wash, causing scoured surfaces and patches of lag gravel such as occur locally in northern Papua (Ruxton 1967*a*), was not recorded here.

Above about 3000 ft in the very wet mountain areas where precipitation is probably augmented by considerable condensation from mist and low cloud there is a thick (generally 10 cm) complete cover of leaf litter, duff, and rotting timber, and raindrops and waterdrops never strike the soil surface. Voids are common between the soil surface and the vegetable layer and may be due to erosive flows of run-off water. The soil is much less permeable than the vegetable layer and during rainstorms run-off will occur whenever water is supplied to the soil surface faster than it can infiltrate.

(iv) *Fluvial Erosion*.—Corrasion, defined as the mechanical wear of bed-rock in stream beds or banks during the transport of detritus by water, is a major process of erosion in the hills and mountains. Thus most streams in many parts of their courses are incising their channels, undercutting their banks, and oversteepening the lower side slopes of the valleys. But the rate of stream incision, or side-cutting, is never extreme and precipitous walled valleys and gorges do not occur. An apparent exception is a short gorge in limestone on the Kapau River which probably originated through solution and not corrasion.

In general, there seems to be a dynamic balance between the rate of slope denudation and the rate of stream action, including transport and incision, and most hill and mountain landscapes are of the graded ridge and ravine type (Ruxton 1967*a*).

Most major slopes are grooved by parallel series of ravines which head to near the ridge crests, and the runnels of water along their axes appear to be fed largely by lateral seepage from between the soil and sedentary weathered rock (Rochefort and Tricart 1959) and from the upper soil layers (Whipkey 1965). In periods of prolonged heavy rain such seepage is augmented by run-off across the soil surface.

(v) *Subsurface Erosion*.—Lateral seepage may transport particles of clay causing subsurface erosion (Ruxton 1958).

Gullies on the margins of the dissected terraces (Olipai land system) lead to lines of surface depressions which are connected by tunnels near the gully heads. The terraces are cut on mudstone, now weathered to clay, and are overlain by alluvial gravel and loam. The permeability difference between the gravel and clay apparently leads to lateral seepage through the gravel causing lateral mechanical eluviation of the finer particles eluviated from the overlying loam.

(*b*) *Aggradational Processes*

The embayments have been filled in by the outgrowth of deltas which are still prograding. The topset delta beds are usually of fine sand grade and are overlain by medium and coarse beach sand along the coast, by silty clay with subordinate peat in tidal and freshwater swamps, and by fine sandy silt grading to heavy clay in alluvial lobes from levee banks to back plains.

(i) *Sand Barrier Accumulations.*—The sandy bed load carried down by the Purari, Vailala, Tauri, and Lakekamu Rivers was initially deposited near their mouths as underwater bars, and was then moved both up and down the coast by longshore currents to form spits, bars, and an active beach (Fig. 5). In time a series of parallel beach ridges was built out from the initial coast.

Alternations of periods of more and less active deposition, punctuated by erosive episodes, and changes of position of the river outlets to the sea led to complex patterns of truncated and obliquely aligned sets of ridges. The result is a chain of beach ridge barriers cut at intervals by tidal channels usually leading inland to swamp, and such coastal complexes have been termed chenier plains (King 1959).

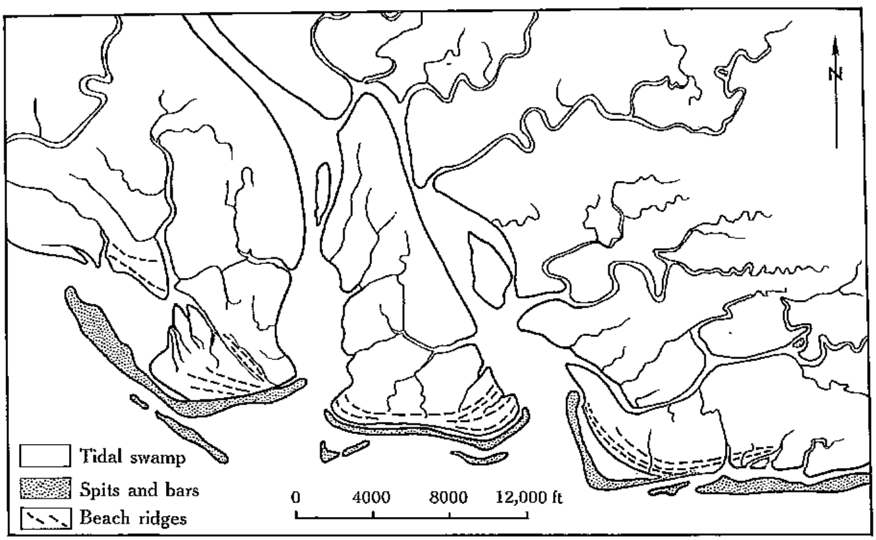

Fig. 5.—Spits and off-shore bars at the mouth of the Purari River distributaries.

The inland margins of the beach ridge barriers are uneven as a result of sapping by the erosive action of meandering streams and tidal scour. As the barriers advance seaward so do the areas of swamp at the rear. The direction of sapping is strongly controlled by the alignment of the ridges so that remnants are commonly parallel and elongate forms (see Malalaua land system diagram, and Allen 1965).

Previous episodes of chenier plain formation are shown by the presence of raised beach plains, about 10–20 ft above mean sea level, several miles inland from the present coast. The ridges and swales on such plains are usually much subdued or even smoothed out and parts of them have been planed by stream erosion and covered with a layer of alluvium. One such remnant at about 100 ft above sea level inland from Rarekau still has a clear pattern of parallel ridges and swales.

Strong winds are characteristic of the south-east season, whereas those of the north-west season are light, and so wind-generated littoral currents are moving material westwards along the coast. This has given rise to trains of spits growing west and to a pattern of broad composite beach ridges separated by muddy hollows with sinuous tidal creeks (see Araimiri land system diagram, and Allen 1965). Each broad ridge consists of a bundle of narrower ridges slightly oblique to the muddy hollows.

The prevalent westward longshore drifting has also given rise to the stepped shape of the coastline. Smooth linear and curvilinear stretches of beach are banked up east of the headlands of The Bluff and Cape Cupola in the lee of which the coast steps northward. A similar step occurs near Ihu but this headland is masked by the small prograding delta of the Vailala River. The funnel-shaped Kerema estuary is maintained partly because it is in the lee of a headland and partly because only relatively small rivers import sand into it. There may in fact be an export of sand from it as there is a continuous sand beach around The Bluff on which there is clear evidence of westward drift.

There is no evidence from the present beach, the beach ridges, or the beach plains of wind-blown sand accumulations, and this may be due to the lack of very strong winds in these low latitudes (Jennings 1965).

(ii) *Swamp Accumulations*.—Although tidal scour at the rear of beach ridge barriers may produce a swamp with sandy surface soils, deposition in the swamp after its formation will almost always be only of fine silt, clay, and/or slow peat accumulation.

On salt and brackish water tidal flats, apart from deposition caused by sediment trapping in mangrove or *Nypa* swamps (Davis 1937), mound-building crabs play an important role in accretion (cf. Macnae 1966). The crab mounds are of conical shape and the largest are 5 ft high with 8 ft basal diameter. They are built from sediment brought up from between the general ground level and several feet below. In estuarine beds this may include gravel, sand, silt, and clay which become mixed in all proportions in the mounds. The mounds are abundant adjacent to tidal channels, and may in places be almost coalescing. They decrease rapidly in number away from channels.

Accretion by crab activity is caused by the building up of mounds to 1 or 2 ft above high tide level and by removal of sediments from intermound areas and channel sides, thus making room for further deposition.

The pattern of roughly rectilinear interconnecting tidal channels on the Purari delta is comparable with that of the Niger delta, even to the detail of sharp-pointed meanders and meander capture patterns (Fig. 6, and Allen 1965). The morphology of the interchannel flats is also similar, with central depressions and raised margins breached by a few drains. Whereas Allen ascribes the raised rims to deposition of suspended load from high tidal water, in Papua they are ascribed to crab activity in brackish water and to deposition of the suspended load from flood waters in the freshwater tidal flats of the inner Purari delta.

In several *Nypa* swamps, closely spaced tidal channels surround small islands, 6–20 ft in diameter, with central depressions and raised rims formed entirely by crab mounds. The microrelief of 9 ft amplitude is thought to be the result of a combination of tidal movements and crab mound building.

Non-tidal freshwater swamps accumulate the finer suspended sediment from flood-laden river waters and are floored mostly by very heavy clay, occasionally interstratified with peat layers.

(iii) *Alluviation and Alluvial Lobes.*—The complete absence of alluvial fans is attributed partly to the lack of abrupt transitions from mountains to plains and partly to the near absence of gravel and cobbles in the bed load of the streams where they emerge from the foothills onto the plains.

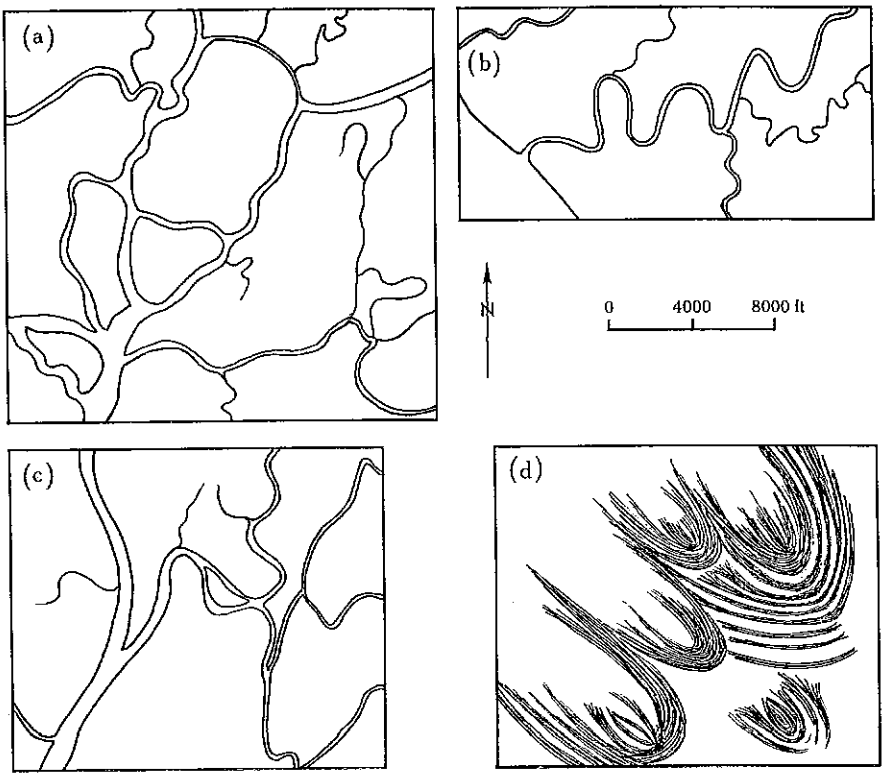

Fig. 6.—Tidal flats of the Purari delta. (*a*) Open-ended channels with rectilinear pattern. (*b*) Curved and sharp-pointed meanders of tidal channels. (*c*) Meander capture by open-ended tidal channels. (*d*) Semi-permanent herbaceous swamp of Waigani land system, showing vegetation patterns attributed to occasional burning.

The riverine tracts through the foothills generally form covered plains (Melton 1936) with sinuous channels, levees, and a thick deposit from the suspended load covering the back plain. Where rivers traverse basins, as the Vailala River does, meander loops, meander cut-offs, and local scroll plains are developed.

The Tauri and Lakekamu Rivers flow down the axes of long narrow alluvial lobes where they cross the swampy plains. The lobes narrow from 2 miles or more near the foothills to less than 1 mile at their distal ends. They terminate at the present limit of tidal influence some 7–10 miles inland.

The lobes are partly covered lacine meander plains (Melton 1936) consisting largely of groups of silty fine sand scrolls separated by narrow swampy sloughs with scattered meander cut-offs and low river levees. Upstream the lobes are covered with an increasingly thick cover of deposits from the suspended load of flood waters. The

TABLE 8

GEOMORPHOLOGY AND LITHOLOGY OF AGGRADATIONAL LAND SYSTEMS

Environment	Drainage	Land Form	Lithology	Characteristic Gradient	Special Diagnostic Features	Land System
Alluvial plains Flood-plains	Good and imperfect	Flood-plain terraces and levees	Sandy loam and clayey silt	Low	Occasional or rare flooding	Hepea
	Imperfect and poor	Back plains	Silty clay	Very low	Common flooding	Tauri
	Poor and very poor	Distal parts of alluvial lobes	Silt and silty clay		Very frequent flooding	Terapo
Basins	Imperfect to very poor	Stable plains	Silty and heavy clay	Very low and level	Distinguished on vegetation	Vailala
Freshwater non-tidal swamps	Very poor and swampy	Swamp margins (in SE.)	Silty clay and littoral sand	Very low	Seasonal inundation	Melaleuca
		Intake areas			Frequent inundation	Karama
	Swampy: Semi-permanent	Swamp margins	Heavy clay and littoral sand	Level		Movori
	Swampy: Permanent	Swamp centres	Heavy clay		Permanent inundation	Waigani
	Swampy: Stagnant	Peat-infilled	Heavy clay and peat			Campnosperma
Littoral plains Beach ridges	Stagnant swamp	Drowned beach ridges	Peat over sand	Level	Ridges and swales largely smoothed out	Malalaua
	Good	Beach plains	Sand			
	Good and poor	Beach ridge barriers		Very high	Linear alternating ridges and swales	Araimiri
Tidal flats	Freshwater	Inter-channel flats with raised rims and depressed centres; abundant crab mounds adjacent to margins	Silty loam, silty clay, clay and peaty clay	Level	Uppermost tidal flats and alluvial levees	Ebala
					Distinguished on vegetation	Murva Purari
	Brackish (*Nypa*)		Variable: Sandy to clay		Crab islands common	Nipa
	Brackish and salt		Variable: Gravel to clay		Mangrove vegetation	Alele

TABLE 9

GEOMORPHOLOGY AND LITHOLOGY OF DENUDATIONAL LAND SYSTEMS

Relief	Characteristic Slope	Characteristic Land Form Features	Lithology	Adjustment to Structure	Special Diagnostic Features	Land System
Very high (>1000 ft)	Very steep	Ridge and ravine	Greywacke and mudstone	Slight		Eruki
			Greywacke and mudstone with limestone		Dip slopes, plateaux, karst	Kapau Complex
High (500–1000 ft)	*Steep*		Greywacke and mudstone	Parallel strike ridges	Local U-shaped valleys	Nabo
				Slight	Local upper flats	Lohiki
			Greywacke and mudstone with conglomerate	Moderate	Scarps and dip slopes, local tectonic relief	Kurai
	High-moderate	Smooth even slopes	Greywacke and mudstone with limestone	Slight	Fluted slopes	*Putei*
Moderate and low *(125–500 ft)*	Very steep	Plateau karst	Limestone	Strong with two sets of joints	Pyramids and dolines	Saw
	High-moderate	Ridge and dissected benches	Greywacke and mudstone	Parallel strike ridges	Accordant ridge crests	Bananu
	Very steep, straight	Ridge and ravine with abundant valley flats			Local earth flows and swampy flats	Aro
		Ridge and ravine with benched spurs		Slight	High altitude	Kwambega
		Ridge and ravine		Some strike ridges	Low altitude	Maipora
Very low (<125 ft)	High-moderate	Concavo–convex forms	Mudstone	Slight	Very low relief	Hauta
	High gradient	Dissected benches	Alluvial silt and gravel and littoral sand over mudstone	Nil	Severe tunnelling and subsurface erosion	Olipai

levee banks, barely perceptible at first, also increase in size and attain several feet in height near the foothills. Lobe growth is very rapid and after one flood 6–12 in. of fresh fine sandy silt was observed on the embryonic levee banks at the seaward end of the Tauri River lobe.

Stream diversion by crevassing may occur near the downstream ends of the lobes where levee banks are low, and a former lobe of the Lakekamu River terminated near the northern tip of the Palipala hills.

III. Geomorphology and Land Systems

The land systems fall naturally into two major groups: those that are being built up by sedimentation are aggradational (Table 8), and those that are being worn down by erosion and solution are denudational (Table 9).

(*a*) *Aggradational Land Systems*

Outgrowing deltas and bay infillings are built from the bed loads of the rivers and are veneered by sediments deposited in the intertidal zone to form littoral plains. Inland above the highest tidal levels surface deposition is almost wholly derived from the suspended sediments of rivers forming alluvial plains. Accurate mapping of the plains is largely accomplished from a study of the vegetation patterns which reflect the subjacent land characters.

(i) *Littoral Plains.*—As the beach ridge barriers grow seawards their inland margins are degraded by tidal scour and converted to swamp; similarly, further inland the tidal swamps merge into, and are being replaced by, accreting alluvial plains. The land systems mapped thus represent the present state of a rapidly changing landscape and any catastrophic changes, such as river diversions so common elsewhere in New Guinea, would immediately alter the character of the land.

The tidal flats range from salt (Alele land system) through brackish (Nipa land system) to freshwater (Purari, Murva, and Ebala land systems) inland. The freshwater tidal flats are most extensive adjacent to the large rivers, especially in the Purari delta, and upstream the rivers are margined by low levees grading back into uppermost tidal flats forming Ebala land system. Purari and Murva land systems, at a slightly lower level, are distinguished only by their vegetation.

The beach ridge barriers on the coast are graded to the present sea level and form Araimiri land system. Inland they are raised up to 25 ft above sea level and are in various stages of gradation to flat plains in Malalaua land system.

(ii) *Alluvial Plains.*—Wherever land gradients and drainage outlets are inadequate to disperse the rain and run-on water, freshwater swamps are maintained. Accretion from the suspended sediment carried in run-on water gradually forms better-drained alluviated basin plains. Near the larger rivers and in confined valleys rapid alluviation has formed higher-lying flood-plain tracts.

The freshwater swamps form a transitional series from newly formed and deep-water swamps (Waigani land system) through older partially alluviated shallower swamps (Movori land system) to old stagnant peat-infilled swamps of Campnosperma land system. Pure sago palm vegetation occurs on the inlet zones of the swamp margins and is distinguished as Karama land system. In the Lakekamu embayment in the south-east, large areas of swamp dry out and burn in the north-west season (Fig. 6(*d*)), and the higher-lying parts bear swamp savannah as Melaleuca land system.

The alluviated basin plains are mostly infilled tectonic depressions with drainage outlets, or with antecedent through-going drainage as on the Vailala River, and have been separated into Vailala land system. Sequential stages of basin infilling and later incipient dissection were recognized in the field but could not be mapped on the aerial photographs.

Sequential stages of flood-plain development are readily recognized both in land form pattern and in vegetation. Thus the flood-plains are divided into three types: newly formed very unstable alluvial lobes transitional to freshwater swamps (Terapo land system); older unstable partially covered lacine meander tracts (Tauri land system); and stable covered plains and raised alluvial terraces (Hepea land system).

(*b*) *Denudational Land Systems*

The hills and mountains are subdivided principally on relief, angle of slope, degree of structural control, and to some extent on lithology. They are described here, and on the land system map, in order of increasing relief.

(i) *Dissected Benches*.—Upraised low alluvial and littoral terraces and benches (Olipai land system) border the depositional plains, especially around the Lakekamu embayment. Though in various stages of dissection, their upper flat surfaces still bear alluvial silt and gravel, and beach sand.

(ii) *Undulating Low Hills*.—A belt of undulating concavo–convex low hills with moderate slopes (Hauta land system) forms the outer fringe of the foothills of the Kukukuku lobe. The hill summits are frequently broad and accordant but mature soils and/or weathering profiles are absent.

(iii) *Low to Moderate Hill Ridges*.—The inner fringe of the foothills of the Kukukuku lobe has very steep slopes (Maipora land system), which in the west form strike ridges separated by a maze of small alluvial flats (Aro land system).

Within the Kukukuku lobe benched spurs adjacent to the Wenna valley at between 4000 and 5500 ft are mapped as Kwambega land system; and at lower altitude, low parallel accordant ridges and dissected alluvial benches between the Ivori and Lohiki Rivers are mapped as Bananu land system.

(iv) *Plateau Karst*.—A narrow plateau of pyramid and doline karst forms the Saw Mountains south of Putei. North of Putei a similar plateau between 3500 and 5500 ft has more irregular karst with large enclosed depressions and residual ridges and minor towers. Locally flat-floored closed depressions occur with fields of dolines similar to poljes. This complex plateau landscape is mapped as Saw land system.

(v) *High Hill Ridges*.—Around Putei are several high hills partly developed on limestone, with very smooth even steep and moderate slopes and local protruding sharp-crested limestone ridges (Putei land system). To the east the gently folded Upper Miocene and Pliocene terrestrial beds of greywacke, conglomerate, and subordinate volcanics are dissected into very steep scarp slopes and moderate dip slopes (Kurai land system).

In the centre and west the high hills are developed on greywacke and mudstone and are mapped as Nabo land system where structural control is dominant and as Lohiki land system where it is subordinate. Lohiki land system is also characterized by numerous small structural benches and local bench karst, whereas Nabo land system is a series of high parallel subaccordant ridges with very broad dissected foot slopes giving a U-shaped cross-section to the major valleys.

(vi) *Mountain Ridges with Very Steep Slopes*.—East of the Kapau River limestone and conglomerate are common and volcanics also occur in the greywacke–mudstone succession. The landscapes resulting from the great variation in lithology, structural attitude, and relief are grouped into the Kapau Complex land system. West of the Kapau River, high subparallel relatively simple mountain ridges developed on Lower and Middle Miocene greywacke and mudstone are mapped as Eruki land system.

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PART VII. SOILS OF THE KEREMA–VAILALA AREA

By P. BLEEKER*

I. INTRODUCTION

(a) General

As in most other areas in New Guinea the soils of the Kerema–Vailala area have formed mainly on materials that have not been subjected to intense weathering. This is noteworthy in an area with high mean annual temperatures and a high to very high rainfall where optimal chemical weathering is expected.

In the hills and mountains, however, with mostly steep to very steep slopes, the weathering products are rapidly removed by erosion and prevent the formation of mature soil profiles. Consequently these parts are covered mainly with young soils.

In the plains the rate of deposition in most areas is more rapid than soil formation and young soils predominate.

The effects of deep mature weathering are therefore found only on stable land surfaces, mainly of the undulating low hills, and on some dissected terraces with low to moderate relief.

The total areas of the principal types of soils (orders) are roughly as follows:

1450 sq miles of undifferentiated alluvial, colluvial, and lithosolic soils (Entisols);

1250 sq miles of uniformly textured soils with altered B horizons and with or without thick acid dark topsoils (Inceptisols);

200 sq miles of organic soils (Histosols);

90 sq miles of weakly acid to alkaline soils with thick dark topsoils (Mollisols);

5 sq miles of neutral to weakly acid soils with textured B horizons (Alfisols).

In contrast to these areas of unweathered to moderately weathered soils, covering 3000 sq miles, there is a relatively small proportion of soils formed on strongly weathered materials, namely:

300 sq miles of strongly weathered acid to strongly acid soils with textural B horizons (Ultisols); and

20 sq miles of strongly weathered red friable clay soils (Oxisols).

(b) System of Classification

The soils have been classified according to the 7th Approximation, a comprehensive system of soil classification developed by the United States Soil Conservation Service (1960). They have been placed into seven orders, subdivided into 15 suborders (one undefined), 20 great groups (two undefined), 26 subgroups (14 undefined), and 54 families. This classification is shown in Table 10. To facilitate cross reference to

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TABLE 10

CLASSIFICATION OF THE SOILS* OF THE KEREMA–VAILALA AREA

Order	Suborder	Great Group	Subgroup	Family
Organic soils (Histosols)	—	—	—	(1*a*) Peaty mucks developed on clays (1*b*) Peats developed on sands
Undifferentiated soils (Entisols)	Strongly gleyed soils (Aquents)	Soft swamp soils (Hydraquents)	—	(2*a*) Fine-textured soils with neutral to weakly acid topsoils over weakly alkaline subsoils (2*b*) Fine-textured acid soils (2*c*) Fine- to medium- over coarse-textured soils
		Normal soils (Haplaquents)	—	(3*a*) Weakly acid to acid soils (3*b*) Soils with weakly acid to acid topsoils over alkaline subsoils (3*c*) Alkaline soils
		Sandy soils (Psammaquents)	—	(4*a*) Acid to weakly acid soils (4*b*) Alkaline soils
	Sandy soils (Psamments)	Non-quartzitic soils (Orthopsamments)	—	(5*a*) Acid to weakly acid soils (5*b*) Uniform grey to dark grey alkaline soils
	Normal soils (Udents)	Normal soils (Hapludents)	Non-gleyed soils (Orthic Hapludents)	(6*a*) Medium-textured acid to weakly acid colluvial soils (6*b*) Medium-textured neutral to acid alluvial soils (6*c*) Medium- over coarse-textured neutral to weakly acid soils (6*d*) Fine-textured acid to weakly acid colluvial soils (6*e*) Fine-textured acid to weakly acid alluvial soils
			Soils with gleyed and/or mottled subsoils (Aquic Hapludents)	(7*a*) Medium- over fine-textured soils (7*b*) Medium- over coarse-textured soils
			Shallow soils (Lithic Hapludents)	(8) Medium-textured gravelly and stony soils

Uniformly textured soils with altered B horizons and with or without thick acid dark topsoils (Inceptisols)	Soils with light-coloured or thin dark topsoils and altered B horizons (Ochrepts)	Neutral to strongly acid soils (Dystrochrepts)	Acid to strongly acid soils (Orthic Dystrochrepts)	(9*a*) Medium-textured yellowish brown to olive-brown soils (9*b*) Fine-textured yellowish brown to olive-brown soils (9*c*) Coarse-textured yellowish brown soils (9*d*) Fine-textured, strongly acid yellowish red and/or strong brown soils (9*e*) Fine-textured, strongly acid yellowish over strong brown to reddish soils
			Weakly acid to neutral soils (Eutric Dystrochrepts)	(10) Medium- to fine-textured soils, generally with sandy subsoils
			Acid soils with grey mottled subsoils (Aquic Dystrochrepts)	(11) Fine-textured soils
			Acid to strongly acid shallow soils (Lithic Dystrochrepts)	(12) Medium-textured soils
	Strongly gleyed soils with altered B horizons (Aquepts)	Soils with light-coloured or thin dark topsoils (Ochraquepts)	—	(13) Medium- to fine-textured, acid to strongly acid soils
	Soils with thick acid dark topsoils and altered B horizons (Umbrepts)	Normal soils (Haplumbrepts)	Acid to strongly acid soils (Orthic Haplumbrepts)	(14*a*) Coarse-textured soils (14*b*) Fine-textured dark greyish brown to brown soils (14*c*) Fine-textured yellowish red to strong brown soils
Weakly acid to alkaline soils with thick dark topsoils (Mollisols)	Normal soils (Udolls)	Soils with textural B horizons (Argudolls)	—	(15) Soils with clay to heavy clay subsoils
		Little-weathered or not weathered soils (Hapludolls)	Coarse- and medium-textured soils (Orthic Hapludolls)	(16*a*) Coarse-textured soils (16*b*) Medium-textured soils
			Soils with topsoils ⩾20 in. thick (Cumulic Hapludolls)	(17*a*) Fine-textured soils (17*b*) Coarse-textured soils (17*c*) Medium-textured soils
	Moderately to strongly gleyed soils (Aquolls)	Little-weathered or not weathered soils (Haplaquolls)	Coarse- and fine-textured soils (Orthic Haplaquolls)	(18*a*) Coarse-textured soils (18*b*) Fine-textured soils

TABLE 10 (*Continued*)

Order	Suborder	Great Group	Subgroup	Family
Weakly acid to alkaline soils with thick dark topsoils (Mollisols) (*continued*)	Shallow stony soils on limestone (Rendolls)	—	—	(19) Medium- and fine-textured soils
Weakly acid to neutral soils with textural B horizons (Alfisols)	Soils dry for a significant portion of the year (Ustalfs)	Soils with clayey subsoils (Typustalfs)	Soils with dark topsoils (Mollic Typustalfs)	(20) Yellowish brown to brown soils
Strongly weathered acid to strongly acid soils with textural B horizons (Ultisols)	Moderately to strongly gleyed soils (Aquults)	Red mottled soils (Plintaquults)	—	(21) Medium- over fine-textured soils
	Soils with light-coloured or thin dark topsoils (Ochrults)	Soils with plastic clayey subsoils (Typochrults)	—	(22*a*) Soils with brown topsoils over yellowish red to red subsoils (22*b*) Soils with yellowish brown topsoils over strong brown and reddish subsoils (22*c*) Soils with yellowish brown topsoils over strong brown subsoils (22*d*) Soils with dark yellowish brown topsoils over yellowish brown, mottled subsoils
		Soils with red mottled plastic clayey subsoils (Plintochrults)	—	(23) Soils with brown to yellowish brown topsoils over strongly mottled subsoils
	Soils with thick dark topsoils (Umbrults)	Soils with plastic clayey subsoils (Typumbrults)	—	(24*a*) Soils with yellowish brown to light yellowish brown subsoils (24*b*) Soils with yellowish red and red subsoils
		Soils with red mottled plastic clayey subsoils (Plintumbrults)	—	(25*a*) Medium- over fine-textured soils (25*b*) Coarse- over fine-textured soils
Strongly weathered red, friable clay soils (Oxisols)	Strongly acid soils (Udox)	Soils with thin dark or light-coloured topsoils (Ochrudox)	—	(26*a*) Soils with mottled subsoils (26*b*) Soils without mottled subsoils

* This classification follows in principle the comprehensive system (7th Approximation) of the U.S. Soil Conservation Service (1960).

the tabulated land systems, the families are indicated by number and letter symbols. No letter is used where there is only one family corresponding with a particular number.

It should be stressed that the 7th Approximation names are used only tentatively because many of the soils could not be completely classified in this system. They have been classified on the basis of field data collected during a reconnaissance survey, and many assumptions have been made. A detailed discussion of the use of the 7th Approximation in relation to the soils of New Guinea is given by Haantjens (1967).

II. Description of the Soils

The terms used to describe soil depth, reaction, and permeability in the following descriptions and in the tabulated land systems are those defined by Haantjens (1965).* In respect of soil depth one modification has been made: shallow soils are those with hard bed-rock within 20 in. or less from the surface. Soil drainage has not been included in the profile descriptions because it was assessed for the agricultural land capability classification, and is based on vegetation indications as well as on soil characteristics. In the profile descriptions gravelly soils have rounded or angular rock fragments of up to 3 in. in diameter, while stony soils refer to those with fragments over 3 in. in diameter. Other terms are those used by the United States Department of Agriculture (1951). All soil colours refer to the moist conditions and are those defined in the Munsell colour charts.† Soil descriptions are based on auger sampling and field pH measurement.

(1) *Organic Soils (Histosols)*.—These soils are characterized by a surface horizon, at least 12 in. thick, with 30% or more organic matter. They occur in the non-tidal permanent swamps, and on degraded beach plains where water-tables are at or above the surface. They support a vegetation of sago, *Campnosperma*, *Thoracostachyum*, and *Hanguana*. Their subdivision into two families is according to differences in the texture of their underlying sediments. Inland peaty mucks have developed on clays, while near the coast on degraded beach ridges peats developed on sands are present.

(1*a*) *Peaty Mucks Developed on Clays (6 records)*.—This family generally consists of a layer 12–46 in. thick of very dark brown to brown peaty muck overlying massive, very sticky, strongly gleyed, heavy clay to clay loam locally interbedded with peaty muck layers.

Soils consisting of 4 ft or more of dark greyish brown organic mud have also been incorporated in this family. The soil reaction is mostly acid to weakly acid. Exceptions are the soils under tidal influence and those in the eastern part of the area which are weakly alkaline throughout or locally are alkaline in the subsoil.

(1*b*) *Peats Developed on Sands (4 records)*.—These soils have up to 7 ft of very dark brown slightly to moderately decomposed peat mixed with many living roots. The peat is acid and overlies acid, grey, medium, and fine sand.

* Haantjens, H. A. (1965).—Agricultural land classification for New Guinea land resources surveys. CSIRO Aust. Div. Land Res. Tech. Memo. 65/8 (unpublished).

† Soils referred to as having dark topsoils are those with a chroma of 4·0 or less and a value darker than 3·5 when moist.

(2) *Strongly Gleyed Undifferentiated "Soft" Swamp Soils (Hydraquents)*.—These soils consist of more or less stratified recent alluvial deposits and are found mostly in non-tidal freshwater swamps and on back plains and tidal flats. Water-tables are close to or above the surface and the soils are generally saturated permanently and have little cohesion.

Similar soils occurring in the south-eastern part of the area have been included in this great soil group although they are only inundated seasonally and tend to dry out during the dry season. Some are plastic and were relatively dry even though covered with several feet of run-on water during the survey.

The subdivision of the Hydraquents into three families is based on texture and soil reaction.

(2*a*) *Fine-textured Soils with Neutral to Weakly Acid Topsoils over Weakly Alkaline Subsoils (10 records)*.—These soils consist of dark greenish grey very sticky massive silty to heavy clays. Dark brown to dark grey A_1 horizons occur where moderate amounts of organic matter are present. In the tidal swamps numerous crab mounds occur, especially adjacent to the tidal channels, and an intensive mixing by crabs has taken place in the soils.

(2*b*) *Fine-textured Acid Soils (9 records)*.—These are very sticky greenish grey silty to heavy clays, locally interbedded with thin very dark greyish brown layers of peaty clay.

(2*c*) *Fine- to Medium- over Coarse-textured Soils (2 records)*.—This family has a grey to dark grey, clay to clay loam topsoil 20–35 in. thick, overlying grey loam to loamy sand. The soils are alkaline throughout near the coast and have weakly acid surface soils over alkaline subsoils further inland.

(3) *Strongly Gleyed Undifferentiated Soils (Haplaquents)*.—These soils are found on flood-plains and back plains, and alluvial flats and basins where they are associated with better-drained alluvial soils (Orthic and Aquic Hapludents) on slightly higher ground. They are mostly fine-textured strongly gleyed soils, generally below about 10–20 in., and subsoils are frequently mottled, which suggests strongly fluctuating ground water tables. Small to locally moderate amounts of manganese and iron concretions are also generally present in these soils and indicate poor drainage.

The Haplaquents have been subdivided into three families based on soil reaction.

(3*a*) *Weakly Acid to Acid Soils (29 records)*.—Generally these soils consist of moderately developed clayey A_1 horizons, 3–12 in. thick, which are grey to dark greyish brown in colour. Subsoils have silty to heavy clay and locally loam to clay loam textures and have typical grey gley colours with few to many small prominent yellowish brown mottles.

(3*b*) *Soils with Weakly Acid to Acid Topsoils over Alkaline Subsoils (3 records)*.—These soils have characteristics similar to those of family (3*a*) except for their generally alkaline reactions in subsoils and coarser textures at depths of 24–48 in. They are found mostly in the comparatively dry south-eastern part of the area where seasonal high evaporation rates may lead to upward movement of brackish water from the underlying beach sands and may cause the alkalinity.

(3*c*) *Alkaline Soils* (*3 records*).—Apart from their alkalinity these soils are similar to those of family (3*a*) and occur in the dry south-eastern part of the area on alluvia lplains.

(4) *Undifferentiated Strongly Gleyed Sandy Soils* (*Psammaquents*).—Together with the Orthopsamments (5) these soils are confined mainly to sandy deposits formed primarily by wave action. They are only slightly weathered and are rich in weatherable minerals. Water-tables vary from slightly below to slightly above the surface. Because of their sandy textures gleying in these soils is not as marked as in some of the fine-textured undifferentiated alluvial soils. Their subdivision into two families is based on soil reaction.

(4*a*) *Acid to Weakly Acid Soils* (*3 records*).—These are found in swales between beach ridges and flats not influenced by the tides. They consist of brown to dark brown sand to loamy sand overlying grey to greenish grey structureless medium sand. In places the topsoil is mixed with partly decomposed plant residues and generally has a few yellowish brown mottles.

(4*b*) *Alkaline Soils* (*4 records*).—These soils occur on degraded beach plains and in swales between beach ridges. They cover a narrow strip of soils along the coast which is subject to tidal influences and they also occur in the south-eastern part of the area up to 1 mile inland. They consist of grey to greenish grey uniform medium to coarse sands locally with mottled topsoils. In the extreme south-eastern part of the area one strongly alkaline soil belonging to this family was covered with a salt crust (Hisiu land system, on the boundary of the Port Moresby–Kairuku area).

(5) *Undifferentiated Sandy Non-quartzitic Soils* (*Orthopsamments*).—These are mostly found in the coastal area on beach ridges, plains, and terraces. The basic difference between these soils and the Psammaquents (4) is that they are not gleyed and water-tables are generally deeper than 44 in. Their subdivision into two families is based on soil reaction.

(5*a*) *Acid to Weakly Acid Soils* (*5 records*).—They consist of loose olive-brown to dark brown structureless loamy sand overlying olive to greyish brown structureless medium sand. The subsoil is generally faintly mottled at depths of 20–40 in.

(5*b*) *Uniform Grey to Dark Grey Alkaline Soils* (*2 records*).—These soils have no profile development and occur on present active beach ridges along the coast. They are very unstable, sand being continually added to or removed from them, and are bare except for areas above high-water mark where a mixed herbaceous vegetation, *Ipomoea–Canavalia*, occurs.

(6) *Undifferentiated Non-gleyed Colluvial and Alluvial Soils* (*Orthic Hapludents*).—These soils have a wide distribution not only on depositional plains in the coastal area but also on the erosional slopes of the hills and mountains. They are divided into colluvial and alluvial soils and subdivided on texture.

(6*a*) *Medium-textured Acid to Weakly Acid Colluvial Soils* (*9 records*).—These soils occur on steep slopes and locally on ridge crests and concave foot slopes. Depth ranges from 30 to 45 in. They consist of light olive-brown to olive-brown friable to plastic loam to clay loam which is generally very gravelly and stony. In places these soils have buried horizons.

(6*b*) *Medium-textured Neutral to Acid Alluvial Soils* (*3 records*).—They occur on flood-plains and back plains and alluvial terraces. They consist of olive-brown to light olive-brown friable to plastic clay loam to silty clay loam locally with a few yellowish brown mottles.

(6*c*) *Medium- over Coarse-textured Neutral to Weakly Acid Soils* (*3 records*).—These soils occur on the sandy beach plains, degraded beach ridges, and back plains which have been covered by a thin veneer of alluvium. They generally have a moderately developed dark brown to dark greyish brown A_1 horizon, 4–8 in. thick, with loam to sandy loam textures that overlie a dark greyish brown to olive-brown loose sandy subsoil. In the dry south-eastern part of the area the subsoils have alkaline soil reactions.

(6*d*) *Fine-textured Acid to Weakly Acid Colluvial Soils* (*4 records*).—Like family (6*a*) these soils occur on steep slopes. They are generally 20–45 in. deep and consist of greyish brown to yellowish brown gravelly clay mixed with many stones.

(6*e*) *Fine-textured Acid to Weakly Acid Alluvial Soils* (*3 records*).—These soils occur on levee banks and have a 36–44 in. thick olive-brown to light olive-brown silty clay topsoil overlying grey and yellowish brown strongly mottled silty clay subsoil.

(7) *Undifferentiated Alluvial Soils with Gleyed and/or Mottled Subsoils* (*Aquic Hapludents*).—These soils have been separated from the Orthic Hapludents (6) because of their pronounced gleyed and/or mottled subsoils and water-tables, which occur mostly at depths of about 22 in. They form an intermediate group of soils between the alluvial Orthic Hapludents (6) and the Haplaquents (3). Subdivision into two families is based on texture.

(7*a*) *Medium- over Fine-textured Soils* (*8 records*).—They occur on alluvial plains and back plains and consist of light olive-brown to brown silty loam or clay loam overlying greyish plastic and very sticky clay with few to many yellowish brown mottles. Soil reaction is acid to weakly acid and locally neutral throughout in back plain areas. Some profiles belonging to this family, especially in Vailala land system, are uniformly fine-textured throughout.

(7*b*) *Medium- over Coarse-textured Soils* (*5 records*).—These soils were found on beach ridges and degraded beach plains and consist of dark greyish brown sandy loam to clay loam overlying greyish medium to fine sand. Soil reaction is generally acid to weakly acid to locally weakly alkaline.

(8) *Undifferentiated Medium- to Fine-textured Shallow Stony Colluvial Soils* (*Lithic Hapludents*) (*5 records*).—These soils are present on steep slopes with greywacke–mudstone and limestone and on bench karst. They have a friable to firm acid to weakly acid dark greyish brown A_1 horizon 4–8 in. thick, which either directly overlies a C_2 horizon or has a thin transitional greyish brown B horizon containing many rock fragments.

(9) *Uniformly Textured Acid to Strongly Acid Soils with Altered B Horizons* and Light-coloured or Thin Dark Topsoils* (*Orthic Dystrochrepts*).—These soils occur on moderate and steep slopes, ridge crests, benches, and terraces. The A_1 horizon is as a rule poorly to moderately developed but varies greatly in thickness and colour. Their subdivision into five families is based on differences in texture and soil colour.

(9*a*) *Medium-textured Yellowish Brown to Olive-brown Soils* (*23 records*).—These soils are deep and generally have a uniform clay loam texture but range from loam to sandy clay. B and C horizons commonly have mottles of completely weathered rock fragments.

(9*b*) *Fine-textured Yellowish Brown to Olive-brown Soils* (*11 records*).—This family has a sandy clay, silty clay, or clay texture, generally with a slightly developed textural contrast between topsoil and subsoil. Subsoils frequently have small prominent grey and yellowish red mottles.

(9*c*) *Coarse-textured Yellowish Brown Soils* (*3 records*).—They consist of a 6–34 in. thick sandy loam to loamy sand overlying medium to fine sand or gravelly coarse sand. Especially on very steep slopes, these soils tend to be stony and gravelly with depths of 45–60 in.

(9*d*) *Fine-textured Strongly Acid Yellowish Red and/or Strong Brown Soils* (*9 records*).—These soils are deep clay to clay loam soils with a 1–14 in. thick yellowish brown to brown A_1 horizon. On very steep slopes this horizon may be absent. The A_1 horizon merges gradually with a 34–45 in. thick plastic B_2 horizon and generally red B/C horizon mixed with some gravel and soft weathered rock fragments. At altitudes above 3000 ft these soils are covered with a 1–6 in. thick black spongy root mat.

(9*e*) *Fine-textured Strongly Acid Yellowish over Strong Brown to Reddish Soils* (*3 records*).—This family occurs only on steep slopes at altitudes above 3000 ft. The soils are similar to those of family (9*d*), and have a black spongy root mat 2–10 in. thick. Topsoils consist of 6–38 in. thick olive-yellow to brownish yellow plastic clay horizons. These merge gradually with strong brown to reddish plastic clay horizons 22–40 in. thick with some weathered greywacke mudstone fragments. However, one soil belonging to this family had an abrupt boundary at 38 in. followed by a very thin limonite hardpan (less than $\frac{1}{4}$ in. thick) underlain by strongly weathered plastic red clay with light grey mottles.

(10) *Uniformly Textured Weakly Acid to Neutral Soils with Altered B Horizons and Light-coloured or Thin Dark Topsoils* (*Eutric Dystrochrepts*) (*4 records*).—Like the Orthic Dystrochrepts (9) these soils are mainly confined to steep and moderate slopes. They are generally yellowish brown to brown medium- to fine-textured soils, locally with sandy subsoils. Textures depend mainly on the type of parent material. Soils

* An altered B horizon (cambic horizon) is defined as a horizon in which soil-forming processes have changed or altered the material enough to form structure (if the texture is suitable), to liberate free iron oxides or form silicate clays or both, and to obliterate most evidence of the original rock structure.

on calcareous sandy conglomerate are sandier than those developed on greywacke–sandstone. Under grassland these soils have clearly developed 6–14 in. thick friable A_1 horizons with clay loam to sandy clay textures and colours ranging from very dark greyish brown to yellowish brown. Some are gravelly and have subsoils with many weathered rock fragments.

(11) *Uniformly Fine-textured Acid Soils with Grey Mottled Subsoils, Altered B Horizons, and Light-coloured or Thin Dark Topsoils* (*Aquic Dystrochrepts*) (*4 records*).—These soils occur on moderate slopes and ridge crests. They are similar to family (9*b*) in texture, which consists mainly of silty clay, sandy clay, or clay, but their yellowish brown to light olive-brown B horizons have common to many medium prominent grey, reddish brown, and brownish yellow mottles. This mottling seems to be mainly due to seepage and rain water gleying. Their parent material consists of greywacke, mudstone, or siltstone.

(12) *Uniformly Textured Shallow* (*10–20 in.*) *Very Gravelly and Stony Soils with Altered B Horizons and Light-coloured or Thin Dark Topsoils* (*Lithic Dystrochrepts*) (*3 records*).—They generally occur on very steep slopes but locally on ridge crests. They are yellowish brown with textures from loam to clay loam and have an acid to strongly acid soil reaction. The topsoil has been mostly removed by erosion, but locally has been preserved and has a brown to dark brown colour.

(13) *Uniformly Textured Strongly Gleyed Soils with Light-coloured or Thin Dark Topsoils* (*Ochraquepts*) (*3 records*).—These soils were found on gentle slopes and foot slopes of hills and mountains. They consist of yellowish brown plastic clay loam to silty clay between 7 and 14 in. thick, merging into greenish grey strongly yellowish brown mottled plastic clay to clay loam. They are slowly permeable and acid to strongly acid.

(14) *Uniformly Textured Acid to Strongly Acid Soils with Thick Dark Topsoils* (*Orthic Haplumbrepts*).—These soils are characterized by their acid thick (>10 in.) dark topsoils and have been subdivided into three families based on texture and colour differences.

(14*a*) *Coarse-textured Yellowish Brown to Greyish Brown Soils* (*2 records*).—These soils occur on the beach plains and foot slopes of the hills. They consist of a 10–15 in. thick very dark greyish brown to dark yellowish brown sandy loam to loamy sand A_1 horizon, merging into a yellowish brown to greyish brown 10–20 in. thick sandy loam B horizon and medium to fine sand or gravelly greywacke.

(14*b*) *Fine-textured Dark Greyish Brown to Brown Soils* (*2 records*).—The soils of this family are confined to the foot slopes of hills. They have 10–12 in. thick very dark greyish brown plastic clay to sandy clay A_1 horizons overlying 22–25 in. thick dark greyish brown to brown sandy clay B horizon with many yellowish brown mottles. The parent materials consist of mudstones, marls, and calcareous greywacke.

(14*c*) *Fine-textured Yellowish Red to Strong Brown Soils* (*1 record*).—This family occurs on a very steep slope. The soil consists of a 10 in. thick dark brown plastic clay A_1 horizon overlying a 25 in. thick yellowish red and strong brown-coloured B horizon and weathered silt and mudstone.

(15) *Soils with Thick Dark Weakly Acid to Neutral Topsoils and Textural B Horizons* (Argudolls) (1 record)*.—This family occurs on bench karst. A 12 in. thick dark brown plastic sandy clay loam A_1 horizon overlies a dark greyish brown to yellowish brown 28 in. thick light olive-brown mottled plastic clay to heavy clay B horizon with a weakly acid to neutral soil reaction. At 38 in. the soil becomes very gravelly and stony due to limestone.

(16) *Little or Not Weathered Weakly Acid to Neutral Soils with Thick Dark Topsoils (Orthic Hapludolls)*.—There is a striking parallelism between the Hapludents (6) and the Hapludolls, the essential difference being the consistent presence of a thick (> 10 in.) neutral to weakly acid dark A_1 horizon in the Hapludolls and its absence in the Hapludents. They have been subdivided into two families based on texture.

(16*a*) *Coarse-textured Soils (3 records)*.—This family occurs on beach plains and degraded beach ridges with *Imperata–Themeda* grassland. The soils have a 10–12 in. thick very dark greyish brown to dark brown mostly friable A_1 horizon with a loamy sand to sandy loam texture, merging into loose olive-brown medium and fine sand.

(16*b*) *Medium-textured Soils (3 records)*.—They occur on concave slopes on colluvium derived from greywacke and conglomerate, and on alluvial gravel terraces. Their A_1 horizons are 10–20 in. thick and consist of very dark greyish brown to dark brown loam to silty clay loam. They have yellowish brown B loam to clay loam horizons which are generally gravelly and stony.

(17) *Little or Not Weathered Weakly Acid to Alkaline Soils with Very Thick (> 20 in.) Dark Topsoils (Cumulic Hapludolls)*.—These soils were found only occasionally in the area, generally under grassland. They are similar to the Hapludolls (16) except for their topsoils which are more than 10 in. thick. They have been subdivided into three families based on texture, each with only one observation.

(17*a*) *Fine-textured Soils (1 record)*.—This soil occurs on alluvial plains and has a 24 in. thick very dark grey neutral plastic clayey A_1 horizon overlying olive-brown alkaline sticky and slightly plastic clay to sandy clay with small brownish yellow and grey mottles. At 40 in. this horizon merges gradually into sandy loam and loamy sand, while at about 50 in. medium and fine sand was encountered.

(17*b*) *Coarse-textured Soils (1 record)*.—This soil occurs on a beach plain and consists of a 30 in. thick weakly acid very dark brown to dark brown loamy sand to sand A_1 horizon overlying dark yellowish brown weakly acid to neutral fine to medium sand.

(17*c*) *Medium-textured Soils (1 record)*.—The soil belonging to this family was found on a foot slope of low hills in the south-east part of the area. The soil has a 36 in. thick weakly acid to neutral very dark greyish brown to yellowish brown clay loam topsoil merging into a yellowish brown weakly acid clay loam subsoil with a few weathered greywacke–mudstone fragments.

* A textural B horizon (argillic horizon) is defined as an illuvial horizon in which silicate clays have accumulated to a significant extent.

(18) *Little or Not Weathered Moderately to Strongly Gleyed Soils with Thick Dark Neutral Topsoils* (*Orthic Haplaquolls*).—These soils occur only in the south-eastern part of the area on beach ridges and alluvial flats. They have been subdivided into two families based on texture.

(18*a*) *Coarse-textured Soils* (*2 records*).—This family occurs on beach ridges mainly with *Imperata* grassland vegetation. The soils show little or no weathering and consist of a 10–14 in. very dark greyish brown sandy loam to medium sand A_1 horizon overlying dark grey to grey medium and fine sand. They have permanent water-tables at depth varying from 15 to 20 in., and a weakly acid to neutral soil reaction in the topsoil to weakly alkaline in the subsoil.

(18*b*) *Fine-textured Soils* (*2 records*).—This family was found on alluvial flats. These soils have black and very dark greyish brown weakly acid A_1 horizon mostly 10–15 in. thick, merging into olive-grey and greenish grey weakly acid to weakly alkaline plastic and sticky subsoils with many yellowish brown mottles.

(19) *Shallow* (*10–20 in.*) *Stony Soils with Neutral Dark Topsoils* (*Rendolls*) (*3 records*).—These soils are typical rendzinas formed on limestone, and occur on steep slopes and bench karst. The Rendolls have a 2–3 in. thick spongy root mat overlying a very dark greyish brown to dark brown friable loam to clay A_1 horizon up to 11 in. thick. The A_1 horizon passes gradually into a stony olive-brown silty clay C_1 horizon and massive limestone.

(20) *Weakly Acid to Neutral Soils, Dry for a Significant Portion of the Year, with Textural B Horizons* (*Mollic Typustalfs*) (*3 records*).—These soils occur in the extreme south-eastern part of the area on ridges and valley plains of Palipala land system of the Port Moresby area. They consist of a 5–6 in. thick very dark greyish brown friable loam to clay loam A_1 horizon, merging into a brown to yellowish brown friable to plastic sandy clay B_2 horizon with moderate amounts of gravel. In the valley plains the A_1 horizon has a transitional B_1 horizon about 9 in. thick and dark grey to dark greyish brown in colour.

(21) *Strongly Weathered Acid to Strongly Acid Grey and Reddish Mottled Soils with Textural B Horizons* (*Plintaquults*) (*1 record*).—This family occurs on a gentle foot slope of an undulating hill. The soil has a 6 in. thick light olive-brown clay to clay loam topsoil. This overlies a B_2 horizon of 32 in. thick greenish grey very plastic slightly sticky strongly mottled red and yellowish red clay with a few manganese concretions. The C_1 horizon consists of greenish grey sticky clay with prominent yellowish brown mottles overlying strongly weathered mudstone. It has been assumed that the red and yellowish red mottles in the B_2 horizon consist of plinthite, although it is not certain that this material hardens when exposed on the surface.

(22) *Strongly Weathered Acid to Strongly Acid Soils with Light-coloured or Thin Dark Topsoils, Plastic Clayey Subsoils, and Textural B Horizons* (*Typochrults*).—These soils were found mainly on moderate and steep slopes, ridge crests, benches, and terraces of the denudational land systems. They have been subdivided into four families based on soil colours and profile development.

(22*a*) *Soils with Brown Topsoils over Yellowish Red to Red Subsoils* (*15 records*). —This family has a 5–20 in. thick A_1 horizon with loam to clay loam textures overlying a 10–40 in. thick yellowish red to red clay to clay loam B_2 horizon, locally with common light grey mottles. The soils have developed on a wide variety of parent materials from greywacke–mudstone in the hills and mountains to alluvial terrace silt and gravel on the dissected benches. Some soils have small amounts of iron and manganese concretions and quartzite gravel in their profiles.

(22*b*) *Soils with Yellowish Brown Topsoils over Strong Brown and Reddish Subsoils* (*3 records*).—They consist of a 7–12 in. thick loam to clay loam A_1 horizon merging into an 11–16 in. thick strong brown clay to clay loam B_1 horizon and a yellowish red to red 14–26 in. thick clay B_2 horizon. Generally, these soils have small amounts of weathered rock fragments in their subsoils.

(22*c*) *Soils with Yellowish Brown Topsoils over Strong Brown Subsoils* (*4 records*). —This family has a 9–12 in. thick clay loam topsoil merging into a 27–38 in. thick clayey subsoil, mostly with a few red and light yellowish brown mottles. At depths of more than 48 in. the soil consists of strongly weathered pale mauve, light grey, brownish yellow, and reddish yellow mottled greywacke–mudstone with a clayey texture.

(22*d*) *Soils with Dark Yellowish Brown Topsoils over Yellowish Brown Mottled Subsoils* (*2 records*).—These soils consist of a 7–9 in. thick clay to clay loam topsoil overlying a clay to heavy clay subsoil with few to many yellowish red and light yellowish brown mottles and a few manganese concretions.

(23) *Strongly Weathered Acid to Strongly Acid Soils with Light-coloured or Thin Dark Topsoils, Plastic Clayey Red Mottled Subsoils, and Textural B Horizons* (*Plintochrults*) (*4 records*).—These soils occur on moderate slopes on high benches and terraces. As in family (21) the mottled subsoils have been assumed to consist of plinthite. The soils have a 10–12 in. thick dark brown to yellowish brown loam to clay loam A_1 horizon overlying a yellowish red, red, yellowish brown, and grey mottled 34–38 in. thick clay to sandy clay B_2 horizon and strongly weathered greywacke, mudstone, and siltstone.

(24) *Strongly Weathered Acid Soils with Thick Dark Topsoils, Plastic Clayey Subsoils, and Textural B Horizons* (*Typumbrults*).—This great group has been subdivided into two families based on subsoil colours.

(24*a*) *Soils with Yellowish Brown to Light Yellowish Brown Subsoils* (*2 records*). —This family was found on ridge crests and moderate slopes. The soils have a 10–14 in. thick very dark greyish brown to dark brown clay to clay loam A_1 horizon merging into a clay to heavy clay B_2 horizon with a few common red and yellowish red mottles.

(24*b*) *Soils with Yellowish Red and Red Subsoils* (*1 record*).—This family occurs on a terrace. The soil has a 12 in. thick dark brown loamy A_1 horizon overlying a clay B_2 horizon with a few manganese concretions and some weathered rock fragments.

(25) *Strongly Weathered Acid Soils with Thick Dark Topsoils, Red Mottled Plastic Clayey Subsoils, and Textural B Horizons* (*Plintumbrults*).—As with families (21) and (23), it has been assumed that the red mottled subsoil consists of plinthite, although it is not certain that this material hardens when exposed on the surface. The subdivision of these soils into two families is based on texture.

(25*a*) *Medium- over Fine-textured Soils* (*3 records*).—This family occurs on ridge crests and moderate slopes and consists of a 10–23 in. thick very dark greyish brown to dark brown loam to clay loam A_1 horizon overlying a strongly red, yellowish red, grey to light grey mottled clay to heavy clay B_2 horizon with some gravel.

(25*b*) *Coarse- over Fine-textured Soils* (*1 record*).—This family was found on a terrace. The A_1 horizon is 12 in. thick with a very dark greyish brown to dark brown colour and a sandy loam to loamy sand texture. The subsoil consists of a 6 in. thick yellowish brown sandy clay loam B_1 horizon merging into a 10 in. thick pale olive sandy clay B_2 horizon, with many red mottles, and a dominantly red, grey, and yellowish brown strongly mottled B/C horizon.

(26) *Strongly Weathered Strongly Acid Friable Clay Soils* (*Ochrudox*).—These soils represent the most weathered soils in the area and occur only very locally on ridge crests and gentle slopes. They have been subdivided into two families, one with and one without mottled subsoils.

(26*a*) *Soils with Mottled Subsoils* (*2 records*).—This family has a dark greyish brown, olive-brown, or brown 10–14 in. thick A_1 horizon overlying a yellowish red to red clay to heavy clay B_2 horizon with common grey, brown, and olive-yellow mottles. Parent materials are derived from greywacke–siltstone and mudstone.

(26*b*) *Soils without Mottled Subsoils* (*2 records*).—This family has an 8–14 in. thick very dark greyish brown to strong brown A_1 horizon merging into a 12–22 in. thick yellowish red, and a more than 28 in. thick red, subsoil with some gravel. As in family (26*a*) the parent material of this family consists of greywacke, mudstone, and siltstone.

III. Soil Distribution

The distribution of the soil families in the land systems is presented in Table 11. Because of the small number of observations the extent of the areas in square miles given for each family can only be regarded as an approximation, especially in the mountains with complex landscapes. However, Table 11 and the soil map provide a clear pattern of soil distribution in relation to environmental factors.

Undifferentiated soils (Entisols) and organic soils (Histosols) are characteristic of all aggradational land systems. Most of the undifferentiated soils (Entisols) consist of fine-textured "soft" swamp soils and strongly gleyed soils with high to very high water-tables (Hydraquents and Haplaquents). They have formed on recent alluvium. Their gleying and high water-tables can be explained by their very low relief and inadequate drainage outlets.

In restricted areas, on slightly elevated sites with moderate drainage, the soils are generally not gleyed and have low water-tables, but subsoils are mottled (Hapludents).

Coarse-textured undifferentiated soils (Psammaquents and Orthopsamments) are typical of the beach ridges that occur along the coast and are formed by deposition of sands by wind and wave action. On the beach-ridge barriers along the coast they have high water-tables associated with gleying (Psammaquents), while further inland on the raised beach ridges their water-tables are much lower (Orthopsamments). Along the coast under tidal influence the undifferentiated soils (Entisols) are mainly alkaline, changing gradually further inland from weakly acid over alkaline to weakly acid and acid. Organic soils (Histosols) have formed on both alluvium and beach sands. They occur inland in sheltered positions where no active deposition takes place, thus allowing plant residues to accumulate and form peat under permanently waterlogged conditions.

Other undifferentiated soils (Entisols) are those occurring in the denudational mountainous and hilly parts of the area. They consist mainly of regosolic soils on unstable very steep and steep colluvial slopes (Orthic Hapludents) and, where denudation is particularly rapid and weathering very shallow, of lithosolic soils (Lithic Hapludents).

Uniform-textured soils with altered B horizons and with or without thick acid dark topsoils (Inceptisols) occur extensively throughout the denudational land systems, generally on steep to moderate slopes. They usually have poorly developed A_1 horizons, but the B horizon is clearly defined due to weathering (Dystrochrepts). On low to moderate slopes and foot slopes they are locally gleyed, owing to slow permeability of subsoils (Ochraquepts). Under well-drained conditions and also on foot slopes these soils locally develop thick acid dark topsoils (Haplumbrepts). These soils also occur frequently on the beach ridges together with their weakly acid to neutral equivalents (Hapludolls). They are found especially where the natural vegetation of beach ridge forest has been largely replaced by *Imperata–Themeda* grassland, and locally develop topsoils of more than 20 in. (Cumulic Hapludolls). Under very poorly drained conditions these soils develop strongly gleyed subsoils (Haplaquolls), especially on fine-textured alluvial parent materials.

Typical soils for those land systems that occur in limestone country are the rendzina-like soils (Rendolls). They are unstable shallow stony soils found on very steep slopes and bench karst. When these soils become more mature they develop into textural B horizons and coarser-textured surface soils (Argudolls), but these are very rare in the area.

The weakly acid to neutral soils with textural B horizons (Alfisols) occur in the extreme south-east part of the area (Palipala hills) with a pronounced dry season (Typustalfs). These differ from the Argudolls in that they lack a thick dark topsoil.

The strongly weathered acid to strongly acid soils with textural B horizons (Ultisols) cover most of the denudational land systems and are closely associated with more stable landscapes. They are best developed and most extensive on terraces, ridge crests, and bench units, but occur also on moderate and even steep slopes. Their subdivision into great soil groups is based mainly on the degree of slope and drainage. Most extensive are the soils with thin dark or light-coloured topsoils

TABLE 11

DISTRIBUTION OF SOIL FAMILIES IN RELATION TO LAND SYSTEMS

Occurrence of soil families is indicated as A, > 100 sq miles; B, 50–100 sq miles; C, 20–50 sq miles; D, 5–20 sq miles; E, 2–5 sq miles; and F, < 2 sq miles

Soils		Aggradational Land Systems																Denudational Land Systems													Port Moresby–Kairuku Land Systems			
		Littoral Plains							Alluvial Plains									Moderate and Low Relief							High Relief									
		Tidal Flats					Beach Ridges		Non-tidal Freshwater Swamps					Basins	Flood-plains			Dissected Benches	Undulating Hills	Hill Ridges				Plateau Karst	Moderate and Steep Slopes				Very Steep Slopes					
		Alele	Nipa	Purari	Murva	Ebala	Araimiri	Malalaua	Campnosperma	Waigani	Movori	Karama	Melaleuca	Vailala	Terapo	Tauri	Hepea	Olipai	Hauta	Maipora	Kwambega	Aro	Bananu	Saw	Putei	Kurai	Lohiki	Nabo	Kapau Complex	Eruki	Palipala	Hisiu	Lesewalai	Galley Reach
Histosols	*1a*			C	B				D	C																								
	1b				E				E	E	C	C																						
Hydraquents	*2a*	B	E			C							C	D	D	D	E																	C
	2b		C	D		C				B	C	B																						
	2c	F			E								C																					
Haplaquents	*3a*		D					D					C	C	D	B	B					D												
	3b													B																				
	3c													E	D																			
Psammaquents	*4a*						D	E	E																									
	4b						E																									E	E	
Orthopsamments	*5a*						F	D										E																
	5b						F																											
Orthic Hapludents	*6a*																			B	F	F	F		D		C	D	A	C				
	6b													D			C																	
	6c						F	D								D	D																	
	6d																				F						D			C				
	6e																D																	
Aquic Hapludents	*7a*													B	D	C	C	F																
	7b						E	E					F																					
Lithic Hapludents	8																			E	F			D	E	D		D	D	E				

Orthic Dystrochrepts	9*a*			C	E	E	B	F	C	E			B	B	A	D	B			
	9*b*					D	B		F			D	D	B	C	C				
	9*c*						C	F	F								C			
	9*d*					D	B	F		D				D	C	B	A			
	9*e*							E									D			
Eutric Dystrochrepts	10					D								D						
Aquic Dystrochrepts	11						D		E					D						
Lithic Dystrochrepts	12					F			E		E	D	C	D						
Ochraquepts	13					D						E								
Orthic Haplumbrepts	14*a*		E						F											
	14*b*					D														
	14*c*						D		F											
Argudolls	15													D						
Orthic Hapludolls	16*a*		D																	
	16*b*			D											C					
Cumulic Hapludolls	17*a*			E																
	17*b*																	E		
	17*c*		E																	
Orthic Haplaquolls	18*a*	E																	E	F
	18*b*			D																
Rendolls	19										F	D		D						
Mollic Typustalfs	20																	E		
Plintaquults	21					E														
Typochrults	22*a*				C	D	D		F	F		D	D		E		E			
	22*b*				E			F		F							B			
	22*c*									D	F			D			B			
	22*d*					D														
Plintochrults	23				F	D			F					D						
Typumbrults	24*a*					D														
	24*b*				E															
Plintumbrults	25*a*					D														
	25*b*				F															
Ochrudox	26*a*					D								E						
	26*b*													E	E					

(Typochrults) which occur generally on more sloping land units than their counterparts with acid thick (> 10 in.) dark topsoils (Typumbrults). Those soils with "plinthite" in their textural B horizons (Plintochrults and Plintumbrults) are generally formed under imperfectly drained conditions. Finally, under poorly drained conditions, grey and reddish mottled soils with textural B horizons (Plintaquults) occur on the foot slopes of undulating low hills, but they are very rare in the area.

Although the Ultisols have a clay increase due to illuviation between A and B horizons this is not easy to detect in the field. Available analytical data show, however, a clay increase between A and B horizons of about 15%.

Strongly weathered friable clay soils (Oxisols) are extremely rare in the area and are therefore not shown on the soil map. They are confined to one great soil group consisting of strongly acid soils with thin dark or light-coloured topsoils (Ochrudox). These soils occur on ridge crests and gentle slopes of some of the denudational land systems.

IV. References

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PART VIII. VEGETATION AND ECOLOGY OF THE KEREMA–VAILALA AREA

By K. Paijmans*

I. Introduction

The climax vegetation over most of the area is tropical evergreen rain forest, locally modified by topography, climate (chiefly amount and distribution of rainfall), and man. In the non-hilly areas, drainage is generally poor and various types of swamp vegetation predominate.

The following is a brief account of the various environments encountered in the area.

A generally narrow discontinuous belt of mangrove stretches along the coast. It widens in the Purari delta, around Kerema Bay, and near the mouth of the Tauri and Lakekamu Rivers where the low-lying land permits the tide to reach further inland.

Extensive areas of *Nypa* palm occur in brackish environment in the Purari delta, where over a wide front large quantities of fresh water mix with salt water.

Owing to the very low gradient in this delta, behind the *Nypa* a rather uniform type of freshwater swamp forest stretches for some 15 miles inland. Sago palm becomes increasingly frequent in the undergrowth and the swamp forest grades insensibly into sago swamp with a more or less dense upper storey of trees.

In the extreme south-east of the survey area vast stretches of *Melaleuca* swamp savannah occur, deeply flooded in the wet season and drying out for a short period during the dry months. Adjacent large areas of permanent and semi-permanent swamp are covered with herbaceous vegetation and bordered by swamp woodland and areas of pure sago palm.

On the well-drained recent beach ridges the original vegetation of littoral woodland and forest has largely been replaced by indigenous and white settlers' coconut plantations. The low-lying country behind is covered with swamp forest, swamp woodland, sago, or herbaceous swamp vegetation, depending on depth and quality of the water. Better-drained raised beach plains carry tall forest, partly replaced by coconut plantings, gardens, and grassland.

The sparsely populated alluvial plains, alluviated basins, and low hills are densely forested. In the east, the hill and basin forests locally contain a high proportion of deciduous trees.

The upland forests, between *c.* 1000 and 3000 ft altitude, show much evidence of damage by shifting cultivation and large areas consist of young and old secondary forest.

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In the lower montane zone above *c.* 3000 ft the relatively dense population, depending entirely on shifting cultivation for their living, have subjected the forest to intensive destruction for a long time, and over large areas virtually no original vegetation remains.

II. Methods

Vegetation typing was initially done by pre-survey photo interpretation, upon which the vegetation–forest resources map accompanying this report is largely based. During the survey, photo predictions could in a number of cases be confirmed or improved by helicopter reconnaissance, particularly in the inaccessible hinterland. After the survey a certain amount of remapping and boundary adjusting was done on evidence gathered by field observations.

In the field all vegetation characteristics were estimated. Scales used to express density, cover, visibility, and frequency are the same as those set out for Safia–Pongani by Paijmans (1967). In Section V the main structural features have been kept in the text; for details refer to Appendix II.

III. Classification

A first division of the vegetation into major groups is based on life form. These major groups, which are also readily recognizable on air photos, are mixed herbaceous vegetation, grassland, scrub, woodland, palm and pandan vegetation, savannah, and forest. Other structural differences and floristic characteristics have led to a further distinction of vegetation types. In the lowlands, the dominance or relatively high frequency of a species commonly indicates a specific environment, and vegetation types have normally been named after one or two dominant genera. In the hills and mountains, distinction of forest vegetation types, if at all possible, had to be based on structural features, since only very rarely was a tree species found to dominate or occur exclusively in a particular forest type or a particular habitat, e.g. *Casuarina papuana* on the crest of limestone pinnacles.

The principal features used to distinguish forest types are average crown size and canopy closure, assessed from air photographs, and height of canopy and emergent trees, assessed mainly from field estimates or measurements.

The close relationship between forest structure and altitude has led to the use of the terms "hill", "upland", and "lower montane" where this was necessary to further define a forest type. In the context, "hill" indicates an altitude roughly below 1000 ft, "upland" between 1000 and 3000 ft, and "lower montane" above 3000 ft. A forest type occurring in basins and back plains has been termed basin forest to distinguish it in name from a hill forest type of similar height and average crown size.

IV. Definition and Discussion of the Major Groups

(*a*) *Mixed Herbaceous Vegetation*

This group comprises the vegetation types in which non-graminoid herbs determine the aspect, with grasses and woody plants usually present but subordinate. They occur in habitats not suited to or not yet fully colonized by trees.

(*b*) *Grassland*

In grassland, grasses determine the aspect although scattered shrubs and trees normally occur. In places the distinction between grassland and savannah becomes vague due to an increased density of the trees. According to their height, grasslands have been subdivided into tall grassland (over 5 ft high), mid-height grassland (between 2 and 5 ft high), and low grassland (up to 2 ft high).

All grasslands in the survey area are anthropogenous, with the exception of tall *Saccharum* grassland, part of the *Phragmites* grassland, and minor littoral low grassland.

(*c*) *Scrub*

Scrub is a closed community dominated by shrubs. Low trees emerging above the shrub layer are usually present. In the survey area, scrub occurs only in the coastal region.

(*d*) *Woodland*

Woodland is a community of scattered low to mid-height (to 100 ft) trees over a usually dense undergrowth in which grasses occur but do not normally play a dominant part. In the survey area woodland is confined to swampy environments, except where it occurs on beach ridges as a vegetation type usually impoverished due to intermittent gardening and other destructive human action.

(*e*) *Palm and Pandan Vegetation*

In vegetation types of this kind palms or pandans dominate. *Nypa* covers large areas in the western coastal part of the survey area, pure or with a scattering of mangroves. Sago palm vegetation normally contains a top layer of widely scattered to fairly dense trees and in the west commonly grades into swamp forest or swamp woodland. *Pandanus* not uncommonly forms small pure stands in oxbows and on frequently flooded low river banks.

(*f*) *Savannah*

Savannah is an open tree community with grass undergrowth. The only type of savannah in the survey area is *Melaleuca* savannah in the eastern part, either in swampy environment or as a dry, probably induced, vegetation type in a minor hilly area north of Malalaua air strip.

(*g*) *Forest*

In forest, trees form a closed community. According to height of the canopy forests have been subdivided into tall (over 100 ft), mid-height (50 to 100 ft), and low (up to 50 ft high).

Sonneratia and *Avicennia* mangrove typically form low forest, which may grade into scrub. Mid-height forest comprises most of the *Rhizophora–Bruguiera* mangrove forests, vast tracts of swamp forest in the Purari delta, forest in basins and back plains with impeded drainage, the larger part of the hill forests, and all upland and lower montane forests. In the category tall forest are forests on alluvial and beach plains, some types of swamp forest, and hill forest in favourable situations.

V. Description of the Vegetation Types

(a) *Mixed Herbaceous Vegetation*

(i) Ipomoea–Canavalia.—This community consists of sand-binding herbaceous creepers, grasses, and sedges pioneering on sandy beaches just above high-water mark. The type is usually dominated by a dense mass of trailing stems and foliage of *Ipomoea pes-caprae*, with *Canavalia maritima* commonly co-dominant, interspersed with grasses, e.g. *Ischaemum muticum*, and sedges, e.g. *Fimbristylis* sp. and *Remirea maritima*, the whole locally overgrown with the parasite *Cassytha*. Landward some creeping *Vigna marina*, seedlings of *Hibiscus tiliaceus*, and low *Desmodium* shrubs occur (Plate 2, Fig. 2).

(ii) Leersia–Nymphaea.—A community of submerged *Ceratophyllum*, floating *Lemna*, partly floating, partly submerged *Nymphaea*, and emerging *Leersia hexandra* and sedges, e.g. *Fuirena*, is found in permanently swampy swales and depressions of Melaleuca land system.

(iii) Thoracostachyum–Hanguana.—A mixed vegetation of coarse sedges and *Hanguana malayana* covers vast areas of herbaceous swamp in Waigani land system. Where the type was examined from a patch of open water in the east, it consisted of dominant *Thoracostachyum sumatranum* and co-dominant *Hanguana* emerging 2–3 ft above the water level. Widely scattered low *Melaleuca* trees overgrown with climbers occur where the swamp is less deep.

(iv) Hanguana (Plate 3, Fig. 2).—Dense nearly pure *Hanguana malayana* to 9 ft high, anchored in a more or less floating mat of roots and organic debris, commonly occurs in deep herbaceous swamp. Associates, locally co-dominant on a somewhat firmer substratum, are gingers and *Phragmites* near rivers and swamp margins. *Thoracostachyum* and *Pandanus* are commonly present, scattered or in small groups. Climbers are very common, e.g. *Nepenthes*, *Stenochlaena*, *Cyclosorus*, and rattan, the non-ferny ones overgrowing the scattered low trees where these occur. Tree species commonly found in this habitat are *Neuburgia corynocarpa*, *Gynotroches axillaris*, *Campnosperma brevipetiolata*, *C. coriacea*, *Nauclea ?orientalis*, and *Intsia bijuga*.

In the east, in Waigani land system, dry-season drainage courses through the swamp, faintly discernible from the air by their different tone, were found to be covered by a facies of pure low *Hanguana*.

In small swampy depressions of Vailala land system *Hanguana* occurs in the deepest central part, surrounded by a rim of gingers and some sago and pandan along the slightly higher edges.

(v) *Marantaceae*.—In Aro land system a herbaceous vegetation of mainly tall Marantaceae was seen to cover large gaps in the forest presumably caused by earthflow. A detailed description is not available.

(b) *Grassland*

(i) *Tall Grassland*

(1) Saccharum.—*Saccharum robustum* in dense pure stands to 16 ft high colonizes low river banks and the outer rim of scrolls and forms an initial stage to *Artocarpus–Octomeles* forest behind. Commonly patches of low *Hymenachne acutigluma* occur in the same habitat, probably secondary after destruction of the *Saccharum* vegetation by fire. *Saccharum robustum* also occurs along the edges of old river courses (Terapo, Tauri, and Hepea land systems), here also probably transitional to forest.

(2) Phragmites.—Pure stands of *Phragmites karka* to 10 ft high occur in narrow bands on frequently flooded low river banks in habitats similar to those of *Saccharum robustum*, and also commonly border herbaceous swamp in the east (Waigani land system).

Phragmites is particularly common in the east and it is likely that, due to fire, it has extended its area through encroachment upon the *Melaleuca* swamp savannah.

It apparently has a high salt tolerance since it occurs in swampy swales in between beach ridges near the coast as well as landward where the complex of ridges and swales borders mangrove. Its occurrence on the banks of rivers in their lower reaches, together with groups of *Sonneratia*, points to an ability to withstand frequent flooding with brackish water.

(3) Imperata–Phragmites.—This vegetation is 5–9 ft high and usually dominated by *Imperata cylindrica* in mosaic with *Phragmites*. *Saccharum spontaneum* and *Coelorachis rottboellioides* are usually present and locally co-dominant. Scattered *Pandanus*, *Livistona* palm, and low trees of *Antidesma ghaesembilla*, *Nauclea orientalis*, *Glochidion*, *Melaleuca*, and *Cordia* occur. Shrubs, e.g. *Leea ?rubra*, are scarce. Sedges of the genera *Cyperus* and *Scleria* are common, as well as climbers, e.g. the fern *Lygodium*, *Cissus*, and *Vigna vexillata*. Forbs are often leguminous, e.g. *Uraria lagopodioides*, but include a host of others, e.g. *Melochia corchorifolia*, *Pouzolzia*, *Ludwigia*, *Abelmoschus*, *Hygrophila*, and *Euphorbia serrulata*. The type occurs in periodically inundated habitats in Melaleuca land system and lowest foot slopes in Palipala land system, and is maintained by burning.

(4) Imperata–Miscanthus.—Tall *Miscanthus floridulus*, mixed or in mosaic with *Imperata cylindrica* and in association with a host of regrowth shrubs, is a common secondary vegetation type in the lower montane zone.

Worthy of note is that a healthy clump of *Miscanthus* grass was found in a garden in *Nypa* palm environment a few feet above sea level. It may have been planted for decorative purposes or with a view to making arrow shafts.

(ii) *Mid-height Grassland*.—Mid-height grasslands in the survey area are usually dominated by *Imperata*, sometimes by *Themeda*. They are rarely homogeneous and other grasses (*Coelorachis*, *Capillipedium*) are locally dominant or co-dominant. Where *Coelorachis* dominates, commonly near the border with forest, the vegetation grades into tall grassland. Other grasses often present are *Sorghum* and *Heteropogon*, and in the coastal region *Ischaemum muticum*; *Sehima*, *Dichanthium*, and *Ophiuros* are rare. On flat occasionally flooded areas grasses become tussocky and sedges are common.

Scattered shrubs, e.g. *Desmodium*, *Leea ?rubra*, *Vitex trifolia*, *Decaspermum ?fruticosum*, *Ficus*, *Albizia procera*, *Timonius timon*, *Melaleuca*, and low trees, e.g. *Antidesma ghaesembilla*, *Timonius timon*, *Melaleuca*, *Nauclea orientalis*, and *Semecarpus* and also *Pandanus*, are commonly present.

A great many forbs occur throughout. Besides those mentioned under (i), they comprise *Stackhousia intermedia*, *Uraria*, *Zornia diphylla*, *Indigofera trifoliata*, *Crotalaria mucronata*, *Anisomeles ?ovata*, *Heliotropium strigosum*, and *Mitrasacme elata*. The presence of *Pygmaeopremna sessilifolia* points to regular burning. Also common is creeping and climbing *Lygodium* fern. Creeping *Pueraria ?thunbergiana* locally overgrows fairly large areas of mid-height grassland in Palipala land system; *Cassytha filiformis* locally covers the *Imperata* on the low ridges of Hisiu land system.

Mid-height grasslands are maintained by burning, and relatively dense population, low water-holding capacity of the soil, and severe dry seasons, often in combination, promote their genesis, survival, and extension. They are particularly common in Malalaua and Palipala land systems. Numerous but small areas occur in the mountains in centres of shifting cultivation, particularly in Kwambega land system, also in Kapau Complex and Eruki land systems. Although most abandoned mountain gardens seem to pass through a quick stage of garden regrowth into secondary forest, degradation to more or less permanent *Imperata* grassland does occur on ridges and wherever shifting cultivation is very intensive.

(iii) *Low Grassland*.—Low grassland occupies minor areas in broad shallow nearly level swales in Hisiu land system of the Port Moresby–Kairuku survey area. Dense *Paspalum vaginatum* is locally common, alternating with nearly pure communities of a low sedge (*Fimbristylis* sp.), and mixed with scattered *Ipomoea pes-caprae* and *Vigna marina* and locally overgrown with *Cassytha*. Low shrubs of *Desmodium umbellatum*, *Premna*, and *Hibiscus tiliaceus* occur on slight rises within the swales.

(*c*) *Scrub*

(i) Hibiscus–Desmodium *Scrub*.—This type is a usually dense vegetation of *Hibiscus tiliaceus* to 20 ft and *Desmodium umbellatum* to 10 ft, either species pure or mixed, occurring on beach ridges and enclosed between *Ipomoea–Canavalia* mixed herbaceous vegetation and mangrove forest. Where the ridges grade into swales the type is less well developed, becoming more open, and gives way to mainly *Phragmites*. Locally the type has been partly or fully replaced by indigenous coconut plantation with an undergrowth of mainly *Paspalum conjugatum*.

The strong fibrous bark of *Hibiscus* twigs is used for making fishing nets.

(ii) Avicennia *Scrub*.—A dense, about 20 ft high, scrub of *Avicennia marina* interspersed with patches of open water occupies a large saline inner tidal flat just above mean high-water mark (Lesewalai land system of the Port Moresby–Kairuku area) between the Palipala hills to the east and *Rhizophora–Bruguiera* mangrove forest to the west. To the south, where the ground rises slightly to a system of inner beach ridges, *Avicennia* is mixed with lower *Lumnitzera racemosa*, and the undergrowth consists of a sward of the edible but salty *Sesuvium portulacastrum* and low *Fimbristylis* sedge. Interspersed with the *Avicennia–Lumnitzera* scrub and at a slightly higher level are narrow stretches of bare salt flat with some *Sesuvium* and *Tecticornia cinerea* along the edges. The salinity of these flats, the surface salt content of which is increased by strong evaporation during the dry season and which are too rarely flooded for the salt to be removed, is apparently too high even to support *Avicennia* (cf. Macnae 1966).

(iii) Lumnitzera *Scrub*.—This scrub to about 10 ft high and with an undergrowth of *Sesuvium* occurs on low inner beach ridges in the east of the survey area (Hisiu land system of the Port Moresby–Kairuku area). In the swales between the ridges *Avicennia* becomes dominant. Slightly higher less saline ridges have been cleared and planted to coconut and other crops. The undergrowth was found to consist mainly of *Imperata*.

(*d*) *Woodland*

(i) *Littoral Woodland*.—This vegetation type occurs on the first and subsequent beach ridges behind a narrow rim of *Hibiscus–Desmodium* scrub or immediately behind the *Ipomoea–Canavalia* community. In the survey area the type was found to be so altered by man that its original structure and composition can only be guessed. The open canopy of low trees consists of species and genera such as *Barringtonia asiatica*, *Terminalia catappa*, *Pterocarpus indicus*, and *Premna* on the front ridge and *Randia*, *Artocarpus*, and *Elaeocarpus* slightly further inland. *Calophyllum inophyllum* is rare and the few specimens that have escaped the axe are distorted. *Terminalia kaernbachii*, where it occurs, is probably planted. Of *Casuarina equisetifolia*, only three (probably planted) specimens were seen in front of a village facing the shore. *Pandanus* is common in the lower tree layer. The undergrowth is usually dense, gingers and ferns are prominent. Density and composition of the herb layer vary with degree of previous disturbance and light intensity. *Crinum asiaticum* is usually present. Climbers are common, particularly *Flagellaria indica* and *Stenochlaena*.

Towards the swales between the ridges, *Pandanus* and/or sago and other palms become prominent and *Phragmites* occurs locally.

Where the type borders mangrove, *Acrostichum* and *Acanthus* come into the sparser undergrowth, and mangrove genera, e.g. *Bruguiera* and *Xylocarpus*, appear.

Most of the habitat is past or present garden. The usual tree is coconut. Undergrowth in coconut plantations on higher ground is commonly a dense mat of *Paspalum conjugatum*, and locally consists of *Imperata* and *Ischaemum muticum*; in lower brackish environment *Acanthus*, *Acrostichum*, *Derris trifoliata*, and *Phragmites* are found.

A common tree planted in gardens is *Gnetum gnemon*, the young leaves of which are eaten as a vegetable.

(ii) *Mixed Mangrove Swamp Woodland* (Plate 2, Fig. 1).—Groups of *Bruguiera* and/or *Rhizophora* trees about 60 ft high form a very open canopy, in mixture with many other slightly lower swamp trees, e.g. stilt-rooted *Myristica*, *Diospyros* ?*ferrea*, *Xylocarpus*, *Inocarpus*, and *Calophyllum*; coconut palm is locally planted on slight elevations. Occasional emergent individuals of *Heritiera* and *Palaquium* reach 100 ft. *Brownlowia argentata* is very common and forms the highest shrub and lowest tree layer, together with occasional sago, *Nypa*, various other palms (e.g. *Areca* and *Arenga*), *Pandanus* with large prop roots, *Barringtonia*, a tree fern, and *Hibiscus tiliaceus*. The lower shrub layer is commonly dominated by a giant sedge, ?*Mapania*. Locally, dense groups of a shrub-pandan 10 ft high exclude all other shrubs. *Acanthus* and the ferns *Acrostichum* and *Marattia* are usually present. The herb layer is practically non-existent except for ?*Crinum* and occasional seedlings of *Pothos*. Climbers, particularly *Flagellaria*, also *Pothos* and thin woody climbers, are common. Epiphytes are rare to rather common. Buttresses (*Bruguiera*) and stilt roots (*Myristica*, *Rhizophora*), as well as knee roots (*Bruguiera*, *Heritiera*), other types of pneumatophores, and surface roots, are very common.

The habitat is a brackish zone transitional between mangrove proper and freshwater swamp woodland or sago swamp. It is subject to tidal inundation as the water in the rivers and creeks draining the area is backed up by the incoming tide.

(iii) *Freshwater Swamp Woodland* (Plate 3, Fig. 2).—The tree layer consists of scattered individuals of freshwater tree genera about 60 ft high. The undergrowth is dense and varies with the habitat.

Near herbaceous swamp margins tree genera include *Campnosperma*, *Nauclea*, *Intsia*, *Elaeocarpus*, *Syzygium*, and *Neuburgia*. Scattered poor sago and *Pandanus* form a very open storey below the trees. The undergrowth consists of tall *Hanguana*, with the tall sedge *Mapania macrocephala* locally co-dominant and with some ferns and other sedges. Climbers, particularly *Flagellaria*, *Stenochlaena*, and rattan, are common.

Where the type grades into swamp forest (Murva land system), trees grow higher and reach 80 ft. Common tree genera are *Calophyllum* and stilt-rooted *Myristica*, *Calophyllum* commonly with abundant regeneration. Well-developed sago, and *Pandanus* form an open lower storey. Most of the undergrowth consists of ?*Mapania*.

In habitats transitional to riverine forest (Terapo land system, Plate 5, Fig. 1) the average tree height is 60 ft but occasional emergents, e.g. *Alstonia*, reach 90 ft. In the lower tree storey palms, e.g. *Arenga*, *Areca*, and *Caryota*, are prominent, *Pandanus* is common, and *Cordyline* present. The herb layer is scarce and practically absent where palms are dense. Fleshy climbers, e.g. *Flagellaria*, and thin woody climbers are prominent. A few of the commoner tree genera of the very many present are *Dracontomelum*, *Vitex*, *Intsia*, *Planchonia*, *Nauclea*, *Syzygium*, and *Elaeocarpus*.

(*e*) *Palm and Pandan Vegetation*

(i) Nypa (Plate 1).—*Nypa fruticans* covers extensive areas of tidal flat around the mouths of the larger rivers subject to daily tidal flooding with brackish water, and also lines tidal creeks. In a well-developed stand of *Nypa* the fronds grow to 30 ft high and form a well-closed canopy. Apart from scarce *Nypa* seedlings, some *Acrostichum*, and ?*Crinum* there is no undergrowth.

Nypa occurs in pure stands and mixed with mangrove species. Common associates are *Bruguiera sexangula, Heritiera littoralis, Sonneratia caseolaris, Dolichandrone spathacea*, and *Xylocarpus moluccensis*. All gradations, from *Nypa* with widely scattered small groups of trees to mangrove with minor areas of *Nypa*, can be found. The vegetation is very sensitive to environmental conditions, salinity of the water probably being one of the main determining factors. In places, *Nypa* palm is seen lining tidal creeks with mangrove trees behind (Plate 1, Fig. 1); elsewhere mangrove trees border smaller tidal creeks within a *Nypa* community.

Over a large area of degraded beach ridges east of the mouth of Aumu River, with a vegetation of *Nypa* mixed with mangrove, the air photos show *Nypa* to occupy the broad swales, with mangrove trees, probably *Bruguiera* and *Heritiera*, concentrated on the former ridges.

Where *Nypa* lines tidal creeks in an environment transitional to freshwater swamp woodland it becomes scarcer with decreasing tidal influence, and *Brownlowia argentata* becomes abundant.

In brackish environment crabs play an important part in forming and transforming landscape and vegetation. Their mounds become densely overgrown with *Acrostichum*. The mounds steadily increase in area and a number of them probably become interconnected. At a later stage and slightly higher level a varied vegetation can be found on these islets, comprising *Arenga* palm, tree fern, *Mapania*, seedlings of *Intsia bijuga*, and climbing *Flagellaria, Marsdenia*, and *Stenochlaena* fern. Man utilizes the islets for gardening (Plate 1, Fig. 2) and planting to coconuts, bread-fruit, banana, pineapple, cassava, and an unidentified leguminous shrub the leaves of which are used as a vegetable. *Nypa* persists in the channels between the islets, associated with young individuals of *Bruguiera sexangula, Heritiera littoralis, Dolichandrone spathacea*, and *Brownlowia argentata*.

(ii) *Sago*.—*Metroxylon sagu* dominates in two land systems, Karama and Ebala. In Karama land system stands are dense, and pure except for widely scattered trees. In Ebala land system sago forms more open stands with a very open tree canopy above and an undergrowth of scattered patches of *Mapania macrocephala*, occasionally *Hanguana*.

The habitat is uppermost freshwater tidal flats and swampy back plains. Under favourable conditions, i.e. near through-going water, the fronds of healthy sago may grow to 35 ft and flowering stalks reach 65 ft; under poor conditions of stagnant water low in nutrients, or brackish water, sago may still be dense but will not grow over about 10 ft high.

In dense and very swampy stands there is no undergrowth and the only ground "cover" consists of the numerous tiny pneumatophores. On less poorly drained ground and in open stands, the shrub layer may consist of ferns and gingers with shrubs such as *Voacanga*, and a herb layer varying in density and composition with light conditions. *Paspalum conjugatum* locally has a 100% cover. Thin woody fleshy (e.g. *Dioscorea*) and ferny (e.g. *Stenochlaena*) climbers are common.

Accompanying trees grow to 80 ft high and belong to many genera. A few of the more common ones are *Sapium, Dolichandrone, Intsia, Cryptocarya* spp., *Litsea*, *Calophyllum*, and *Inocarpus*, also *Caryota* palm and *Pandanus*. Stilt roots (Myristicaceae) and pneumatophores (*Intsia*) are rather common.

(iii) *Pandan*.—*Pandanus* spp. form dense pure stands of limited extent, to about 25 ft high, in old river courses, swampy depressions in back plains, and on scrolls and low banks in the lower reaches of the large rivers. In the latter habitat it occurs adjacent to, but not mixed with, *Sonneratia caseolaris*.

(*f*) *Savannah*

(i) Melaleuca leucadendron *Savannah* (Plate 4, Fig. 2).—Pure stands of *Melaleuca leucadendron*, which vary from very open to fairly dense and from low to tall, cover large areas of temporary swamp in the east of the survey area. They dry out during the dry season and are inundated by at least 2 ft of water at the end of the wet period.

The undergrowth consists largely of *Phragmites* to 7 ft high, locally of scattered sago. Creepers and climbers such as *Passiflora* and *Cayratia* are common.

Well-developed stands have an average height of 70 ft, the tallest trees are 90–100 ft. Girths are up to 4 ft. All trees as well as sago palms are scarred and damaged by fire. Where a fire has swept through the crowns, these are bare of leaves or are producing dense small green tufts of fresh foliage.

Nauclea, *Cordia*, and *Livistona* palm are some of the few trees sparsely mixed with *Melaleuca*. *Livistona* becomes more frequent towards higher ground and occasionally forms a fringe between *Melaleuca* swamp and adjacent forest or grassland. *Hanguana* occurs in permanently swampy patches. Old river courses form narrow bands of open water without *Melaleuca* and with floating aquatic plants such as *Lemna* and *Ceratophyllum demersum*, which in the wet season spread through the whole swamp.

In situations marginal to herbaceous swamp, *Melaleuca* trees are more widely scattered, lower, and overgrown with climbers; the undergrowth consists of *Hanguana* and low sago.

(ii) *Low* Melaleuca argentea *Savannah*.—This vegetation type consists of very scattered *Melaleuca argentea* trees, the tallest 50 ft high, over mid-height *Themeda–Imperata* grassland. It occurs in the low hills of Hauta land system and is probably secondary after destruction of the original forest by fire. Scattered shrubs or low trees of *Timonius*, *Antidesma*, *Decaspermum*, *Nauclea*, and *Melastoma* occur. Other grasses present are *Coelorachis*, *Sorghum*, *Capillipedium*, and *Alloteropsis*. A host of forbs is mixed with the grass, including the genera *Dianella*, *Tephrosia*, *Euphorbia*, *Indigofera*, and *Abelmoschus*. Sedges are always present though usually inconspicuously so. *Cassytha* is parasitic in the crown of *Melaleuca*. Very common epiphytes are *Myrmecodia* and two species of *Dischidia*.

Locally dense thickets occur within the savannah, either poor remnants of the original forest or stages in the regeneration to forest; *Acacia auriculiformis* is the most conspicuous tree.

Eucalyptus spp., occupying similar habitats in the Port Moresby–Kairuku area (Heyligers 1965), do not continue into the survey area.

(iii) *Mid-height* Melaleuca argentea *Savannah.*—Scattered *Melaleuca argentea* trees to 70 ft high form a very open canopy over grassland, mid-height where it consists of *Imperata* and *Themeda*, tall where *Coelorachis* co-dominates. It occurs in the east on poorly drained sites in Vailala land system, most probably secondary after destruction of the original forest, and is maintained by burning in the dry season. Accompanying trees, shrubs, and forbs include those mentioned under (ii) above. In damp places *Phragmites* and *Saccharum* occur and sedges become more prominent.

(*g*) *Forest*

(i) *Low Forest*

(1) Sonneratia.—*Sonneratia caseolaris* with lanceolate leaves forms small pure stands 20–30 ft high on almost all low scrolls and islets subject to daily brackish inundation in rivers and creeks in Nipa and Murva land systems. Undergrowth is normally rare to absent and occasionally consists of dense sedge.

Sonneratia caseolaris with broad roundish leaves locally occurs as a narrow fringe, about 20 ft high, on tidal flats between beach ridges with *Hibiscus–Desmodium* scrub and inner lagoons with *Avicennia*. Associates of this broad-leaved *Sonneratia caseolaris* are *Avicennia marina*, *Bruguiera cylindrica*, *Rhizophora ?apiculata*, *Aegiceras corniculatum*, and *Nypa*. The thick, old, and emergent individuals of *Avicennia* are probably remnants of a preceding seral stage of pioneering *Avicennia*.

(2) Avicennia.—Gnarled wide-crowned stems of *Avicennia marina* in dense pure stands occur locally on inner tidal flats. Except for the innumerable small pneumatophores, ground cover is absent in stands subject to daily tidal flooding and consists mainly of *Sesuvium portulacastrum* where flooding is only occasional.

In tidal lagoons between beach ridges and in sheltered situations near the mouths of large rivers, the older *Avicennia* is commonly fronted by a "forest" of pioneering *Avicennia* saplings and seedlings. Their foremost ranks are submerged for most of the time and the *Avicennia* plumules emerge only around low tide. They probably play a part in accumulating and consolidating sediment.

Later stages show *Avicennia* stands mixed with *Sonneratia* in about equal proportions, and also including some *Rhizophora*. *Sonneratia* and *Rhizophora* seedlings as well as those of *Avicennia* are able to withstand daily submersion for several hours.

A long stretch of dead or dying *Avicennia* along the coast west of the mouth of the Aumu River is probably a result of increased exposure to wave action after disappearance of a frontal sand bar.

(ii) *Mid-height Forest*

(1) Rhizophora–Bruguiera (Plate 1, Fig. 1; Plate 2, Fig. 2).—Since the majority of the *Rhizophora–Bruguiera* forests fall in the mid-height class they are treated under this heading.

Several species of both *Bruguiera* and *Rhizophora* occur in the area (of *Bruguiera* at least three: *B. cylindrica*, *B. sexangula*, and *B. parviflora*). Since distribution and ecology of the individual species could not be assessed, a general description must suffice.

Young stands have a densely closed canopy about 50 ft high and *Rhizophora* often dominates. Accompanying species are *Avicennia marina* and *A. officinalis*, often old and emerging some 15 ft above the canopy. The undergrowth consists of mangrove seedlings. Climbers and epiphytes (ferns) are rare.

Old stands attain heights well over 100 ft. Here, *Bruguiera* tends to be more frequent than *Rhizophora*, and common associates are *Camptostemon schultzii* and *Xylocarpus moluccensis*. The rather open canopy admits sufficient light for mangrove seedlings to survive and, although usually sparse, regeneration in all stages of development can be seen. Apart from mangrove seedlings and saplings the sparse undergrowth consists of *Acanthus*, *Acrostichum*, *Nypa*, and ?*Crinum*. Small epiphytes are locally common and comprise *Hoya*, *Dischidia*, *Myrmecodium*, orchids, and occasional ferns.

The surface layer of mud has a relatively firm clayey foundation and, apart from the huge multi-branched stilt roots of *Rhizophora* and the pneumatophores and buttresses, to 3 ft high and wide, of *Bruguiera parviflora*, the forest is rather easy to walk through. A sharp snapping sound of molluscs closing their shells breaks the silence.

Along the tidal creeks trees are locally killed by ring-barking and the crab mounds are gardened. The increased light causes an enormous increase in abundance of *Acrostichum* and *Acanthus*.

With increasing freshwater influence, genera such as *Brownlowia* and stilt-rooted *Myristica* appear. In situations transitional to freshwater swamp forest the mangroves do not regenerate any longer.

Circular gaps in the canopy of mangrove forest are locally clearly visible on the air photographs, notably towards the coast. Seen from a helicopter they appear to have pyramidal groups of mangrove regeneration underneath. The occurrence is similar to that described for the Safia–Pongani area (Paijmans 1967).

Mangrove trees bordering creeks are tallest, probably as a result of better drainage. Away from creeks the height gradually drops. Lower growth of mangrove in the east of the survey area is probably climatic, i.e. due to seasonality and lower rainfall.

(2) *Small-crowned Mixed Swamp Forest*.—This rather monotonous type of swamp forest covers vast areas in the Purari delta. It is flooded regularly by fresh water from the maze of creeks and tidal channels as the water in these is backed up by the incoming tide.

In appearance, particularly in the aerial photographs, the type resembles mangrove forest and the term "freshwater mangrove" which is sometimes used (Austen 1938) is appropriate.

The canopy of small-crowned trees is rather open (with a closure of about 50%) and about 80 ft high. Emergents, e.g. *Calophyllum* and a deciduous *Palaquium*, reach 100 ft. The lower storeys are usually open. In canopy and lower storeys, trees of the Lauraceae family are remarkably well represented; common also are Myristicaceae, *Campnosperma*, *Syzygium*, *Diospyros*, and *Intsia*. Towards the coast emergent

Camptostemon, *Heritiera*, and lower *Brownlowia* become frequent. The undergrowth commonly consists of dense *Mapania* sedge to 7 ft tall. Locally sago or *Pandanus* dominates the lowest tree storey and excludes all undergrowth. Thin woody, fleshy, and ferny climbers are common and comprise *Flagellaria*, *Pothos*, and *Stenochlaena*. Stilt roots, pneumatophores, and surface roots are very common.

Within the mixed swamp forest, *Campnosperma* and also a stilt-rooted *Calophyllum* species occur in pure dense mid-height small-crowned stands of limited extent. *Campnosperma* stands were only seen from a helicopter; however, a *Calophyllum* stand was visited in the field. The well-closed canopy is about 80 ft high; lower storeys are open and consist of *Calophyllum* trees of various ages. Tall *Mapania* and locally *Hanguana* form a dense undergrowth. Climbers, apart from *Stenochlaena* fern, are very scarce. Girths of canopy trees are very uniformly between 3 and 4 ft. Apart from the numerous large stilt roots, *Calophyllum* develops a great number of small adventitious roots. They probably develop during inundation and later shrivel.

Towards the coast the mixed swamp forest grades into mangrove; inland tall sago becomes increasingly frequent.

Where conditions of drainage and/or aeration are less favourable, trees become lower and more scattered. Pandans, also low sago, are abundant and the swamp forest degrades into swamp woodland. In non-tidal basins with stagnant or very sluggish water a further degradation to herbaceous swamp is observed.

Along the creeks, *Sonneratia caseolaris* with lanceolate leaves and also occasional *Bruguiera* penetrate for miles inland, probably pointing to far-reaching brackish influence.

(3) Octomeles–Artocarpus.—*Octomeles sumatrana* and *Artocarpus altilis* are the dominant species in pioneering forest on river banks and scrolls in Terapo, Tauri, and Hepea land systems. The vegetation pattern on scrolls reflects their topography and periodic colonization by trees. The trees grow in from two to four narrow concentric successively older bands on the slightly higher ridges, smoothly parallel to the curve of the scroll, each band consisting of individuals of equal age. The depressions in between the rims of trees are unforested and bear a vegetation of tall Marantaceae and gingers.

The quick-growing *Octomeles* usually tops the *Artocarpus*; surviving individuals eventually reach heights well over 100 ft, whereas *Artocarpus* does not normally exceed this height. Lower associates are *Macaranga* and *Ficus*. The undergrowth commonly consists of ferns, e.g. *Cyclosorus*, also *Athyrium*. Climbers, particularly *Mucuna novoguineensis* and also *Piper*, are very common and often completely overgrow and smother the *Octomeles* trees, using the horizontal branches as convenient pegs.

The forest is an intermediate stage in the seral development from tall *Saccharum robustum* grass to tall mixed forest on alluvial plains. Normal development is commonly interrupted and disturbed by shifting cultivation (banana gardens).

(4) *Small- to Medium-crowned Basin Forest* (Plate 6).—This forest type is rather irregular in tree height and canopy closure. The canopy consists of small- to medium-crowned and occasional large-crowned trees and varies in height between 70 and 100 ft, the average height being 85–90 ft. Gaps in the canopy, often large, are common. Emergents may reach 145 ft, but their average height is 115 ft. The lower tree storeys

are moderately dense to dense; sago occurs in places. Boles are generally straight, but not uncommonly crooked and low-branched (e.g. *Vitex cofassus, Pterocarpus indicus*). The cover of the shrub layer is very variable, depending on canopy closure, but averages 40 %. The visibility is poor to moderate. The herb layer is very irregular and patchy, but has an average cover of only 5 % or less.

The forest is floristically very mixed. Most frequent are the tree genera *Terminalia, Pometia, Pterocarpus, Vitex, Intsia,* and *Endospermum.* Other commonly occurring genera are *Pterygota, Homalium, Cananga, Dysoxylum, Dracontomelum,* and *Teysmanniodendron.*

The habitat is of very poorly to imperfectly drained alluviated basins and back plains. Part of the forests on the back plains of the Vailala River is above average height and crown size and locally reaches the dimensions of tall forest. Basin forest north of Malalaua air strip was found flooded by 2 ft of water with floating *Lemna* on the surface; basin forest north-west of Malalaua, on alluvial clay with alkaline sandy subsoil, is below average in height and also otherwise anomalous because of the absence of rattan and shrub palms.

(5) *Small- to Medium-crowned Hill Forest.*—Except on steep slopes this forest is fairly regular in tree height and closure. The canopy of small- to medium-crowned trees is 70–90 ft, on average 80 ft high. Emergents occasionally reach 130 ft and average 110 ft. The lower tree storeys are moderately dense to open. Boles are usually straight. The shrub layer is very variable: open to moderately dense, with an average cover of 35 %. Gesneriaceae, chiefly *Cyrtandra,* are locally very common. In the east of the survey area, a species of *Maniltoa* is common in the shrub layer and lowest tree storey. Visibility is generally moderate. The irregular and patchy herb layer has a cover that is generally below 5 % and often below 1 %, and consists of seedlings, ferns, *Selaginella, Elatostema, Dianella,* and occasional sedges and grasses (e.g. *Leptaspis*).

The floristic composition of the forest is extremely mixed; nowhere was one particular species found even approaching dominance. Frequent tree genera are *Pometia, Pterygota, Cryptocarya,* and *Celtis*; also fairly common are *Koompassia* (Plate 9, Fig. 2), *Homalium, Parastemon, Canarium, Mastixiodendron, Buchanania, Dysoxylum, Xanthophyllum,* and *Anisoptera.* Tree palms are locally common, often as high as the canopy or even emergent.

In response to the marked dry season, deciduous trees, particularly *Terminalia* sp., become more common in the east of the survey area, notably in the hills around Putei and Hauta; also *Celtis* increases in frequency.

(6) *Very Small-crowned Hill Forest.*—In this forest, canopy trees are about 60 ft tall, very small-crowned, straight-stemmed, and of small to moderate girth. Occasional emergents reach 80 ft. Trees of 5 ft girth and over are very rare. Lower tree strata are moderately dense to open. The shrub layer has a cover of 20–40 % and visibility is moderate to good. A common shrub is *Maniltoa*; other locally common genera in the shrub layer are *Croton, Psychotria,* a small-leaved *Garcinia,* and a tall herb, *Amorphophallus.* The very scarce herb layer is formed by seedlings, grasses, sedges, and a locally common ginger, *Curcuma.*

Locally common tree genera include *Neonauclea, Intsia, Protium, Garuga, Vitex,* and *Pleiogynium*, and old individuals of *Melaleuca argentea* also occur scattered throughout the forest.

The habitat is low hills of Hauta land system, particularly in the drier east, and gently undulating country of Olipai land system east of Hauta.

(7) *Upland Forest*.—The generally well-closed canopy at a height of 85 ft consists of predominantly small-crowned trees. Larger-crowned, scattered emergents average 100 ft, and very occasionally (e.g. *Koompassia*) reach 130 ft. Lower tree storeys are moderately dense to open. The stem form is straight. Trees of large girth are somewhat scarcer than in hill forest. The shrub layer is generally open, and visibility moderate to good. At higher altitude stilt roots are locally common, and mossy epiphytes come into prominence. On steep and rocky slopes the forest is open and many trees are bent at their bases. Increased light favours the growth of climbers, which become more common.

The forest is extremely complex in composition. In the lower part of the zone *Alstonia*, *Pometia*, *Pterygota*, and *Dysoxylum* were found fairly common throughout; *Terminalia* spp., also *Celtis*, are frequent in the east. At higher altitude *Elaeocarpus* and *Sloanea* are fairly common, and *Castanopsis* appears.

A very large proportion of the upland forests is old secondary. In the field the secondary nature may be indicated by lower-than-average tree height, irregular structure, more climbers, and the presence or above average frequency of such tree genera as *Albizia*, *Elmerrillia*, *Rhus ?taitensis*, and (probably planted) *Terminalia kaernbachii*.

(8) *Lower Montane Forest*.—The canopy of lower montane forest is 65–75 ft high. Emergents reach 90 ft. Lower tree storeys are moderately dense to dense. The shrub layer consists of a very large number of slender individuals with poorly developed side branches and relatively little foliage. Visibility is moderate to poor. Apart from mosses which locally form a nearly complete ground cover, the herb layer consists of ferns, seedlings, *Elatostema*, some *Begonia*, and sedges, etc. The uneven ground surface with many hollows and moss-overgrown fallen branches and logs, in combination with the many shrubs, makes walking through the forest difficult. Old trees have many thick crooked dead or dying branches, and dead stumps of broken trees apparently stay upright for a long time.

On the highest ridge crests and plateaux the lower montane forest is lower, probably due to exposure, and has a very small-crowned and dense canopy.

Some of the more frequent tree genera are *Dryadodaphne*, *Nothofagus*, *Schizomeria*, *Syzygium*, *Podocarpus*, *Elaeocarpus*, *Sloanea*, *Papuacedrus*, *Castanopsis*, and *Lithocarpus*. In the shrub and lowest tree stratum *Polyosma*, *Garcinia*, *Dacrydium falciforme*, and Monimiaceae, e.g. *Levieria*, are well represented. *Nothofagus* is common on ridges but the trees are usually old and dying and no regeneration was seen.

Forest destruction through shifting cultivation has been and is on a large scale and virtually no undisturbed forest is left, for even very steep slopes are not spared (Plate 8, Fig. 1). Patches of older forest commonly show signs of ring-barking and cutting of trees, poles, and shrubs.

Forest regrowth usually is a densely closed regular forest of even height, dominated by *Castanopsis* but with a host of associates, e.g. *Nothofagus*, *Syzygium*, *Euodia*, *Calophyllum*, *Elaeocarpus*, *Eurya*, *Podocarpus*, *Lithocarpus*, *Finschia*, etc., and at lower altitude *Elmerrillia*. The *Castanopsis* trees commonly have a larger girth and crown than the accompanying genera. It must be concluded that they grow more quickly, possibly because of coppicing from old stumps. The number and variety of orchids are astounding; most are epiphytic but some are terrestrial.

More intensive cultivation leads to development of patches of *Imperata* or *Miscanthus* grassland, and garden regrowth in which tree ferns and clumps of bamboo are conspicuous.

(9) *Mixed* Casuarina *Forest*.—This forest has an open to fairly well closed canopy of *Casuarina papuana* at 70–80 ft. It occurs on limestone pinnacles in Saw land system on a lower montane plateau in the north (only seen from helicopter), and on top of the Saw Mountains at about 2000 ft above sea level.

Among the lower trees are *Dacrydium*, *Neonauclea*, *Grevillea glauca*, and *Psychotria*; and *Amaracarpus* is a common shrub. The presence of *Grevillea glauca*, a tree prominent in savannah, seems to point to temporary moisture stress.

On the Saw Mountains the forest in depressions and dolines between the pinnacles contains no *Casuarina*, and comprises huge trees of *Koompassia*, *Lagerstroemia*, and others.

(10) *Semi-deciduous Forest*.—This forest, probably largely deciduous in the dry season, has a canopy at 60–70 ft and emergents to 90 ft. It occurs in the east fringing lower foot slopes of hills, and adjacent to *Melaleuca* swamp savannah. *Pterocarpus indicus* with wide crowns and crooked branchy boles is commonly dominant in the canopy. Among the other tree genera are *Planchonia*, *Ficus*, *Alstonia*, and *Neonauclea*. The lower tree storeys are open. Palms are common and include *Licuala*, *Caryota*, and *Livistona* which is often gregarious. Rattan is locally abundant. The undergrowth has a variable cover and may be dense where it consists of tall gingers and Marantaceae or, locally, tall *Thoracostachyum*. *Cordyline* is of common occurrence.

(iii) *Tall Forest*

(1) *Medium- to Large-crowned Mixed Swamp Forest*.—This forest has a very open and irregular canopy 100–110 ft high, and widely scattered emergents up to 130 ft tall. Where the type was visited, i.e. in the coastal region, the commonest emergent trees are *Nauclea* and, near the margins, also *Neonauclea*. Frequent in the canopy and in the rather open lower strata are *Pterocarpus indicus*, *Planchonia papuana*, and *Terminalia canaliculata*. The lowest tree storey consists mainly of sago with a variable cover between 30 and 70%. Patches of *Hanguana* occur in the undergrowth.

The habitat is permanent non-tidal freshwater swamp, extensive areas of which occur in the north-west.

(2) Campnosperma *Swamp Forest* (Plate 4, Fig. 1).—In structure this forest is very similar to mixed swamp forest. *Campnosperma* is the predominant tree genus. The canopy is somewhat more even, and emergent *Campnosperma* trees are 110–120 ft tall. Sago and locally also *Pandanus* are prominent in the lowest tree storey. The usually dense undergrowth consists of patchy tall *Thoracostachyum* and *Hanguana*,

mixed with ferns. Climbers are very common to abundant and include *Freycinetia*, *Stenochlaena*, and *Nepenthes*. *Campnosperma* is well equipped with buttresses (up to 4 ft high and 1 ft wide), stilt roots, and kneed pneumatophores.

Two species of *Campnosperma* occur, *C. brevipetiolata* and *C. coriacea*, as far as could be ascertained with about equal frequency. *Campnosperma* regenerates well, though rather irregularly and in groups. Scarce associated tree genera include *Palaquium*, *Syzygium*, and *Terminalia*; locally common lower tree species are *Gynotroches axillaris*, *Schuurmansia elegans*, *Alstonia spatula*, and *Rhus* sp.

The habitat is similar to that of mixed swamp forest.

Gregarious occurrence of *Campnosperma* is readily recognized on aerial photographs by its rather smooth even greyish pattern of broad umbrella-shaped crowns. Since the twigs with large whorled leaves are evenly spread over the crown surface, the large almost horizontal main branches do not reflect a star-shaped appearance on the photograph.

(3) *Large-crowned Forest* (Plate 6, Fig. 1).—The canopy of this forest is irregular in closure and tree height and usually has many gaps. Emergents and most canopy trees have large crowns. The average height of the canopy is 100–115 ft, emergents reach 150 ft. Lower tree strata are moderately dense, often also rather open. In poorly drained situations, pandan and sago are locally common and pneumatophores often conspicuous, notably those of *Intsia*. The stem form is generally straight, sometimes low-branched and crooked. The shrub layer is very variable in cover and density but generally moderately open to open. Locally, high Marantaceae form a dense cover. Visibility, generally moderate, varies from poor to good. The cover of the irregular and patchy herb layer is 5–10% on the average, but locally much higher. It is very mixed, mainly composed of ferns and seedlings, also Araceae, and often with local abundance of *Elatostema*, *Selaginella*, gingers, Commelinaceae, and others. Palm seedlings, particularly those of rattan, not rarely form an important part of the herb layer. Where shrub palms are abundant the herb layer is absent.

The species composition is very mixed. Frequent tree genera are *Pometia*, *Octomeles*, *Dracontomelum*, *Canarium*, *Dysoxylum*, and *Terminalia*; other common genera include *Pterocarpus*, *Cananga*, *Celtis*, *Sterculia*, and *Elaeocarpus*.

Some genera, e.g. *Octomeles* and *Pometia*, also *Cananga*, show marked local increases in frequency. Local dominance of *Octomeles* or *Pometia* could indicate previous disturbance. It is likely that the copious fruiting and the often abundant regeneration of *Octomeles* in the open, and of *Pometia* in closed, forest, contribute to later dominance. On old beach plains near Malalaua, a *Celtis–Dracontomelum* facies was observed with *Terminalia* and *Syzygium* co-dominant.

The habitat is stable level imperfectly to well drained alluvial and beach plains, partly subject to occasional flooding, in Hepea and Malalaua land systems. Over large areas, particularly in the coastal region, the original forest has been replaced by grassland, coconut plantation, garden regrowth, and secondary forest (Plate 3, Fig. 1).

(4) *Open Large-crowned Forest*.—This forest is rather similar in structure to the type described under (3) above. The main differences are that the canopy is very open and has large gaps, and that emergents are lower and more widely spread. Further minor structural differences are that the canopy is slightly lower, the shrub

layer denser, and the herb layer sparser. Climbers, including rattan, also shrub palms, are more common. Tall ?*Mapania* sedge locally features in the undergrowth.

Apart from the tree genera mentioned under (3) above, *Chisocheton*, *Alstonia*, *Planchonia*, and *Vitex* are frequently found; *Pometia* and *Celtis* are less common.

The habitat is unstable flood-plains liable to flooding and with imperfectly to very poorly drained soils, in Tauri land system.

(5) *Medium- to Large-crowned Hill Forest*.—This forest is structurally and floristically related to mid-height small- to medium-crowned hill forest, but differs from this in greater average height and more variability in height and crown sizes of canopy and emergent trees. The canopy is about 100 ft high. Emergents are between 110 and 130 ft tall, but occasionally reach 145 ft. The other structural characteristics are very similar to those of mid-height small- to medium-crowned hill forest.

The floristic composition is extremely rich. Most frequent are *Pometia* and *Terminalia*. Relatively numerous are *Celtis*, *Homalium*, *Pterocymbium*, *Dracontomelum*, and Myristicaceae, but many other genera have an equal or only slightly lower average frequency. *Pometia* and less often *Celtis* and *Mastixiodendron* are locally subdominant. East of Kerema, a *Pometia–Celtis–Terminalia* variant was seen.

Tall medium- to large-crowned hill forest is of local occurrence in all hill land systems below 1000 ft, notably in Maipora and Lohiki land systems and near Kerema, also in Hauta land system. It is the usual forest type on gentle foot slopes where it is floristically and structurally transitional to tall large-crowned forest of the plains. It also occurs on moderate slopes and small level areas within the hills, occasionally on crests and steep upper slopes.

VI. Ecology

The most important vegetation-controlling factors in the Kerema–Vailala area are soil, water, climate, and man. As regards climate, two separate trends must be kept in mind, i.e. a south–north gradient relative to increase in altitude, and a west–east gradient caused by differences in amount and distribution of rainfall. In the following sections, vegetation types and their interrelationships are discussed for each major environment. Modifications caused by climatic gradients are mentioned under each environment. Man's impact on the various vegetation types is dealt with in a separate section.

For the non-hilly areas, where vegetation types correspond with land systems, relationships between vegetation types and their connexion with habitat are shown on the land system map and in the plan diagrams of the land system tables.

(*a*) *Saline Swamp Environment*

In habitats flooded daily by salt water, mangrove is found. *Sonneratia caseolaris* and *Avicennia marina* form the pioneering stage wherever the major rivers deposit large quantities of silt. Thus, mangrove stands of these species are best developed in the mouths of the Purari delta rivers, commonly fronting the sea. In Kerema Bay they occur in the mouth of the Karabure River, the other rivers that discharge in Kerema Bay being much shorter and not carrying large loads of silt. In the east, *Sonneratia* is only found as very small stands on low river banks, scrolls, and islets. On upper tidal flats *Avicennia marina* is restricted to the landward side of the mangrove, where it is the sole species able to grow under extreme saline conditions brought about by constant evaporation and salt accumulation during the dry season.

Rhizophora is either a pioneer genus in its own right or invades *Avicennia–Sonneratia* stands and, at a later stage, takes over and becomes mixed with *Bruguiera*. *Bruguiera* seems to have its optimum in a less saline environment, and to landward mixed *Rhizophora–Bruguiera* stands tend to be dominated by *Bruguiera*. The largest areas of tall and pure stands of *Rhizophora–Bruguiera* are found in the Kerema embayment where tidal salt water influence, not hampered by discharge of very large amounts of fresh water, penetrates to near the hills surrounding the estuary. Over large areas of upper tidal flat the mangrove forest seems to have reached a stable edaphic climax, in equilibrium with the environment as long as the level of the ground does not rise above the level of daily tidal flooding.

In the Purari delta the *Rhizophora–Bruguiera* zone is relatively narrow, commonly mixed with *Nypa*, and not far inland grading into freshwater tidal swamp forest.

In the east, tidal influence does not reach far inland owing to steeper gradients, and no extensive areas of mangrove occur. The mangrove is lower, probably because of water stress in the dry season due to high evaporation, possibly also because of sandy substrata (the air-photo pattern shows a number of beach ridges within the mangrove). *Rhizophora* seems to be more prominent than *Bruguiera*, and patches of *Avicennia* occur on degraded beach ridges. Fairly large complexes of *Rhizophora–Bruguiera* forest are found north of the mouth of the Tauri River and south-east of the Lakekamu River; around the lower Lakekamu River itself there is no proper mangrove, and brackish mixed mangrove swamp woodland reaches to the coast.

(*b*) *Brackish Swamp Environment*

Nypa palm is common in the brackish transition zone between mangrove and freshwater vegetation types. *Nypa* is very extensive in the Purari delta, although normally mixed with mangrove, and of minor importance in the Kerema embayment, where it occurs only to the north against the hills. A fairly large and pure stand is found south of the mouth of the Tauri River.

The other major vegetation type in brackish environment is mixed mangrove swamp woodland, a mixture of mangrove, freshwater tree species, sago, and pandan. The largest occurrence is around the mouth and lower reaches of the Lakekamu River.

For the purpose of land use planning it may be important to know the extent of the brackish zone. Where *Nypa* occurs in pure patches this is easily done by air-photo interpretation. Thus, in the Purari delta, the presence of *Nypa* was the main criterion in interpreting a boundary between mangrove and tidal freshwater swamp forest, which, like mangrove, has a dark-toned photo aspect and only slightly larger average crown size. Where *Nypa* only lines creeks in bands too narrow to be discernible on air photos, other photo characteristics must be used, e.g. groups of small-crowned usually dark-toned mangrove trees in open mixture with larger-crowned often lighter-toned freshwater species. Increasing frequency of sago palm often helps in establishing a boundary.

(*c*) *Freshwater Swamp Environment*

Tidal freshwater swamp forest occurs only in the Purari delta. Daily flooding takes place near the coast, but decreases in intensity and frequency inland and away from creeks, and is probably only occasional in the furthest reaches about 20 miles inland. Here, non-tidal tall *Campnosperma* and mixed swamp forest occur, and on higher ground tall alluvium forest. Under less favourable conditions a lower more open swamp woodland develops. In central parts with stagnant water outside tidal reach, the forest degrades to herbaceous swamp through a belt of swamp woodland.

As the mangrove moves further out to sea, it is likely that the southern boundary of the freshwater swamp forest will shift southwards with decreasing saline influence. To the north, decreasing swampiness might cause alluvium forest to move southwards.

The eastern counterpart of the tidal freshwater swamp forest of the west is seasonally flooded *Melaleuca* swamp savannah. Like the western tidal swamp forest, *Melaleuca* swamp savannah has a forest facies with rather dense often tall *Melaleuca* trees, and a woodland facies with lower widely scattered trees. In the undergrowth of the forest facies, *Phragmites*, which is rare in the west, is more prominent than sago. A similar undergrowth of *Thoracostachyum*, *Hanguana*, and very low sago features in the woodland facies. Under the least favourable conditions herbaceous swamp develops, in the east more purely herbaceous and with fewer shrubs and trees, and also partly semi-permanent.

Although *Melaleuca* commonly forms pure stands, its recognition on air photos is thwarted by great variability in density, height, crown size, and photo tone. Bordering *Avicennia* scrub, similar in photo tone, is distinguished by its lower height and denser canopy of small crowns.

The air-photo pattern, confirmed by helicopter reconnaissance, suggests that *Melaleuca* disappears somewhere halfway between Kukipi and Kerema. In the absence of rainfall figures the decreasing frequency and subsequent disappearance of *Melaleuca* have been assumed to mark the gradual change from "dry" to "wet".

(*d*) *Riverine Environment*

The main factors influencing vegetation on river banks are frequency of flooding as a function of the height of the river bank, and nature of the water, i.e. brackish or fresh. Since river-bank height increases inland together with freshwater proportion of the flood-water, the two influences cannot be clearly separated.

Sonneratia caseolaris with lanceolate leaves in small low pure stands occupies the lowest river banks, islets, and scrolls in the mouths of the larger rivers. The habitat is frequently flooded with brackish water, and *Sonneratia* is commonly associated with *Acrostichum* and *Acanthus*. Smaller rivers and tidal creeks with practically no river banks are lined with *Nypa*, and here *Sonneratia* only occurs on small scrolls. Landward on slightly higher banks *Pandanus* appears, followed by *Phragmites*. The three can often be found together, each commonly in small pure stands, rarely mixed. Still further upstream, scrolls are pioneered by *Saccharum robustum*.

At the level where *Pandanus* occurs at the water's edge, *Artocarpus* also makes its appearance on top of the banks. The environment, only little above high-water mark, is very different from the mangrove-dominated swamp behind. With slight increase in bank height, *Artocarpus* is joined by *Octomeles*, upstream increasing in frequency. Where *Saccharum robustum* occupies the scrolls, proper *Octomeles–Artocarpus* forest develops behind it. In the transitional stages from *Octomeles–Artocarpus* forest to tall mixed forest the frequency of *Octomeles* seems to drop more quickly than that of *Artocarpus*, possibly because *Octomeles* is more liable to be smothered and killed by climbers, notably *Mucuna novoguineensis*.

The above-mentioned sequences can be observed in both the east and the west. However, along the Tauri River, *Sonneratia* goes no further upstream than Terapo, whereas along the Purari River its occurrence was noted much further inland.

Forest vegetation along river banks reflects the different nature of the major rivers. The gradual transition from mangrove through tidal freshwater swamp forest and sago palm vegetation to tall open and moderately closed forest reflects the low gradient of the Purari River. Along the Tauri and Lakekamu Rivers, one passes from mixed mangrove swamp woodland and sago palm vegetation into a vegetation type intermediate between swamp woodland and tall very open forest, full of patches of herbaceous swamps in oxbows and other low-lying areas. This vegetation complex stretches for 10–12 miles along both rivers, then grades into tall open forest. Its presence is thought to be linked with instability of the land caused by great changes in water level and frequent seasonal flooding. Along the more stable Vailala River, which is not subject to such large fluctuations in water level, tall forest covers the banks to near the mouth.

(*e*) *Plains*

Tall large-crowned forest, similar in structure and floristics throughout except for a larger proportion of deciduous trees in the east, is the natural vegetation on imperfectly to well-drained plains, be they alluvial, alluviated, or sandy. On beach plains the vegetation often reveals or accentuates a pattern of degraded beach ridges, which generally escapes notice in the field but gives a useful clue in photo-interpreting the boundary with alluvial plains. Around Malalaua the presence was noted of *Pluchea indica* and *Hibiscus tiliaceus*, indicative of a former coastal environment.

(*f*) *Hills and Mountains*

With increasing altitude, hill forest gradually changes into upland forest which in turn grades into lower montane forest. Forest-type boundaries have been mapped on photo aspect, which shows a change around 1000 ft from the hill forest type with a canopy rather uneven in height and crown sizes, to the upland forest type with a more even canopy of predominantly small crowns. Similarly, around 3000 ft there is a change to the smoother smaller-crowned generally darker-toned lower montane forest type. A gradual change in floristics accompanies structural changes.

Water stress in the dry season presumably accounts for the presence of extensive very small-crowned forest of below average height, and minor *Melaleuca argentea* savannah, in the hills north of Malalaua.

The proportion of deciduous trees in the eastern hill and basin forests is markedly above average, and the crests of hill ridges north of Putei show evidence of extensive burning. Locally, the forest may well be semi-deciduous for a short period in the dry season. However, with all trees in leaf, the view from the air is no different from that of evergreen forest.

A species of *Maniltoa* in the shrub and lowest tree stratum is frequent in presumably seasonally dry forest, and absent or rare in wetter forest. Its distribution pattern as reconstructed from field observations has contributed to establishing approximate climatic boundaries. *Cycas*, a common savannah genus, is not a reliable indicator of dryness, as it also occurs in non-dry forest. However, its increased frequency in drier environment is a helpful contributory indicator.

(g) *Human Influence*

Man's impact on the natural vegetation is severest in the coastal region, where virtually all littoral woodland and large portions of the beach plain forests have been converted to coconut plantation, garden, and grassland. Grassland is particularly common in the east, where the effect of burning is more severe owing to seasonal dryness.

Mangrove, *Nypa*, swamp forest, and swamp woodland are little affected by human action. Along tidal creeks, *Nypa* vegetation and mangrove forest are locally cleared and gardens made on the crab mounds. Coconut is planted only just above high-water mark on crab mounds and ridges within the mangrove, and apparently thrives (Plate 1, Fig. 2).

In the east, semi-permanent herbaceous swamp and *Melaleuca* swamp savannah, including sago undergrowth, are regularly burnt in the dry season.

Extensive gardening is practised on river banks, even where these are very low. *Saccharum* grass and *Octomeles–Artocarpus* forest are cleared and the area planted to banana, which is apparently little affected by flooding of short duration.

Forests of the lower hills have remained relatively undisturbed. There is a tendency for the mountain-dwelling Kukukuku population to descend and open up new areas lower down.

The lower montane forests have suffered severely. The seemingly sparse Kukukuku population largely lives in isolated groups of a few huts all along the ridges, and from there practises very widespread shifting cultivation. Fortunately the wet climate makes burning less disastrous. Abandoned gardens quickly become covered with forest regrowth, notably *Castanopsis*, but normally common genera such as *Mallotus*, *Macaranga*, and *Saurauja* are rare. There is little evidence of erosion, except on ridges. On denuded ridges, also near streams as a result of more frequent gardening, patches of more or less permanent grassland of *Imperata* and *Miscanthus* develop.

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PART IX. FOREST RESOURCES OF THE KEREMA–VAILALA AREA

By K. Paijmans* and R. Pullen*

I. Introduction

Forest of various types covers 82% of the area. Generally, the forest with the highest timber volume occurs on rather limited areas of well-drained plains and foothills, notably along the Tauri River. Areas of very poorly to imperfectly drained alluviated basins, particularly large along the Vailala River, have a moderately high timber potential but would require costly road development if they were to be exploited by tractor and truck haulage. Forest on the beach plains, basically of good quality, has suffered much from interference by the local population.

Approximately 30% of the forested area occurs in rugged terrain with slopes exceeding 30°; it is unsuitable for timber exploitation, and lies largely above 1000 ft altitude. The forests on hills below 1000 ft have moderate timber potential, and generally these areas have been much less affected by clearing for shifting cultivation than the upland and lower montane forests above 1000 ft, which in any case are difficult of access for normal exploitation.

Logging has been and is being carried out on a very limited scale and consists of levee bank exploitation along the Vailala and Tauri Rivers. A sawmill at Moveave takes in logs floated down the Tauri River from a timber permit area near Hauta. An intermittently operating band-saw at Ihu turns out a small amount of sawn timber for the local market; logs are floated down the Vailala River from a timber permit area some 10 miles upstream.

Earlier reconnaissance in the area has been carried out by Lane-Poole (1925), who travelled up the Purari River and also to a point above the Ivori junction up the Vailala River. He measured nine strips totalling 180 ac parallel, and at right angles, to the river, and found an average timber volume of 383 cu ft per acre. He further reports, "... it was found that the good timber was all close on to the river, and the traverses cut at right angles to the course all carried very inferior trees. The country either became swampy—this was usually the case on the lower reaches—or it became hilly, as was the case higher up. In both cases the quality degenerated, and the number of trees to the acre decreased". Tree species listed as frequent by Lane-Poole were found to be so during the present survey with the exception of *Pentaspadon motleyi* which was not recorded.

A forestry patrol report (E. C. G. Gray, unpublished data, 1956) deals with a timber reconnaissance survey of an area of 27,000 ac on both sides of the Tauri River north of Rim Ridge and up to the junction of the Tauri and Kapau Rivers. The forests on the levee banks, 3% of the total area surveyed, are reported to have a (visually) estimated timber volume of 10,000 super ft per ac, of which *Octomeles* and

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TABLE 12

ESTIMATED NUMBER OF STEMS AND VOLUME (SUPER FT/AC) BY TIMBER QUALITY GROUP AND GIRTH CLASS FOR EACH FOREST TYPE

Timber Quality Group	Girth Class (ft)	Forest Type																			
		Tall Large-crowned Forest (Tauri River)		Tall Large-crowned Forest (Elsewhere)		Tall *Campnosperma* Swamp Forest		Basin Forest		Medium-quality Hill Forest		Good-quality Hill Forest (SE. of Kerema)		Good-quality Hill Forest (Near Ivori River)		Poor-quality Hill Forest		Very Poor-quality Hill Forest		Lower Montane Forest	
		No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.	No.	Vol.
1	5–6	2	1100	1	440	—	—	<1	270	<1	120	—	—	<1	260	—	—	—	—	—	—
	7+	1	600	<1	420	—	—	<1	200	<1	80	—	—	—	—	<1	450	—	—	—	—
	5+	3	1700	1	860	—	—	<1	470	<1	200	—	—	<1	260	<1	450	—	—	—	—
2B	5–6	—	—	—	—	—	—	—	—	<1	60	—	—	—	—	<1	120	—	—	—	—
	7+	—	—	—	—	—	—	—	—	<1	50	—	—	—	—	—	—	—	—	—	—
	5+	—	—	—	—	—	—	—	—	<1	110	—	—	—	—	<1	120	—	—	—	—
3	5–6	—	—	1	450	<1	310	<1	80	1	380	—	—	<1	310	<1	330	—	—	—	—
	7+	—	—	<1	400	—	—	1	1380	<1	690	—	—	4	6560	<1	740	—	—	—	—
	5+	—	—	1	850	<1	310	1	1460	1	1070	—	—	5	6870	1	1070	—	—	—	—
4A	5–6	1	430	1	600	<1	170	1	610	1	630	—	—	<1	220	1	580	1	740	—	—
	7+	—	—	<1	650	—	—	<1	330	<1	680	—	—	<1	620	<1	680	—	—	1	1730
	5+	1	430	1	1250	<1	170	1	940	1	1310	—	—	1	840	1	1260	1	740	1	1730
4B	5–6	3	1750	4	2490	<1	170	4	2470	3	2060	6	5100	4	2630	3	2280	—	—	1	620
	7+	3	9680	2	3110	—	—	<1	480	1	1250	1	1070	1	2250	<1	150	—	—	<1	350
	5+	6	11,430	6	5600	<1	170	4	2950	4	3310	7	6170	5	4280	3	2430	—	—	2	970
5	5–6	8	4700	3	2110	5	3070	3	2230	4	2290	4	3080	6	3000	3	1710	4	2570	3	2070
	7+	3	7200	1	1910	1	1650	1	1050	2	2370	2	9650	<1	800	<1	990	—	—	2	2160
	5+	11	11,900	4	4020	6	4720	4	3280	6	4660	6	12,730	7	3800	3	2700	4	2570	5	4230
1–5	5–6	14	7980	10	6090	7	3720	8	5660	9	5540	10	8180	12	5820	7	5020	5	3310	4	2690
	7+	7	17,480	3	6490	1	1650	3	3440	4	5120	3	10,720	6	10,230	2	3010	—	—	4	4240
	5+	21	25,460	13	12,580	8	5370	11	9100	13	10,660	13	18,900	18	16,050	9	8030	5	3310	8	6930
Area (sq miles)		10		138		10		212		652		2·5		12·5		341		52		146	
No. of sample plots		12		42		5		28		74		3		5		22		5		7	

Dracontomelum form 50%. Forest on well-drained flat land and hilly country with slopes to 30° is estimated at 3000 super ft per ac with *Pometia, Terminalia, Alstonia,* and *Dracontomelum* forming 65–70% of this volume. On periodically inundated terrain, mainly *Terminalia, Planchonia,* a member of the Rubiaceae, and *Vitex* comprise 70% of the total timber volume estimated at 1500 super ft per ac.

In 1965 the Department of Forests, Port Moresby, carried out a two days' reconnaissance flight by Cessna and helicopter between the Tauri and Vailala Rivers (Hammermaster, unpublished data, 1965).

Sample plot measurements and identification of herbarium specimens for the present survey were done jointly by R. Pullen and K. Paijmans in the field, temporarily assisted by Maru, a very able tree namer, made available by the Department of Forests, Port Moresby. Wood samples have been identified partly by J. C. Saunders, CSIRO, Canberra, and partly by H. D. Ingle, of the Division of Forest Products, CSIRO, Melbourne.

Where appropriate, brief notes on forest potential and accessibility of each land system are given below the relevant land system tabular description.

II. Methods

A preliminary division of the forests into various types was carried out by air-photo interpretation, chiefly based on habitat, canopy closure and height, and crown size. In the field, where an observation site fell in forest at least one and often two or more sample plots were measured. Including additional plots along the Vailala and Tauri Rivers, a total of 212 plots was measured, i.e. 0·005% of the forested area. Each plot was circular with a radius of 68 ft, thus representing one-third of an acre. In measuring the radius no allowance was made for slope. Where the centre of a tree fell within the plot the whole tree was included; if the centre of a tree was on the line, half the tree was included in the plot. Data recorded for each tree with a girth of at least 5 ft at breast height or above buttresses included botanical and indigenous name, girth in whole feet, merchantable bole length, total height to the nearest 5 ft, and form class. Form class was recorded in the categories: A, straight and without visible defect; B, slightly wavy or bent; and C, crooked, hollow, or with bole length less than 10 ft. Trees in the C category were recorded but not measured. For each unknown tree a wood sample and, where possible, leaf material were collected.

From the sample plot data average stocking rates were calculated per forest type and within the type per timber quality group, using a form factor of 0·5. Trees of form classes A and B have been grouped together, those of class C are excluded. In Table 12 numbers of stems and volume have been converted to per acre figures. Several points must be borne in mind:

Figures in Table 12 are very approximate only, in view of the extremely low sampling percentage.

No allowance has been made for hidden tree defects.

Plots have only been measured in forest and no allowance has been made for unforested inclusions within the forest type.

Table 13 lists the tree genera recorded on timber plots with their frequency in each forest type.

TABLE 13

TREE GENERA RECORDED ON SAMPLE PLOTS AND THEIR COMMONNESS OF OCCURRENCE

Occurrence of trees is listed as D (dominant, 50–80%); SD (subdominant, 20–50%); VC (very common, 15–20%); C (common, 10–15%); O (occasional, 5–10%); R (rare, <5%); ( ) (locally)

Botanical Name	Timber Quality Group	Mangrove Forest	Tall *Campnosperma* Swamp Forest	Tall Large-crowned Forest	Open Tall Large-crowned Forest	Basin Forest	Medium-quality Hill Forest	Good-quality Hill Forest	Poor-quality Hill Forest	Very Poor-quality Hill Forest	Upland Forest	Lower Montane Forest
Aglaia spp.	3					R	R		R			
Ailanthus integrifolia	5					R						
Albizia minahassae	5						R					
Aleurites moluccana	5			R			R					
?*Alseodaphne*	5			R								
Alstonia scholaris	5			R	O	R	R		R		O	
Amoora	3					R			R			
?*Amoora*	3						R					
Anisoptera kostermansiana	4B			R			R	R				
Annonaceae	5			R								
Anthocephalus ?*cadamba*	5			R	R	R	R					
Antiaris toxicaria	5			R								
Aphananthe philippinensis	5					R						
Aporosa	5											R
Aquilaria	5						R					
Archidendron	5								R			
Artocarpus	5			R		R	R		R		R	
Astronia	5						R					
Barringtonia	5					R						
?*Beilschmiedia*	5			R								
Bischofia javanica	4B				R							
Bruguiera	4B	SD										
Buchanania ?*macrocarpa*	5			R			R	R	R	O		
Calophyllum	4A			R			R(O)					

Campnosperma brevipetiolata	5		SD									
C. coriacea	5		SD									
C. ?montana	5											R
Camptostemon schultzii	5	C										
Cananga odorata	5			R(C)	R	R	R			R		
Canarium spp.	4B			O		R	R		R			
Cedrela	3			R								
Celtis spp.	5			R		O	O(VC)	R(O)			R	
Chisocheton	5			R	C		R				R	
Chrysophyllum	5						R					
Cinnamomum	4B						R					
Citronella ?brassii	5						R					
Cordia	4B			R	R							
Cryptocarya spp.	5			O		R	O	R	O(C)	R	R	
Cynometra	5						R					
Dillenia ?papuana	4B							R				
Diospyros	3			R		R	R					
Dracontomelum mangiferum	1			O	O	O	R	R	R		R	
Dryadodaphne novoguineensis	5											O(VC)
Drypetes	5			R			R					
Dysoxylum spp.	4B			O	O	C	R(O)	R	O		O	
Elaeocarpus spp.	5			R	R		R			R	R	O
Elmerrillia papuana	3						R	R				
?Endiandra	5			R								
Endospermum	5			R	R	R	R	R			R	
Erythrospermum candidum	5			R								
Erythroxylon	5					R						
Euodia	5						R			R	R	
Euphorbiaceae	5					R	R					
Euroschinus papuanus	5						R					
Ficus	5			R	R		R		R		R	
Flindersia	3			R		R	R		R			
Ganophyllum falcatum	5						R					
Garcinia	4B				R		R					
Garuga floribunda	4A					R	R		R		R	

TABLE 13 (*Continued*)

Botanical Name	Timber Quality Group	Man-grove Forest	Tall *Campno-sperma* Swamp Forest	Tall Large-crowned Forest	Open Tall Large-crowned Forest	Basin Forest	Medium-quality Hill Forest	Good-quality Hill Forest	Poor-quality Hill Forest	Very Poor-quality Hill Forest	Upland Forest	Lower Montane Forest
Gmelina	3						R					
Gnetum	5						R				R	
?*Grewia*	5						R		R			
Heritiera	4B					R						
Homalium foetidum	4A			R		O	O(C)		R			
?Icacinaceae	5											C
Ilex	5			R		R	R					R
Inocarpus	5			R	R							
Intsia bijuga	4A		O	R		O	R		R		R	
Jagera ?*serrata*	5						R					
Kingiodendron	5						R					
Kleinhovia hospita	5			R								
Koompassia	3			R			R(O)	O(C)			R	
Lagerstroemia	5			R							R	
Laportea	5			R								
Lauraceae	5			R			R				R	
Lithocarpus	4B						R					R
Litsea spp.	5			R			R					R
Lophopetalum	5					R						
Macaranga	5					R						
Maniltoa	5					R	R		R			
Mastixia	5					R						
Mastixiodendron pachyclados	5			R		O	R(O)		R			
Mitragyna speciosa	5			R								
Myristicaceae	5		O	R		R	R	R	R			
Nauclea	4B			R	R	R						
Neonauclea	4A			R		R	R		R(C)	R(O)		
Neuburgia	5			R								

Nothofagus	4A											R(C)
Octomeles sumatrana	4B			O(C)	O	R	R	R			R	
Palaquium	3		O	R	R		R					
Pangium edule	5					R						
Parartocarpus	5					R	R					
Parastemon versteeghii	5						O(C)	R	R			
Parinari	5			R		R	R	R				
Pimeleodendron amboinicum	5			R		R	R	R	R			
Planchonella	5							R	R		R	R
Planchonia	4A			R	O	R						
Pleiogynium	5					R						
Podocarpus amarus	2B						R		R			O
P. blumei	2B						R					
Polyalthia	5			R		R	R					
?Polyalthia	5			R					R			
Pometia pinnata	4B			C		VC	O(VC)	R	O(C)		O	
P. tomentosa	4A						R	R				
Prainea papuana	5						R	R				
Prunus	5			R				R				
Pternandra	5						R					
Pterocarpus indicus	3			R	O	O			R			
Pterocymbium	5			R	R	R	R	R				
Pterygota horsfieldii	4B			R		R	O	O	O		O	
P. ?forbesii	4B						R					
Rhizophora	4A	D										
Rhus	5							R		R		
Sapium	5			R								
Schizomeria	5											O
Semecarpus	5			R		R	R					
Sloanea	4B					R	R	R			R	O
Spondias	5			R			R	R				
Sterculia	5		O	R		R	R					R
Syzygium	4A		O	R	O	R	R					R(O)
Talauma	5										R	
Terminalia spp.	4B			O	O	VC(SD)	O(VC)	R	R		O(C)	

TABLE 13 (*Continued*)

Botanical Name	Timber Quality Group	Man-grove Forest	Tall *Campno-sperma* Swamp Forest	Tall Large-crowned Forest	Open Tall Large-crowned Forest	Basin Forest	Medium-quality Hill Forest	Good-quality Hill Forest	Poor-quality Hill Forest	Very Poor-quality Hill Forest	Upland Forest	Lower Montane Forest
Teysmanniodendron bogoriense	5			R		R	R	R	R			
Thespesia ?robusta	3				R	R	R					
Timonius	5						R					
Trichadenia philippinensis	4B			R								
Tristiropsis acutangula	4A			R	R				R			
Vatica papuana	4A			R		R	R		R	R		
Vitex cofassus	4A			R	O	O	R		R		R	
?Weinmannia	5						R					
Wrightia laevis	5						R					
Xanthophyllum papuanum	5			R		R	R	R	R			
Xanthostemon	4A						R					
?Xylopia	5								R		R	
Unidentified No. 259 plot 156							R					
No. 312 plot 192							R					
No. 350 plot 211							R					
No. 369 plot 223							R					
— plot 232							R					

III. Mapping

The combined vegetation and forest resources map shows main vegetation types as well as forest quality types. Where no figure for stocking rate in the legend is given behind a vegetation type, it indicates that the vegetation type is considered unproductive of timber. Mappable areas of secondary forest have the symbol S printed over the colour of the original forest type. In the upland and lower montane zones all secondary vegetation has been given the colour of upland forest, since no air-photo contour mapping was done and separation of lower montane on characteristics of secondary vegetation alone is not possible. Although locally appreciable log volume remains in areas mapped as secondary, notably in the beach plain forests, these areas are considered unproductive because the scattered nature of the forest remnants makes harvesting uneconomic. Similarly, areas mapped as mixtures of forest and grassland are regarded as unproductive.

Because of the intricate pattern of occurrence within the mangrove, no individual communities have been mapped except for one or two stands of nearly pure *Avicennia.*

For practical purposes, scattered small patches of mixed *Casuarina* forest have been joined and mapped in two minor areas on top of the Saw Mountains and one larger complex on a plateau in the lower montane zone.

A very small-crowned facies of lower montane forest occurring on the highest crests and plateaux has been mapped separately.

IV. Access Categories

The system of classification used in the Bougainville report (Saunders 1967) has been followed. The area has been divided into three major access categories on the basis of dominant slope 0–10°, 10–30°, and over 30°. The first two major categories have been further divided into four and two categories respectively, thus giving seven categories in all (see access category map).

Category Is includes all land with slopes less than 10°, either permanently inundated or subject to frequent or prolonged seasonal flooding. It comprises the freshwater and tidal swamps and covers 20% of the area, mainly in the extreme west and south-east.

Category If includes all land with slopes less than 10° liable to flooding for short to moderate periods. It chiefly comprises the wetter flood-plains (Terapo and Tauri land systems) and occurs mainly along the major rivers. Because of the large percentage of swales and generally poor drainage, Araimiri land system is also included in this category which in total covers 5% of the area.

Category I includes all well-drained land with slopes less than 10°. It comprises the drier alluvial and beach plains (Hepea and Malalaua land systems) and covers 6% of the area.

Vailala land system does not fit in either category I or If. On the one hand, the larger part of the land system is imperfectly to very poorly drained because of abundant run-on water from surrounding hills. On the other hand, considerable portions are not liable to flooding. The land system has been given a separate colour on the access category map. It covers 6% of the area.

Category Ia includes all land with dominant slopes less than 10°, but with up to 20% of slopes exceeding this angle. It comprises the land systems of gentle and low moderate slopes (Olipai and Hauta). The category is scattered throughout the foothills, covering 5% of the area.

Category II, which includes land with a slope of 10–30°, does not occur as such, but a number of land systems fall within IIa, which includes land with a dominant slope of 10–30° but with up to 20% of the slopes exceeding 30°. Category IIa comprises the land systems Kwambega, Bananu, Kurai, Lohiki, Putei, Aro, and Nabo. In Aro and Nabo land systems over 20% of the slopes exceed 30°, and strictly speaking they would fall in the next higher category. However, the presence of an appreciable proportion of alluvial flats and gentle slopes in Aro land system, and fairly easily accessible parallel U-shaped valleys in Nabo land system, justify inclusion in category IIa. The category covers 22% of the area and mainly fringes the central high hills and mountains.

Category III includes all land with a dominant slope angle greater than 30°. It comprises Maipora, Saw, Kapau Complex, and Eruki land systems, covers 35% of the area, and has its main occurrence in the central high hills and mountains.

Slope descriptions for the land units have served as the basis for assessing the access categories. In accordance with the topography of the dominant land unit, whole land systems have been made to fall within one category, and consequently the resulting map gives only a rough indication of the accessibility to and within forest types. For detailed information on terrain parameters the reader is referred to the tabulated land systems.

It should be noted that accessibility is considered generally within the land system and regardless of the surrounding land systems.

In the swamp forest types, access other than by the main waterways is difficult, due to permanent swampiness or frequent flooding.

Considerable tracts of forest on plains and alluviated basins are rather difficult of access because of seasonal near-swampiness and local permanent swamps.

In the lower montane forests and the majority of the upland forests ruggedness of the terrain and isolation make access very difficult to impossible.

Communications to and within the survey area as a whole are discussed in Part I.

Floating logs down the major rivers is possible and is practised on a small scale. Logging is limited to strips along the rivers; exploitation of the hinterland is dependent on road development.

Considering the problems of access, together with the quality and composition of the forests, the timber potential of the Kerema–Vailala area is only moderate. The most important potentially productive area may be the forests along the Tauri River, and possibly also the Lakekamu together with the lower hills around Putei. Secondly, the forests of the Vailala River basin would be worth considering.

V. Classification and Description of Forest Types

(a) General

As mentioned earlier, the actual forest typing has been done by air-photo interpretation; type descriptions are based on the average of the total number of sample plots measured within each forest type.

On the flat low-lying country, initial stratification according to habitat, i.e. drainage conditions, and further division based on tree height and canopy pattern, have led to the delineation of seven forest types: mangrove, mid-height mixed swamp forest, tall *Campnosperma* swamp forest, tall mixed swamp forest, tall large-crowned forest on alluvial and beach plains, open tall large-crowned forest on poorly drained alluvial plains liable to flooding, and basin forest on generally poorly drained alluviated basins and back plains. Each of these forest types is described under the same name in Part VIII, and very nearly corresponds with a land system, with the exceptions that tall large-crowned forest comprises Hepea and Malalaua land systems and tall *Campnosperma* swamp forest and tall mixed swamp forest jointly form Campnosperma land system.

In *Melaleuca* swamp savannah no trees of 5 ft girth or over have been recorded, and although tall fairly dense stands do occur the type as a whole is not regarded as forest.

As valuable species and trees of timber size are uncommon and as access is difficult, mid-height mixed swamp forest is considered unproductive and will not be discussed here.

In the hills and mountains the relationship between altitude and forest structure and floristic composition led to a primary stratification into hill forest below about 1000 ft, upland forest between 1000 and 3000 ft, and lower montane forest above 3000 ft. On the basis of differences in size and closure of crowns, hill forest has been further divided into four main types: good-quality (large-crowned and tall or very dense and mid-height), medium-quality (small- to medium-crowned and mid-height to tall), poor-quality (small-crowned or open), and very poor-quality (very small-crowned or very open).

Minor areas of a fifth type termed mixed deciduous hill forest occur as narrow foothill fringes in the east. Although the type contains a high proportion of *Pterocarpus indicus* in the canopy, it is considered unproductive because the areas are small, scattered, and difficult to reach.

The upland forests have not been further divided. They are deemed unproductive because of steep slopes and general inaccessibility.

Lower montane forest also is unproductive due to remoteness, steep slopes, and scattered occurrence of the remaining forest stands. For comparison with other forest types, measurements are included in Table 12.

Mixed *Casuarina* forest with a patchy occurrence on karst in upland and lower montane environment is unproductive because of poor timber volume and inaccessibility.

In the hills and mountains, land systems are based on land form characters largely independent of altitude. Furthermore, human action has considerably altered the vegetation. Consequently, land system boundaries do not normally show clear correlations with forest types; each land system tends to comprise various types, or alternatively, one type may cover several land systems.

(*b*) *Mangrove* (*79 sq miles*)

Results from two sample plots indicate that mature mangrove stands in places contain a high volume of timber in the 5- and 6-ft and occasionally higher girth classes. In one plot in Kerema estuary 15,000 super ft of timber was measured consisting of *Rhizophora* and *Bruguiera*, and another plot in the Purari area contained 1900 super ft made up of *Bruguiera* and *Camptostemon*. In view of the sampling inadequacy, no average stocking rate can be given. A tentative figure for the Kerema estuary, which has the highest potential, is some 7 sq miles of mature mangrove at 15,000 super ft per ac from 12 trees per ac.

Apart from possible importance for the cutch industry, mangrove species could supply valuable raw material for the production of kraft pulp (von Koeppen and Cohen 1955).

(*c*) *Tall* Campnosperma *Swamp Forest* (*10 sq miles*)

From five plots measured in tall *Campnosperma* swamp forest, the stocking rate is estimated at 5370 super ft per ac from 8 trees, of which 4240 super ft are *Campnosperma* and 1130 super ft other trees. Most trees fall in the 5- and 6-ft girth class.

Helicopter reconnaissance revealed that *Campnosperma* is a rather common tree throughout the western swamp forests. Only gregarious occurrences, readily recognizable on air photos, are mapped. It appeared that on air photos the density of *Campnosperma* trees in these stands is easily over-estimated.

Fairly large stands occur in the north near the Vailala River and smaller areas east of the mouth of this river.

The sapwood of *C. brevipetiolata* exudes a dark brown phenolic oil. Dalton and Lamberton (1958) report that some large trees in the Lake Kutubu area, when tapped in the native fashion, have yielded oil at the rate of three-quarters of a gallon per month. The exudate, known as tigaso oil, is locally used by the indigenous population as an insect deterrent or possibly as an antiseptic, but otherwise does not seem to have any known use. It is not known whether *C. coriacea* produces a similar oil.

(*d*) *Tall Mixed Swamp Forest* (*6 sq miles*)

This forest type is characterized by a canopy of scattered tall large-crowned trees. No plots have been measured and the stocking rate is estimated to be similar to that of tall *Campnosperma* swamp forest with which it occurs in mosaic.

(*e*) *Tall Large-crowned Forest* (*148 sq miles*)

The main species in this forest type, which occurs on stable imperfectly to well-drained alluvial and beach plains, are *Pometia pinnata*, *Octomeles sumatrana*, *Dracontomelum mangiferum*, and *Terminalia* spp. Largely due to the frequency of *Octomeles* a considerable proportion of the trees falls in the 7-ft and over girth classes.

Twelve plots were measured along Tauri River between Hauta and Putei. These forests, covering an area of approximately 10 sq miles and including a timber permit area, have an above-average tree density and girth and are calculated to have an average stocking of 25,460 super ft per ac from 21 trees. The most frequent tree is *Dracontomelum*, which is particularly common along the river banks but often has a rather irregular and low-branched bole.

Elsewhere the forest type has an average stocking of 12,580 super ft per ac from 13 trees (calculated from 42 plots).

The main occurrences are along the middle reaches of the Purari, Vailala, Tauri, and Lakekamu Rivers.

(*f*) *Open Tall Large-crowned Forest* (*120 sq miles*)

This forest type differs from the one described above by a more open canopy and, consequently, fewer merchantable trees, and by its poorly drained habitat liable to flooding. There is no great difference in composition and frequency of tree species. *Vitex cofassus* is more common but often of poor stem form. The number of plots is too small to rely on for an estimate of stocking. With the lesser tree density taken into account the volume would be in the neighbourhood of 8000 super ft per ac.

The type is most extensive in the east along the Lakekamu River. Smaller scattered areas occur in the coastal region and in the north-west.

(*g*) *Basin Forest* (*212 sq miles*)

Apart from the most frequent trees (*Terminalia* spp. and *Pometia pinnata*), the forest contains a fair number of *Dracontomelum mangiferum*. Rather common are *Homalium foetidum*, *Vitex cofassus* (commonly of poor stem form), and *Dysoxylum* sp. Sampling results of 28 plots show an average stocking rate of 9100 super ft per ac from 11 trees, an overall figure to be considered with some reserve as locally common patches of swamp woodland and sago are included in the forest area but not in the sampling.

The alluviated basins and back plains of the Vailala River form the main area. The low-lying poorly drained terrain would present access difficulties if exploitation along with the levee bank forest were to be considered. Further occurrences are in many scattered irregularly shaped low-lying areas within and fringing the hills of Maipora land system throughout the survey area.

(*h*) *Good-quality Hill Forest* (*15 sq miles*)

Good-quality hill forest was distinguished and mapped in two complexes rather far apart from each other and differing in structure and species composition. Delineation of an area some 7 miles south-east of Kerema, bordering Epo rubber plantation and within Hauta land system, is based on a crown size above average for hill forest. The type falls in the category tall medium- to large-crowned hill forest described in Part VIII. The second and rather remote area was distinguished on above-average density, and is situated some 15 miles north-east of Lohiki near Ivori River in Bananu land system; the forest is of the mid-height small- to medium-crowned hill forest type. In view of the difference in species composition plot results have been kept separate. On three plots in the Kerema complex (approximately 2½ sq miles), only trees in quality classes 4B and 5 were recorded. The stocking rate is calculated as 18,900 super ft per ac from 13 trees. In the Ivori River area (approximately 12½ sq miles) the most frequent tree in 5 plots was *Koompassia*. The stocking rate works out at 16,050 super ft per ac from 18 trees.

(*i*) *Medium-quality Hill Forest* (*652 sq miles*)

This forest type contains the larger part of the hill forests. It falls mainly in the vegetation category mid-height small- to medium-crowned hill forest described in Part VIII, but does include numerous areas of tall hill forest not mapped because of limited or unknown extent. Measurements of 74 plots result in a calculated stocking rate of 10,660 super ft per ac from 13 trees per ac.

The most frequent trees as recorded on plots are *Terminalia* spp., *Pometia pinnata*, *Celtis* spp., *Homalium foetidum*, and *Pterygota horsfieldii*. *Pometia*, *Homalium*, and *Pterygota* are common throughout, whereas *Terminalia* and also *Celtis* are more frequent in the east. Two fairly common trees in quality class 3, *Amoora* and *Koompassia*, reach large dimensions, *Amoora* in girth, *Koompassia* particularly in height. *Koompassia* is recognized from the air by its large emergent round crown, at the time of the survey commonly very light green. It occurs both in the west and in the east, mainly in hill forest but also in upland forest, and has an irregular distribution. It was found to be fairly common in the hills north-west of Ihu and also east of Kerema; it is locally rather common in Nabo and Bananu land systems, but appears to be rare in Lohiki land system both in the coastal hills and further inland.

Fairly common trees in class 4B are *Dysoxylum* spp. and *Mastixiodendron pachyclados*. Like *Koompassia*, *Mastixiodendron* has a varying frequency; the species was found to be common in the hills north-east of Lohiki.

Trees in class 5 that are fairly common throughout are *Parastemon versteeghii*, *Cryptocarya* spp., *Buchanania ?macrocarpa*, and *Xanthophyllum papuanum*; *Buchanania* and *Parastemon* commonly have long straight clear boles.

Large and fairly undisturbed forests of the medium-quality type are found in the central and western parts of the area in Lohiki, Nabo, Aro, and Maipora land systems. In Lohiki land system the quality decreases in south-westerly direction towards the Vailala River.

(*j*) *Poor-quality Hill Forest* (*341 sq miles*)

This forest type of medium height either has a dense canopy of generally small-crowned thin-stemmed trees as described in Part VIII, or is of normal average crown and girth size but has many gaps in the canopy.

The species composition as recorded on 22 plots is not very different from that of medium-quality hill forest. The calculated stocking rate is 8030 super ft per ac from 9 trees. The type is common on the lower foothills of Hauta land system, and the main areas are found to the west of the Vailala River and in the east on the foothills fringing the higher hills and mountains to the north.

(*k*) *Very Poor-quality Hill Forest* (*52 sq miles*)

The canopy is dense and consists of very small-crowned thin-stemmed trees (see Part VIII) or, less commonly, has many gaps in a canopy of normal average crown size. The stocking rate calculated from five plots is 3310 super ft per ac from five trees, all in the 5- and 6-ft girth classes. *Neonauclea* is locally common.

The type occurs predominantly in Hauta land system, and the main areas are found north and north-east of Malalaua and to the west of the Vailala River, some 12 miles north of Ihu.

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PART X. POPULATION AND LAND USE OF THE KEREMA–VAILALA AREA

By J. R. McAlpine*

I. Introduction

Administratively, the survey area occurs mainly in the Gulf District of Papua, excluding Kikori subdistrict. The district headquarters is situated at Kerema and other administrative centres are at Ihu, Kukipi, and Kaintiba (Fig. 1). Initial European contact was made with the coastal section during the 1880s and 1890s, and the main consolidation of administrative influence (i.e. the spread of Pax Britannica) occurred in the first decade of the twentieth century, during which period Kerema was established. While intermittent contact was made before and during the inter-war period with the inland mountain people, partly as a result of raids by them on the coastal people and partly through gold-seeking activities and exploratory patrols, the area has been fully controlled only since World War II.

The rate of spread of this controlling influence is directly related to the ease of communication. Until the war, communication within and outside the district was chiefly by sea and river in the coastal area and solely by foot inland. In the post-war period, the provision of air strips and short vehicular roads from them has greatly increased and speeded passenger traffic, while sea and river transport still provides the major form of cargo movement. By June 1965, 172 miles† of vehicular tracks, of which a portion is on low tide beach, existed in the Gulf District as a whole, the greater part being in the area surveyed. Six air strips situated at Malalaua, Kerema, Ihu, Murua, Terapo, and Kaintiba have been constructed. Only the first is suitable for DC3 aircraft; Kaintiba is at present out of commission. The Purari and Vailala Rivers are navigable to the limits of the map for barges, and the navigability of the Lakekamu and Tauri Rivers depends on seasonal conditions, but Putei and Bulldog may be reached during flood periods.

Elsewhere, except in the inhabited mountain regions, walking tracks are few compared with areas of similar population density elsewhere in New Guinea. Thus access to the interior, apart from rivers, is difficult. The main approaches to the inhabited mountains from the coast are from Putei to Kaintiba and Murua to Moiwari along little-used bush tracks.

II. Population

(a) *Statistics*

The enumerated indigenous population of the coastal, deltaic, and riverine areas is 28,420, with a further estimated 3000 living in the hills and mountains. The

* Division of Land Research, CSIRO, Canberra.

† Source: Transport and communications. Bull. Bur. Statist. T.P.N.G. No. 2, 1965.

enumerated figures are derived from quasi-annual censuses by village assembly and the estimated figures are based ultimately on field officers' reports. An analysis of land use by air-photo interpretation (see below) indicates that for the area south-west of Kaintiba this estimate may be too conservative. McArthur (1955) has dealt with the inconsistencies and qualified the reliability of these censuses but the individual village population totals used here are considered sufficiently reliable for the purposes and scale of this report.

Overall population density is approximately 9 to 10 persons per sq mile. Locally, densities on tribal or used lands may rise to over 600 persons per sq mile, as in the Orokolo–Harevavo area; this, however, is a density related to a particular form of land use (see below). Actual population distribution is indicated in Figure 7 by

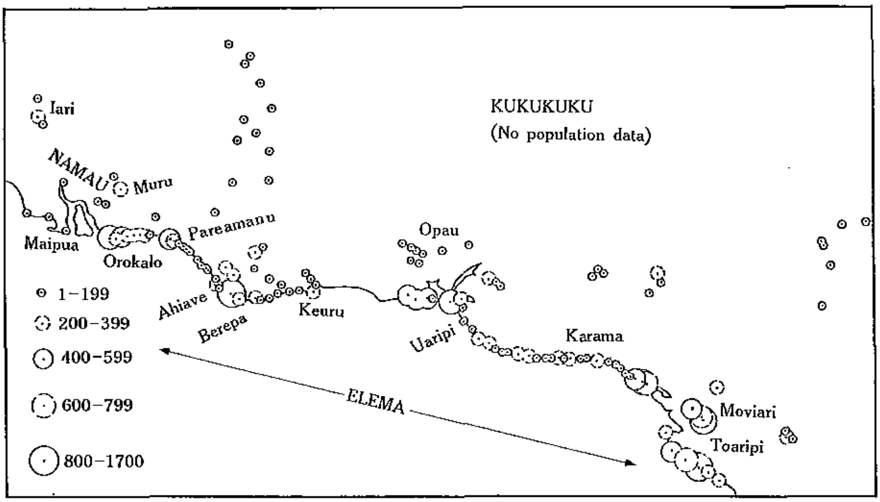


Fig. 7.—Population distribution and social grouping. Village sizes are indicated by circles.

means of graduated circles in the areas of littoral and alluvial plains. Because of the lack of census data, population can be estimated only very roughly from land use distribution (Fig. 8) in the mountains.

To estimate the population growth a comparison of the unpublished data for individual census divisions, lying wholly within the survey area, for the period 1959–60 to 1964–65 has been made. This indicates an annual rate of increase for those census divisions covering the coastal and alluvial areas where the Elema people live of between 2 and 3% per annum, a figure in accord with the Papua–New Guinea average. The rate of increase for Iari and Maipua people of the Purari deltaic area is, however, now virtually stationary. Maher (1961) discusses at some length the demographic characteristics of this area, and states that between the early 1920s and early 1950s the population for these two groups declined 5·9 and 59·8% respectively. Nothing reliable is known of population growth rates among the Kukukuku people of the hills and mountains.

The indigenous population is engaged chiefly in subsistence agriculture and food collecting supplemented by some cash cropping. In 1964 an additional 717 of the

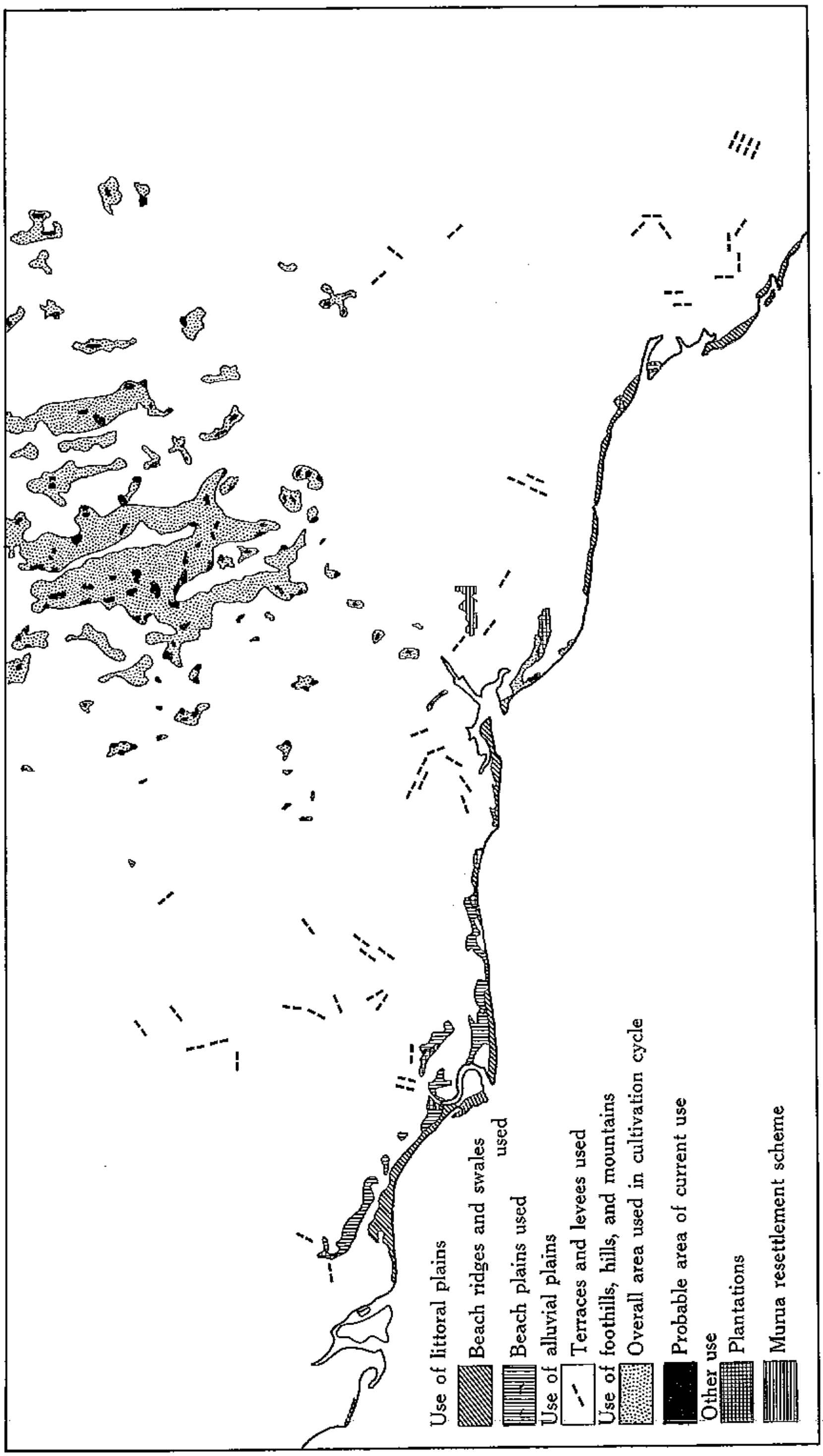


Fig. 8.—Land use.

Gulf District population was employed for cash wages within the district and 2812 outside it. A further 523 indigenous persons were employed in the district from areas outside it.* The non-indigenous population in the area is estimated to be 170 and is engaged in government, mission, trading, and planting activities.

(*b*) *Settlement*

Two distinct types of settlement patterns are found in the area and these are directly related to the land use–land form associations described later. On the littoral and alluvial plains settlement is nucleated, particularly so on the coastal beach ridges where village sizes are, by Papua–New Guinea standards, relatively large, averaging 300 in population. Villages are usually situated on the first stable beach ridge near the sea.

Village sizes on the inland alluvial areas are considerably smaller, averaging only 80 persons per village, yet the largest village in the whole survey area (population 1733) is found in this environment. Where villages are situated in riverine alluvial areas they are built on levees; where they are situated in deltaic alluvial areas they are raised on stilts along tidal channels. Village settlements in this alluvial environment are considerably more scattered than those of the coastal beach ridges. Where the beach ridge environment extends furthest inland village clustering increases, and this is probably a direct result of a greater area of suitable land being available for subsistence cropping. Conversely, where the beach ridge environment is narrowest villages tend to be of equal size, under average population size, and evenly distributed along the coast rather than clustered.

Since European contact, villages in the Purari deltaic area have split into smaller groups, a movement which has been mapped and described by Maher (1961). Elsewhere the present distribution of settlement is probably similar to the pre-contact situation.

In contrast to the nucleated settlement of the coast and alluvial plains the settlement pattern of the hills and mountains is dispersed. Settlement size normally ranges from a single house to small hamlets of 3 to 5 houses, rarely larger. These settlements are mostly situated on ridges and occasionally on small alluvial flats or gently sloping benches. Associated land use is similarly dispersed.

(*c*) *Social Groups*

The population consists of three broad groups of people, the coastal Elema, the Namau of the Purari delta, and the Kukukuku of the mountains.

With regard to the coastal people, Williams (1940) considers them to be "sufficiently homogeneous to be distinctive" (p. 3) and "to constitute one ethnic group" (p. 23). This group, which Holmes (1924) had previously referred to as the Ipi, Williams names the Elema. They extend along the coast and some way inland from 15 miles east of the survey area, at Biaru, to the Aviei River on the border of the Purari delta. He divides the Elema into 12 territorially differentiated tribes, 11 of

* Source: Labour Information Bulletin No. 2, March 1965, Department of Labour, Territory of Papua and New Guinea.

which are situated in the survey area and number 22,000 people. The distribution of these groups is shown in Figure 7 in conjunction with population distribution. Capell (1962) states that they speak one language in a variety of forms, though these are not mutually intelligible. Williams (1940) claims that they are mutually intelligible and emphasizes the homogeneity rather than the differences between these groups. Ryan (1963*a*) implies that possibly these tribal groups are now groups mainly in the sense of any opposition they receive or afford to neighbouring groups.

Beyond the Elema to the west, in the Purari delta, live the people referred to by Holmes (1924) as the "Namau". Williams (1924, 1940) uses this term but earlier calls them, more simply, the Purari, the term later adopted by Maher (1961). Two groups exist in the area, the Iari and the Maipua, with a population of 950.

To the north, the Kukukuku people live in the foothills and mountains. Nothing is known of the grouping of these people except that they do not form one homogeneous group but are socially differentiated.

The ethnography of all these people is outside the scope of this report. The reader is referred to Holmes (1924), Williams (1924), Maher (1958, 1961), and Conroy and Bridgland (1947) for information referring to the Purari people and to Holmes (1924), Williams (1924, 1940), Hogbin (1964), and Ryan (1963*a*, 1963*b*) for information concerning the Elema people.

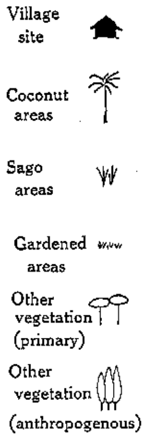
III. Subsistence Land Use

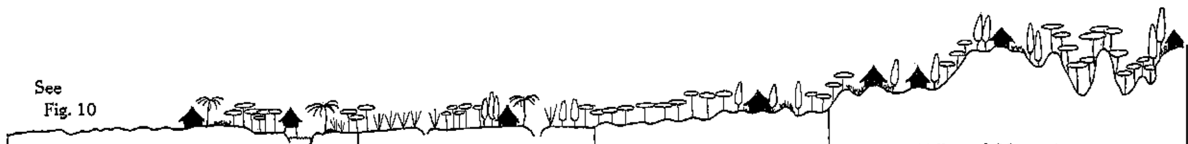
(*a*) *Introduction*

Land use information in this Part and in Figure 8 has been compiled from an analysis of cultivation and regrowth patterns on air photographs together with limited field observations, official statistics, and reference to existing literature. Areas mapped as used land at the scale employed are those showing signs of current cultivation and distinguishable secondary growth thought to be anthropogenous and less than 50 years old. Beyond this it is difficult to distinguish primary from secondary vegetation at the photo scale used. Some modifications to this mapping procedure were found necessary and these are indicated in the appropriate place.

(*b*) *Land Use–Land Form Associations*

Four distinct types of land use occur within the area and these are directly related to the land forms on which they occur. This makes discussion of land use in terms of association of land use–land form feasible and illuminating. The end product of these four distinct associations is to provide four varying methods by which the population derives its subsistence livelihood in this area. Cash cropping is discussed separately. These broad associations are: use of beach ridges and plains; tidal flats; alluvial plains; and foothills, hills, and mountains. Their areal distribution is shown in Figure 8. Quantitative relationships of land use to land form are given in the tabulated land systems in Part III. This discussion places these broad associations in the context of the major environments given in Part II and the result is synthesized diagrammatically in Figure 9.





Major Environment	Littoral Plains			Alluvial Plains			Foothills			Hills and Mountains	
Land form	Beach ridges and swales	Degraded beach ridges and beach plains	Tidal flats	Non-tidal freshwater swamps	Basins	Flood-plains	Benches	Undulating hills	Hill ridges	Low to moderate relief	High relief
Population	17,580	1900	3830	0	410	2120	0	0	1040	1000 (est.)	2000 (est.)
Area (sq miles)	29	56	270	341	212	304	52	121	413	51	1428
Used area (sq miles)	20	12	<1	Sago	<1	<1	0	0	1·4	10	115
Population density (per sq mile)	606	33	14	0	2	7	0	0	3	20	1
Area non-indigenous plantations (sq miles)	0·6	2·3	0	0	0	0·2	0	0	0·2	0	0·6 (at Epo)
Main social group	Elema		Namau and Elema	Elema			—	—	Elema on coast	Kukukuku	
Main land form used	See Fig. 10	Plains and alluvial flats	Crab mounds and crab islands	—	Terraces and levees		—	—	Crests, benches, spurs, gentler slopes, and alluvial terraces		

Fig. 9.—Land use–land form associations.

(i) *Beach Ridge and Beach Plain Use.*—The first major environment of the area, the littoral plains, covers the first two land use–land form associations. The use of the coastal beach ridges is restricted to the Elema people; thus 60% of the population live on less than 1% of the survey area. Sago (*Metroxylon rumphii* or *M. sagu*) is the chief source of food and is collected from the swampy swales. It is supplemented by gardening, coconuts, bread-fruit, fishing, and pigs. Coconuts and gardens are planted on the beach ridges, forming with the sago in the swales a banded pattern of land use extending for ¼ to 1 mile inland. The nearest stable beach ridge to the coast is the most intensively used part of the sequence. Garden crops seen were sweet potatoes (*Ipomoea batatas*), yam (*Dioscorea* sp.), taro (*Colocasia* sp.), bananas (*Musa* spp.), cassava (*Manihot esculenta*), edible pit-pit (*Saccharum edule*), and papaw (*Carica papaya*). Maize, tomatoes, pineapples, peanuts, and cucurbits were also noted. Gardens are shifted regularly on the bush fallow system with a rotation cycle of less than 10 years in the more densely populated areas.

The detailed use of the beach ridges (Araimiri land system, and Hisiu land system of the Port Moresby–Kairuku area) is shown in Figure 10. The use of the inland beach plains (Malalaua land system) differs from the beach ridge use in that they are less densely populated. Sago is collected from the surrounding alluvial plains environment and fishing is carried out in nearby rivers rather than the sea.

The major areal variation to this pattern of use of beach ridge and plains results directly from the differences in rainfall regime which occur in the area (Part IV). The eastern occurrences of this environment suffer seasonally drier conditions making them less favourable for garden cultivation. As a result, the eastern beach plains are virtually unused and the inhabitants of the coastal beach ridges appear to have fewer gardens per head than in the west. Fishing and sago collecting are consequently of greater importance.

(ii) *Tidal Flat Use.*—The use of the tidal flats segment of the littoral plains environment is restricted to the Namau of the Purari delta and the Moviari–Elema in the east. These latter people were not visited by the author and their methods of land use may differ from those of the Namau which are given here. Maher (1961) and Williams (1924) deal with the use made of this environment generally, and Conroy and Bridgland (1947) detail its use in regard to one village, which, although not part of the area surveyed, is nevertheless typical of the delta section of it. Williams (1924, p. 3) states that these people are "essentially hunters, fishers and collectors". Sago forms an even greater part of the diet than it does for the beach ridge and plain dwellers mentioned previously. It is supplemented by some garden crops listed by Conroy and Bridgland (1947), who refer to the viscous mud "soil" on which cultivation takes place. The origin of this "soil" and its use deserves mention.

In the mixed mangrove and *Nypa* areas of this environment, crab mounds probably built by crabs (*Thalassina anomala*) occur and have been described for Queensland by Macnae (1966). They are most abundant close to tidal channels where they form the only part of the surface above high-water mark. The small scattered gardens that provide the starchy foodstuffs accessory to sago, and vegetables, are planted on these mounds in areas where the *Nypa* and mangrove have been ring-barked or felled. The areas cleared are of about ½ acre, of which up to 5% is

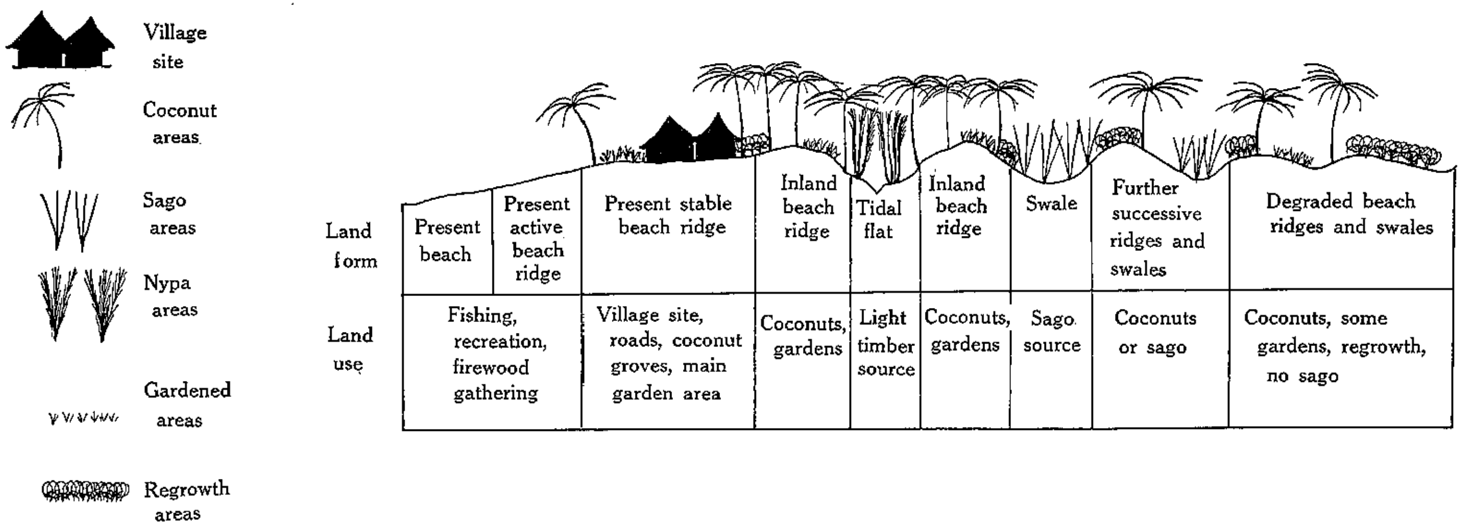


Fig. 10.—Land use–land form associations for Araimiri land system, and Hisiu land system of the Port Moresby–Kairuku area.

crab mound tops above high-water mark, the largest individual mounds being 4 sq yd. In sections of Nipa land system crab mounds are enlarged into crab islands, separated by narrow tidal channels, which cover up to 50% or more of the total area with individual islands reaching 10–20 sq yd in area.

In other areas these gardens may be submerged at high tide, a fact that Barrau (1958) has previously observed. The chief source of protein for these people comes from crabs and to a lesser degree from fish.

Owing to the small map scale employed it is not possible to show areas of this form of land use in Figure 8. Areas can only be roughly inferred from population distribution in Figure 7.

(iii) *Alluvial Plain Use.*—The non-tidal freshwater swamps of the alluvial plains environment are uninhabited, but are used by the population of the beach ridges and plains and the other sectors of the alluvial plains environment as a source of sago. The population of these other sectors, the basins and flood-plains, lives on, and gardens only, the terraces and levees on a long-term bush fallow basis. The crops grown are similar to those of the beach ridge and plain environment but probably form a slightly larger portion of the overall diet. Areas of cultivation and regrowth, being restricted to narrow levees and terraces, cannot be mapped at the scale used, and the major occurrences that are represented diagrammatically on Figure 8 have no areal accuracy.

(iv) *Foothill, Hill, and Mountain Use.*—The use of the foothills is restricted to a very small area of the hill ridges sector used by the Uaripi–Elema peoples near Kerema.

The use of the hills and mountains of the Kukukuku lobe is mainly on the areas of low to moderate relief where population density on land mapped as used is approximately 100 persons per sq mile, and on the less steep slopes of Eruki land system between 2000 and over 5000 ft above sea level where population density is approximately 20 persons per sq mile. The Kukukuku people derive their subsistence from this area by means of shifting cultivation of a less intensive nature than elsewhere in the mountains and uplands of New Guinea (Brookfield and Brown 1963; McAlpine 1965), and in a manner more akin to the pattern found in the less densely populated lowland areas.

However, the system of cultivation is unusual by highland or lowland standards in that tree felling is carried out after, rather than before, planting, and consequently no burning is possible, in contrast to the more usual "slash and burn" routine of shifting cultivators.

Undergrowth is first cleared in areas of 1–2 acres and left lying for some time. The crops are then planted and after several weeks the surrounding trees are felled and the crops left to grow through or climb up the mass of branches. The general effect is rather chaotic (Plate 11, Fig. 2). Blackwood (1939) has listed some of the food crops grown by the Kukukuku in an area to the north-east where sweet potato (*Ipomoea batatas*) forms the staple. The type of local agricultural practice and its extensive nature have made it difficult to delimit with certainty areas of current cultivation within the area mapped as used land (defined above), as has been possible elsewhere in New Guinea (McAlpine 1965, 1967). However, an attempt has been made to give some indication of the areal distribution of current cultivation within the area mapped as used land by delimiting areas containing a higher percentage of apparent gardening, clearing, and regrowth up to 2–4 years old. Many small areas, of up to 4 acres, chiefly on ridges are covered by *Miscanthus* or kunai (*Imperata cylindrica*) and it is impossible to distinguish these from currently gardened areas. Using the estimated population of 3000 and making allowance for grass patches, inclusions of unusable land, and the presence of regrowth, it would appear that 0·3–0·4 ac per head is cultivated in this area per annum.

IV. Cash Cropping

Cash cropping is confined wholly to coastal and navigable river areas, due partly to their accessibility and partly to the present population distribution. A small trial area of coffee (arabica) has recently been planted in the hills behind Kukipi.

Cash cropping by the indigenous population is generally carried out within the area used for subsistence cultivation for crops other than coconuts. Palms used for copra production are not distinguished from those used for subsistence. Two further exceptions to the normal areas used for cash cropping are the Cupisi rubber project near Kerema, discussed in detail by Hogbin (1964), and the Murua Resettlement Scheme, in which 77 blocks totalling 7207 acres, of which 33 are currently occupied, are, or will be, planted chiefly to rubber.

Table 14

CASH CROP PRODUCTION IN 1964–65

Crop	Produced by Indigenous Population*	Produced by Non-indigenous Population†
Copra	1582 tons	644 tons
Rubber	11,800 lb	685,440 lb
Cacao	Nil	132 cwt
Coffee (robusta)	2541 lb	Nil
Rice	4 tons	8 tons

* Data supplied by Department of Agriculture, Stock, and Fisheries, T.P.N.G.

† Source: Rural industries production. Bull. Bur. Statist. T.P.N.G. No. 7, 1964.

Cash cropping by non-indigenous persons is based on plantation economy, with the exception of Terapo mission rice production. These plantations occupy 7 separate areas, 6 of which are planted to coconuts and cacao and 1 to rubber. Details of the land types occupied by these plantations are given in the tabulated land systems in Part III and generally in Figure 8.

Cash crop production for the year 1964–65 is shown in Table 14.

V. Present Land Use and Land Use Capability

As the criteria for the assessment of land use capability (from Part XI) differ considerably from those used by the present indigenous cultivators, a direct comparison of capability with present use is not valid. The comparison of present and potential use made here serves solely to indicate the degree to which land of certain capability is already being used.

Areas of high to moderate potential for arable or tree crops are little used or unused at present, except on Malalaua land system which is fairly intensively used in the west but virtually unused in the east where, because of the seasonal rainfall regime, it is rated only as highly suitable for improved pasture. Araimiri and Hisiu land systems of the Port Moresby–Kairuku area are listed as moderately suitable for improved pasture but are already fully utilized by the existing population. The only other occupied areas in the Kukukuku lobe are considered unsuitable for European-type agricultural development.

VI. Acknowledgment

Field information for the Purari delta and Kukukuku areas was provided by Mr. B. J. Leach, of the Department of Agriculture, British Solomon Islands Protectorate, who also helped to detail the land use in the tabulated land systems of Part III.

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PART XI. AGRICULTURAL LAND CAPABILITY OF THE KEREMA–VAILALA AREA

By B. J. LEACH*

I. INTRODUCTION

The general objectives of agricultural land classification are to measure and record land characteristics of a given area and to assess the effect of limitations that may be imposed by these characteristics on the agricultural capability of the land.

In recent land resources surveys in Papua and New Guinea, land capability classification has been based on the American system of Klingebiel and Montgomery (1961). In this system the subclasses indicate the kinds of hazards for agricultural use as observed in the field, while the classes of land are assessed from the kind and degree of the subclass hazards and indicate the general capability of the land. Haantjens (1963) made modifications to this system for use in New Guinea using the same general principles and based on modern agricultural practices for permanent settlement excluding shifting cultivation. Considerable changes have since been made (Appendix I). An important feature is that land is classified separately for four different kinds of agricultural use and the system is thus more specific than those previously used. This latest system was tried for the first time on the Kerema–Vailala survey. Classification of agricultural land capability is based on the physical characteristics of the land and the general nature of the climate. No account is taken of economic and social factors such as markets, communications, population, or land ownership.

This assessment of land capability is based on limited data because of the reconnaissance nature of the survey and because very little information was available locally on such matters as flooding and climate. More detailed surveys would need to follow on in the areas indicated in this report before development is considered.

The possibilities of swamp reclamation, drainage, and irrigation are also assessed in broad terms from very limited data and would, of course, have to be specially investigated.

II. CLASSIFICATION SYSTEM

(a) *Land Characteristics Measured*

Fifteen characteristics were measured or estimated at each field examination site. They were altitude, erodability, stoniness, cobbliness, rockiness, flooding, inundation, drainage, permeability, soil depth, available soil water storage capacity, topsoil consistency, soil reaction, salinity, and nutrient status. These characteristics were given letters and each rated with a number, as summarized in Appendix I, and these corresponded roughly to the subclasses of the American system.

Characteristics were measured and rated as set out by Haantjens (unpublished data, 1965†), with a few modifications, notably for flooding for which the damage

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† CSIRO Aust. Div. Land Res. tech. Memo. No. 65/8 (unpublished).

factor was weighted more heavily as a land use limitation than that of frequency. Estimation of frequency and length of flooding and inundation was difficult as local knowledge was seldom obtainable, and other evidence, mainly from vegetation and land form, often had to be used alone.

Salinity of soil was judged from vegetation and soil reaction was measured in the field.

Nutrient status was estimated by considering texture, organic matter, apparent degree of weathering, and crop performance where possible. Ratings were generally made to be moderate unless indications of high or low fertility appeared obvious, e.g. beach sands were given ratings of low or very low, and organic, fine-textured soils were generally rated high.

Stoniness, cobbliness, and rockiness of the land were rated from estimation of percentage surface cover at randomly selected small areas near the examination site.

In addition to the other land characteristics mentioned climate was also considered, together with soil depth and available soil water storage capacity giving a drought stress limitation in some areas. The climate was divided into three types: wet (no dry season), normal (dry season, but not severe), and dry (severe dry season). Climatic factors are discussed further in Part IV and by Haantjens (unpublished data, 1965).

(*b*) *Assessment of Land Capability*

Land was classified according to its suitability for arable crops, tree crops, improved pastures, and irrigated rice. Arable crops are annual cultivated crops excepting wet rice, tree crops are perennial plantation crops, pastures are improved pastures, and rice here is irrigated or paddy rice.

Six capability classes were given for each type of use: 1 (very high), 2 (high), 3 (moderate), 4 (low), 5 (very low), and 6 (nil).

The assessment of capability class was made from the cumulative effects of all limitations imposed on land use by land characteristics measured. The severity of the limitations for each type of land use and their cumulative effects have been specified by Haantjens (unpublished data, 1965). Assessment of capability class for irrigated rice also included consideration of the general feasibility of irrigation, the main criteria being water supply, soil permeability, and topography.

These assessments were made for all sites examined in the field and these were related to individual land units (see tabulated land system descriptions). The agricultural capability of each land system was determined by considering the relative areas and distributions of the land units.

Assessments were also made in the field of the relative ease or difficulty of control of flooding or inundation and improvement of drainage where these problems were present.

(*c*) *Land Capability Mapping*

Land capability maps (Figs. 11–14) were made from the land system map for arable crops, tree crops, rice, and pastures. The same land system sometimes occurs in different climatic zones, necessitating separate capability classification.

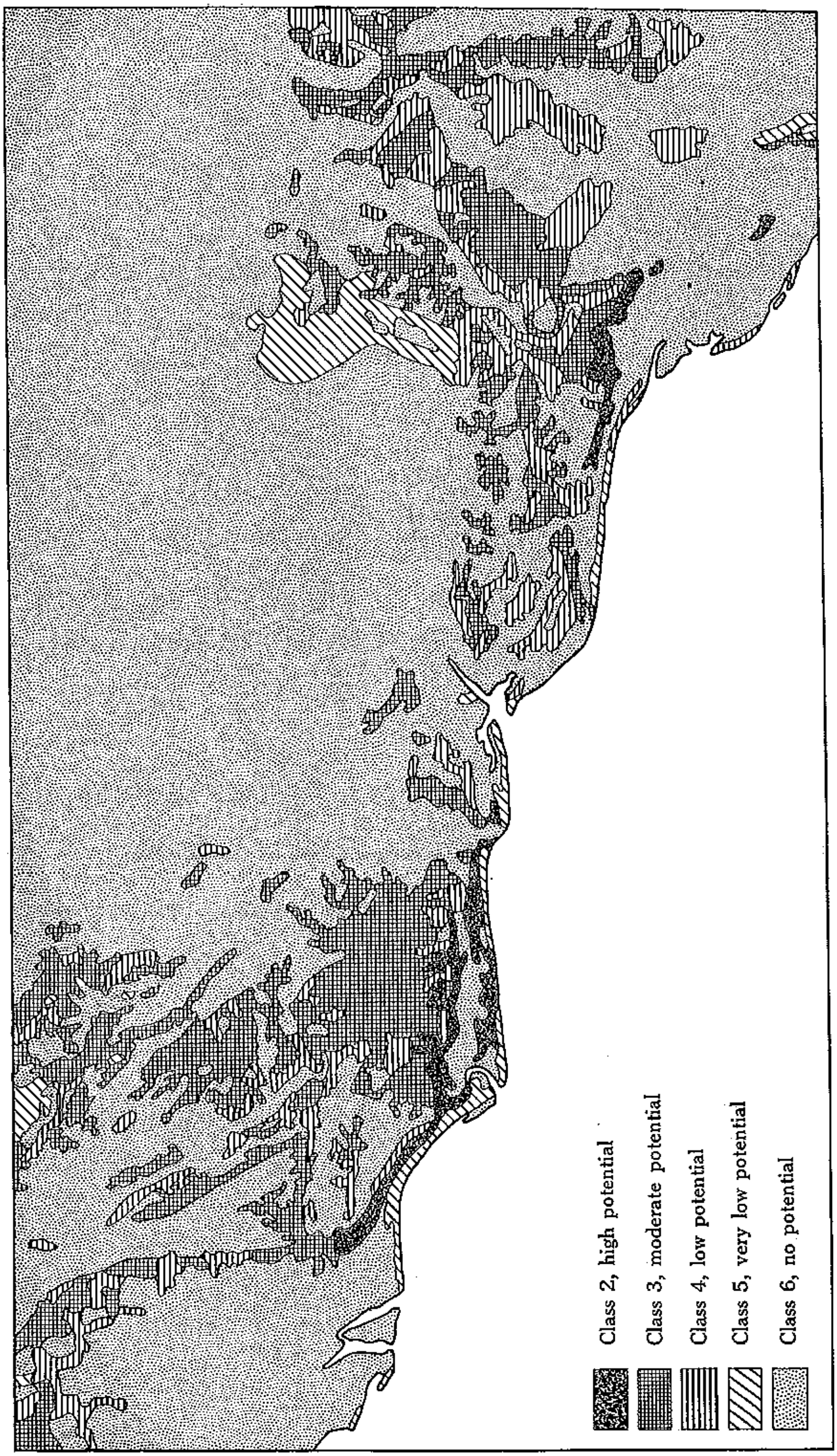

Fig. 11.—Land use capability classes for arable crops.

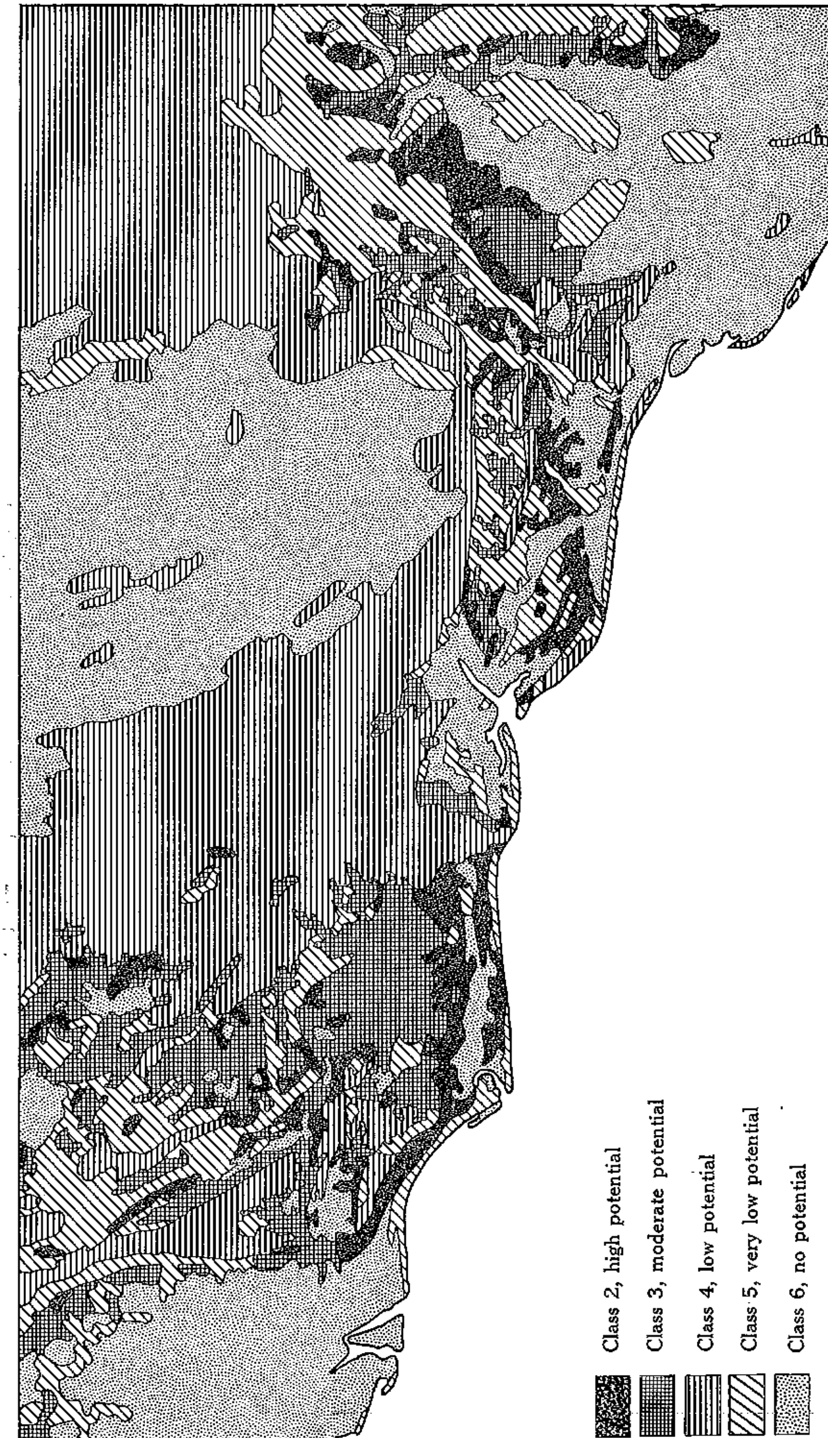

Fig. 12.—Land use capability classes for tree crops.

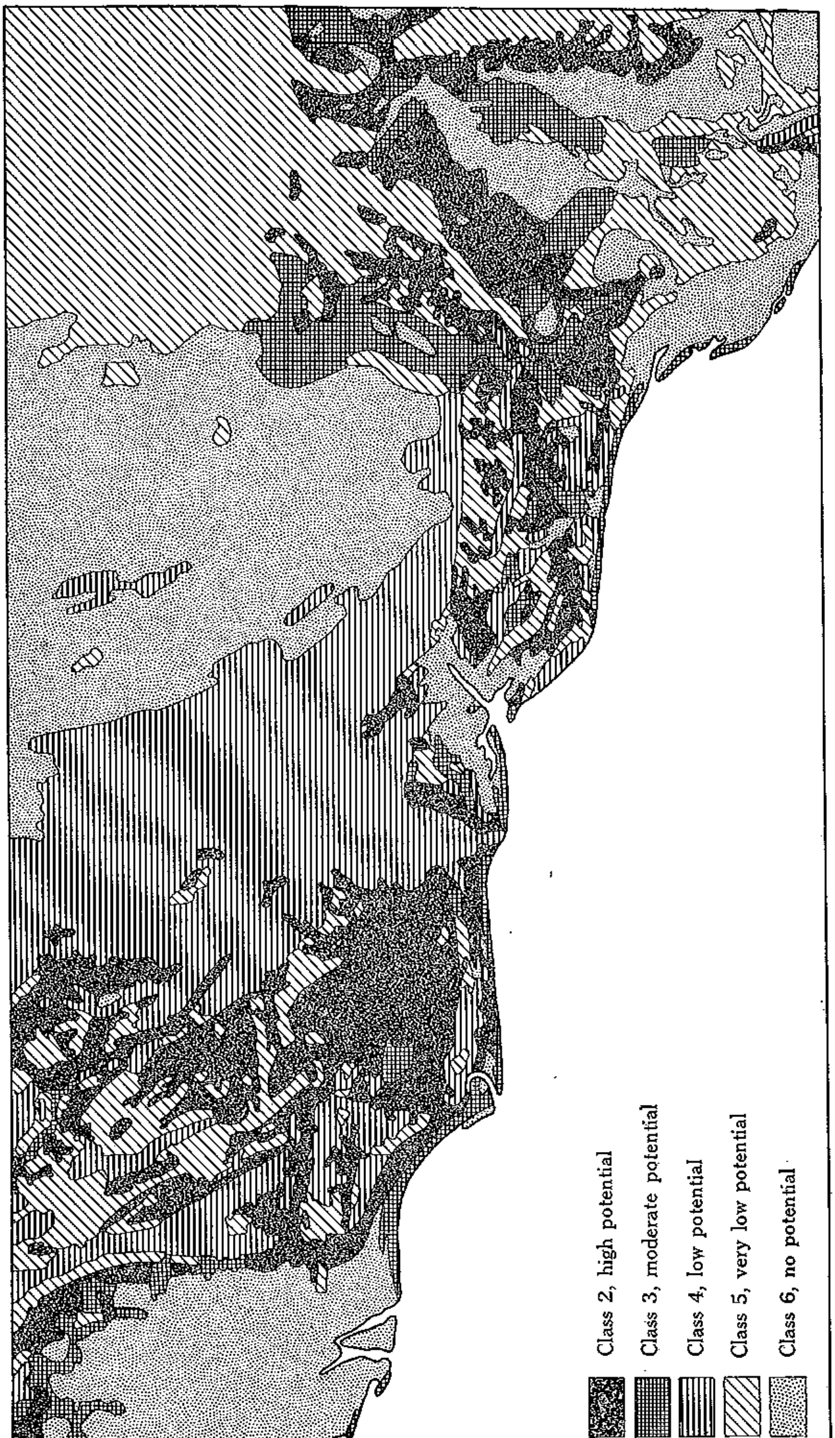

Fig. 13.—Land use capability classes for improved pastures.

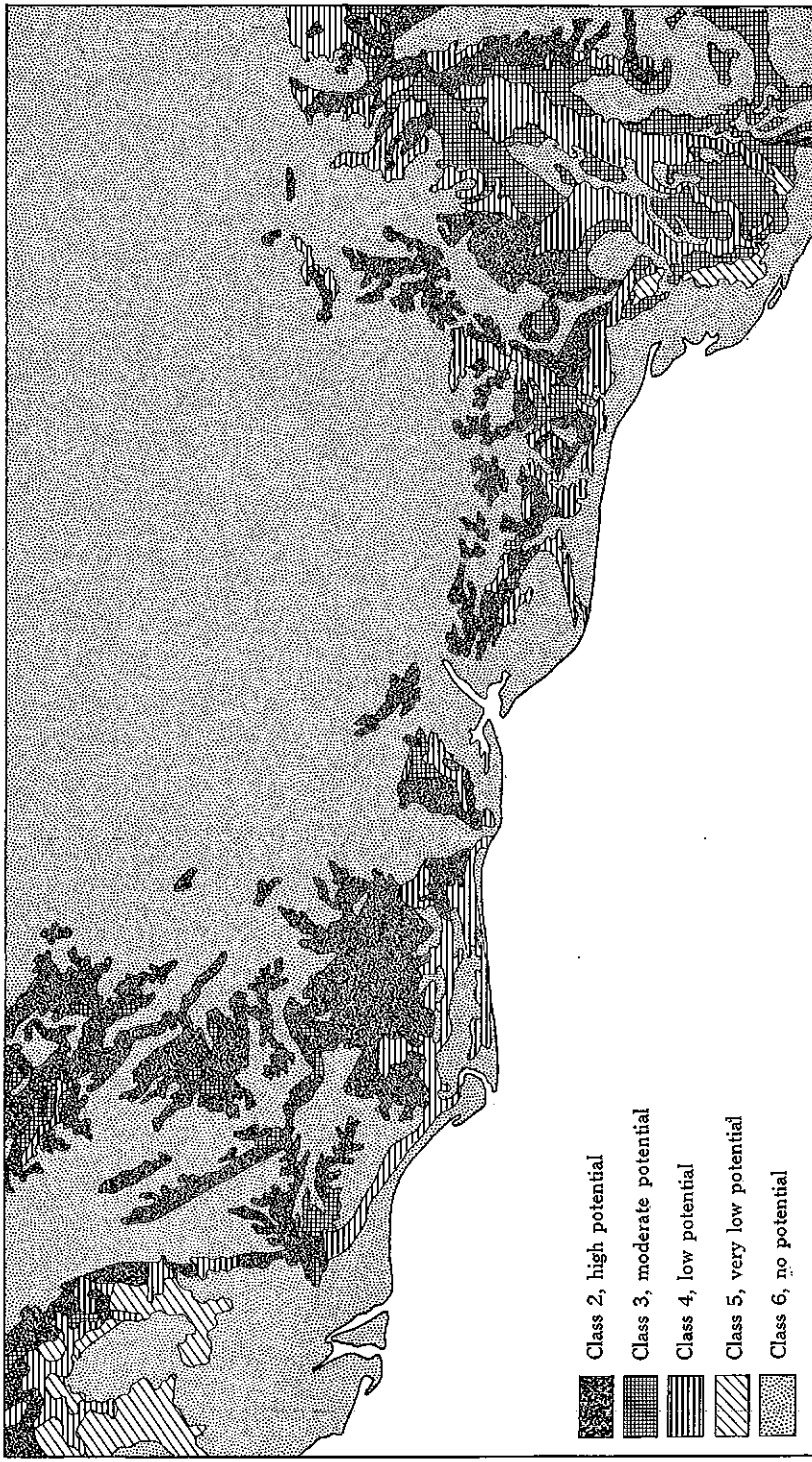

Fig. 14.—Land use capability classes for irrigated rice.

In some cases (e.g. Campnosperma land system) individual land units occurred in distinctly separate areas and were therefore mapped on their individual assessments rather than on those of the land system as a whole.

(*d*) *Use of the Classification*

For a general indication of the extent and location of the various classes of land the four maps in Figures 11–14 can be used, together with the assessment of land capability in the tabulated land systems.

Where more detailed information is required, particularly in considering suitability of land for any specific crop or form of agriculture, the column on land use limitations in the land system descriptions should be used. In these, individual limitations for each land unit are given, and capability for any specific use can be assessed by the user.

In some land systems there is great variation in land capability between the various land units. It is therefore possible that land mapped, for example, as moderate for tree crops may have capability of land units ranging from very high to nil. The mapping is thus based on the dominant class of land within each land system.

III. Regional Agricultural Land Capability

Figures 11–14 illustrate the distribution, shape, and size of the areas classified according to their assessed capability for arable crops, tree crops, improved pastures, and irrigated rice. The total land areas for each capability class in respect of the four types of agricultural use are presented in Table 15. No land systems were rated in capability class 1 (very high), so this has been omitted from the table.

Table 15

AREAS (SQ MILES) OF LAND CAPABILITY CLASSES FOR FOUR TYPES OF AGRICULTURAL USE

Capability Class	Arable Crops	Tree Crops	Improved Pastures	Irrigated Rice
2 (high)	56	208	583	403
3 (moderate)	416	360	204	178
4 (low)	243	1030	665	256
5 (very low)	86	509	859	55
6 (nil)	2515	1209	1005	2424
Total	3316	3316	3316	3316

(*a*) *Potential for Arable Crops*

A total of 56 sq miles is considered to be highly suitable for arable crops and a further 416 sq miles moderately suitable. Apart from several large areas much of this land is in scattered small areas, some of them difficult of access. The main areas of high and moderate class land lie in the alluvial plains, beach plains, and low hills, with gentle slopes in the broad belt between swamps and steep hills and mountains.

The largest unbroken area (more than 50 sq miles) occupies the lower Vailala basin, mainly east of the river. It includes levee banks and extends south to the Kira Hari hills and to the beach plains. Further north on the Vailala alluvial plains are several quite large areas (Vailala and Hepea land systems), of which the southernmost (west from Lohiki), with 10–15 sq miles, is the largest.

Other moderately sized areas in the west are the inland beach plains (Malalaua land system) between Araimiri and Vailala East, and a narrow strip between ½ and 1½ miles wide from Ihu westwards and parallel to the coast and extending as a narrow band for about 5 miles up the eastern side of the Purari delta in Hepea land system. Areas of alluvial land to the north and north-east of the Purari delta also appear to be suitable (Hepea land system).

Apart from near the Vailala River the largest contiguous areas of suitable land appear to be in the eastern part of the area, the largest being around Hauta on the Tauri River (Hepea, Vailala, and Olipai land systems) between the seasonally flooded swamps to the south and the low hills to the north. This area is about 10–15 sq miles and is mainly west from Hauta. A further strip of good land 1 mile wide and 15 miles long stretches in a north–south direction on the western fringe of the Kurai hills (Vailala, Hepea, and Olipai land systems).

Climatic differences within the area can limit production of arable crops in several ways. In the high-rainfall areas with no definite dry season cultivation and harvesting could be hampered by excessively wet soils, particularly in the alluvial plains. The rapidly draining sandy soils of Malalaua land system would not present cultivation problems.

Lack of a definite high-sunshine and low-rainfall period for crop maturation and ripening could also be a disadvantage for many arable crops. The dry and normal or transitional climate types in the eastern area (Part IV), with a severe and moderate dry season respectively, would not have these disadvantages. However, particularly in the dry areas and with reliance on rainfall alone, choice of crops would be limited, and with short-term annuals fewer crops could be grown in a year. Occasional drought stress may also occur during a growing season, more frequently on the sandy soils of Malalaua land system with a lower soil water storage capacity.

(*b*) *Potential for Tree Crops*

A total of 208 sq miles is mapped as being highly suitable and a further 360 sq miles as moderately suitable for tree crops. The areas of best potential for tree crops are in the foothills and better-drained plains. Apart from the dry zone the best areas occur in the same general regions as land of moderate to high suitability for arable crops, but with the addition of the low hills with moderate slopes of Hauta land system which are for the most part contiguous with the best areas for arable crops, i.e. Hepea, Vailala, Olipai, and Malalaua land systems. Thus, the largest areas are around the Vailala River, particularly east near the Evori River and the Kira Hari hills. Further areas are south-west and north-east from Hauta and on the western fringe of the Kurai hills.

The area around Malalaua appears to be only of low suitability for tree crops largely because of liability to seasonal drought. Between Kerema and Malalaua there are considerable areas of highly and moderately suitable land, but, apart from on and around Epo plantation, these are of a discontinuous pattern being broken by both swamps and rugged low hills.

Vailala and Hepea land systems, while having sufficient well-drained land to be rated as moderately suitable, have large areas with poor drainage, which if drained should be highly suitable for tree crops, although probably still less so than for arable crops.

Little could be gauged of general fertility problems, but a strong yield response to general fertilizer application on an experiment on mature rubber at Epo plantation was reported by the manager, Mr. W. van der Brink. Fertilizers would probably be generally required, but this would depend considerably on the type of tree crop to be grown.

The sandy soils of the beach plains (Malalaua land system) appear to be best suited to coconuts. However, the moderately to strongly weathered acid soils of the flat-topped terrace remnants of Olipai land system may be well suited to such crops as rubber or oil palms but could be poor for coconuts.

Climatic factors appear to be generally favourable for tree crops requiring a steady high rainfall for optimum production, except for areas in the south-east. Lack of any rainfall figures for this area, apart from Kukipi, makes this factor difficult to assess, but it appears from natural vegetation that the Malalaua area has a more severe dry season than the areas around Hauta and the Kurai hills. The last two apparently still experience a regular dry season but this would not be too severe for successful tree crop growing.

(c) *Potential for Improved Pastures*

Land systems rated as highly suitable for improved pastures total 583 sq miles in area and those rated as moderately suitable total 204 sq miles. Areas of moderate and high suitability are mainly in the foothills and plains, excluding the swamps, and, although more extensive, occupy the same general areas that are suitable for tree crops; they also include land with poorer drainage and some areas of the dry zone. Areas regarded as highly suitable include all those areas rated highly and moderately suitable for tree crops, with the addition of the dry-zone areas of the beach plains (Malalaua land system). Moderately suitable areas are Araimiri, Tauri, Putei, and Hisiu land systems (the last of the Port Moresby–Kairuku area) and the dry zone of the Hauta land system.

The main limitations of these areas that are only moderately suitable are very poor drainage (Tauri and Araimiri land systems) and erosion hazard due to steep slopes (Putei land system).

Only parts of the south-eastern areas in Malalaua, Olipai, Vailala, and Hauta land systems (including hills, alluvium, and beach sands) are under natural grassland or savannah grassland; most of the areas are under forest. These limited areas of grassland are mainly of *Imperata* and *Coelorachis*, with *Themeda*, *Capillipedium*, and other grasses, and could provide some grazing at present.

(*d*) *Potential for Irrigated Rice*

A total of 403 sq miles is considered of high suitability for irrigated rice, with 178 sq miles moderately suitable. In the absence of any detailed investigation, it appears that most of this area could without great difficulty be irrigated with water by gravity from storage reservoirs or streams or by pumping from large rivers. Many of the potential rice-growing areas are small but several large blocks occur, particularly in the Vailala basin and west of Hauta on the Tauri River.

The land best suited to large-scale irrigated rice is on the better-drained alluvial plains in Hepea and Vailala land systems. The swamps of Campnosperma and Movori land systems, where they are on fine-textured alluvium, also appear to be highly suitable, except for Movori land system in the east which is seasonally inundated and is rated as moderately suitable. Karama land system, where it is on fine-textured alluvium and not on degraded beach ridges, together with Melaleuca land system, also appears to be moderately suitable, but the eastern part of the former and the whole of the latter are seasonally inundated. In these areas, without control of seasonal river flooding, quick-maturing varieties could possibly be grown under controlled irrigation in the drier period. Alternatively, crops could probably be grown by relying on shallow inundation for water supply, although this would be risky without any control over water levels.

(*e*) *Possibilities for Land Reclamation*

Drainage improvement over much of the plains appears quite feasible. On the alluvial soils closely spaced drains may be required but most of them probably could be adequately drained.

In the Vailala area, drainage could probably be directed towards the rivers, but in the eastern areas some drainage may have to be directed to the back-plain swamps. On the coarse-textured soils of the coastal plains drainage towards the sea would appear to be simple, except for very low-lying swamps where the ground level may be only just above sea level.

Large parts of the Kerema–Vailala area are at present unsuitable for most agricultural purposes because of flooding, inundation, and poor drainage.

Flooding is at its worst on the alluvial lobes of Terapo land system. Most of the Lakekamu embayment is seasonally inundated on the low-lying back plains. General tidal inundation occurs over a very large area in the Purari delta as well as other coastal areas of Alele, Nipa, and Galley Reach (of Port Moresby–Kairuku survey area) land systems. In addition, drainage problems occur over most of the plains on both alluvial fine-textured soils and coarse-textured beach soils.

Control of seasonal overflow from the Tauri and Lakekamu Rivers and consequent inundation of the back plains would be extremely difficult, and would require complete river control.

Prevention of tidal inundation in the Purari delta and other coastal areas would require complete empoldering and pumping out of excess water, and would create an expensive, large-scale, and difficult reclamation problem.

(*f*) *General Conclusions*

The best general agricultural land in the Kerema–Vailala area appears to be in the low hills, alluvial plains, and beach plains. The largest single area of moderate and good land is around the lower part of the Vailala River, involving mainly alluvial land (Vailala levee banks and Evori basin), with considerable areas of beach plains (Malalaua land system) and the Kira Hari hills with gentle and moderate slopes. However, much of this land is poorly drained. The largest area of almost entirely well-drained land is in the low hills north-west of Hauta on the Tauri River and in another large area including and extending eastwards from Epo plantation. These areas appear best suited to tree crops, e.g. rubber or oil palms, and their areas are roughly 13,000 and 8000 ac respectively. However, rainfall reliability near Hauta is doubtful and further data are required before a more reliable assessment of suitability can be made. Favourable aspects of the Hauta area are almost total absence of population at present, relatively easy terrain for construction of roads and air strips, and convenient access to the Tauri River for transport of bulk cargo.

Other than the plains and low hills there is very little potential for agricultural development because of swampy conditions and inundation in tidal or seasonal swamps, or severe erosion hazards with problems of accessibility in steeply sloping hills or mountains.

Improvement of alluvial and beach plains by drainage appears feasible but reclamation of swamps of the Purari delta and Lakekamu embayment would be extremely difficult and involve very large-scale engineering works.

IV. Present Land Use and Land Capability Classification

Much of the land classed as generally unsuitable for agricultural development is in fact used for cultivation by indigenous people. This is because the agricultural land capability classification is based on permanent agriculture using modern techniques, and much of the land unsuitable for these methods can still be used on a small scale for subsistence and possibly cash crops. Several examples are given below.

Parts of the mountains are quite heavily populated, and subsistence gardens are cultivated on very steep slopes up to 5000 ft altitude. Parts of these areas could possibly be used for cultivation of crops such as tea or coffee, but accessibility is so difficult that the area is considered unsuitable.

Well-drained land is so scarce that in the Purari area small patches of land above high tide are cultivated. These areas may be very small and very poorly drained and could not be used for any larger scale of agriculture.

River scrolls which are frequently damaged by flooding are planted with garden crops, mainly bananas, particularly on the Tauri River. This form of agriculture is obviously successful but the land is regarded as unsuitable for development of permanent cropping because of flood damage. Similarly, tree and garden crops are successfully grown on the seasonally flooded river banks of Terapo land system, which is rated as of low suitability because of this flooding.

Araimiri land system has been rated as being of very low suitability for tree crops but in fact is of major importance for copra production in the district. This apparent anomaly is explained largely by the fact that much of this land system is swampy and the coconuts are grown on the better-drained parts. For classification and mapping purposes the land system is considered as a whole and the large proportion of swamp lowers the land capability class.

Land at present producing rubber in the Kerema Bay area on Nabo and Maipora land systems is rated as low and very low in suitability for tree crops, due to steep and very steep slopes and consequent erosion and accessibility problems. It is obvious that rubber can be grown in these areas, but there are other areas of greater suitability. On Epo plantation most of the rubber is on the moderate slopes of Hauta land system, rated as highly suitable, and only marginal areas are on the steeper Nabo and Maipora land systems. Similarly in any proposed development project fringing areas of less suitable land could be incorporated with better land in the same block.

Vaiviri, Maira, and Muro plantations, all growing coconuts, occur mainly on the beach plains of Malalaua land system which was rated high for tree crops. Copra yields appeared moderately high but cocoa was very poor. Leaf analyses on young replanted palms showed clear potash deficiency, associated with high magnesium content, which may also have occurred with the cocoa. Possible fertility problems such as this on land rated highly suitable for tree crops do not affect the classification greatly, as ordinary agricultural practices such as fertilizer applications are assumed, and it is beyond the scope of this report to assess soil fertility other than in a very general way.

V. References

Haantjens, H. A. (1963).—Land capability classification in reconnaissance surveys in Papua and New Guinea. *J. Aust. Inst. agric. Sci.* **29**, 104.

Klingebiel, A. A., and Montgomery, P. H. (1961).—Land capability classification. U.S.D.A. agric. Handb. No. 210.

APPENDIX I

Ratings of Limiting Agricultural Characteristics*

Symbol and Rating	Explanation
l0	Lowland, 0–2000 ft
l1	Upland, 2000–3500 ft
l2	Low highland, 3500–5500 ft
l3	High highland, 5500–8000 ft
l4	High mountain, 8000–10,000 ft
l5	Subalpine, 10,000–12,000 ft
l6	Alpine, > 12,000 ft
e1	Very slight erosion hazards
e2	Slight erosion hazards
e3	Moderate erosion hazards
e4	Serious erosion hazards
e5	Very serious erosion hazards
e6	Extreme erosion hazards
s1 or r1	Slightly cobbly (10–20%); or stony or rocky (1–5%)
s2 or r2	Moderately cobbly (20–40%); or stony or rocky (5–10%)
s3 or r3	Cobbly (40–60%); or stony or rocky (10–20%)
s4 or r4	Very cobbly (60–80%); or stony or rocky (20–40%)
s5 or r5	Extremely cobbly (> 80%); or stony or rocky (> 40%)
f1	Very minor flood hazards
f2	Minor flood hazards
f3	Moderate flood hazards
f4	Serious flood hazards
f5	Very serious flood hazards
f6	Extreme flood hazards
i1	Very minor inundation hazards
i2	Minor inundation hazards
i3	Moderate inundation hazards
i4	Serious inundation hazards
i5	Very serious inundation hazards
i6	Extreme inundation hazards
w1	Imperfectly drained
w2	Poorly drained
w3	Very poorly drained
w4	Swampy

* Detailed explanation of these ratings is available in Division of Land Research tech. Memo. 65/8 (unpublished).

Symbol and Rating	Explanation
p1	Rapidly permeable
p2	Moderately permeable
p3	Very rapidly permeable
p4	Slowly permeable
p5	Very slowly permeable
d0	Very deep soil, >60 in.
d1	Deep soil, 45–60 in.
d2	Moderately deep soil, 30–45 in.
d3	Moderately shallow soil, 20–30 in.
d4	Shallow soil, 10–20 in.
d5	Very shallow soil, <10 in.
m0	Very high water-holding capacity, >10 in. in 6 ft
m1	High water-holding capacity, 8–10 in.
m2	Moderately high water-holding capacity, 6–8 in.
m3	Moderate water-holding capacity, 4–6 in.
m4	Low water-holding capacity, 2–4 in.
m5	Very low water-holding capacity, <2 in.
t1	Moderate tillage difficulties
t2	Serious tillage difficulties
a0	Weakly acid soil, pH 6·0–6·5
a1	Neutral soil, pH 6·6–7·5
a2	Acid soil, pH 5·0–5·9
a3	Weakly alkaline soil, pH 7·6–8·0
a4	Alkaline soil, pH 8·1–8·5
a5	Strongly acid soil, pH $<5{\cdot}0$
a6	Strongly alkaline soil, pH $>8{\cdot}5$
c1	Weakly saline soil
c2	Saline soil
c3	Strongly saline soil
n0	Very fertile soil
n1	Fertile soil
n2	Moderately fertile soil
n3	Infertile soil
n4	Very infertile soil
I1	Simple irrigation water supply
I2	Minor problems in irrigation water supply
I3	Major problems in irrigation water supply
I4	Irrigation impracticable

APPENDIX II

Structural Features of the Main Forest Types Distinguished in the Kerema–Vailala Area

(*a*) *Mid-height Forest*

(i) *Small-crowned Swamp Forest.*—Canopy rather open, about 80 ft high. Emergents 100 ft high. Lower tree storeys usually open, locally dominated by sago or pandan. Dense sedge shrub layer to 7 ft. Thin woody, fleshy, and ferny climbers common. Pandans common, locally abundant. Tree ferns rare. Stilt roots very common. Pneumatophores and surface roots very common.

(ii) *Small- to Medium-crowned Basin Forest.*—Canopy rather irregular in height (average 85–90 ft) and closure. Emergents to 145 ft, average height 115 ft. Lower tree storeys moderately dense to dense. Shrub layer very variable, averaging 40% cover. Herb layer patchy, averaging 5% cover or less. Thick woody climbers present to moderately common; thin woody climbers common, locally very common. Epiphytes in crown present to common, lower down on bole present to rare, occasionally moderately common. Tree palms usually present, often moderately common to common. Shrub palms usually common, often present to moderately common. Rattan usually moderately common, often present to rare, occasionally common. Scrambling bamboo occasionally present, very locally moderately common to common. Pandans often rare to present, locally (Vailala basins) very common to abundant. Buttresses moderately common to common. Stilt roots locally common. Pneumatophores locally (Vailala basins) common.

(iii) *Small- to Medium-crowned Hill Forest.*—Canopy fairly regular in height (average 80 ft) and closure. Emergents occasionally to 130 ft, average height 110 ft. Lower tree storeys moderately dense to open. Shrub layer very variable, averaging 35% cover. Herb layer patchy, cover usually averaging $<5\%$, often $<1\%$. Thick woody climbers usually present to rare, often moderately common to common; thin woody climbers usually common, often present to moderately common.

Epiphytes in crown usually common, lower down on bole present to rare. Tree palms usually moderately common, often present or common. Shrub palms usually moderately common, often common or present. Rattan usually present to rare, often moderately common. Scrambling bamboo locally (on crests) moderately common to common. Pandans usually rare, often present or moderately common. Tree ferns rare. Low and medium-height buttresses moderately common, high buttresses present. Stilt roots locally moderately common.

(iv) *Very Small-crowned Hill Forest.*—Canopy at about 60 ft. Emergents scarce, to 80 ft high. Lower tree storeys moderately dense to open. Shrub layer moderately dense to open, cover averaging 20–40%. Thin woody climbers common. Low buttresses moderately common, high buttresses rare.

(v) *Upland Forest.*—Canopy usually well closed, at about 85 ft. Emergents scarce, averaging 100 ft, occasionally to 130 ft high. Lower tree storeys moderately dense to open. Shrub layer usually open. Herb layer patchy, averaging 5% cover or less. Thick woody climbers present; thin woody climbers moderately common. Epiphytes in crown present to moderately common, rare lower down on bole. Tree palms rare. Shrub palms present. Rattan present to rare. Pandans rare. Low buttresses moderately common. Stilt roots locally (at higher altitudes) common.

(vi) *Lower Montane Forest.*—Canopy 65–75 ft high. Emergents to 90 ft high. Lower tree storeys moderately dense to dense. Many slender individuals in shrub layer. Herb layer variable, averaging 10% cover, locally much higher (mosses). Thick woody climbers present to rare; thin woody climbers moderately common to common; ferny climbers often common. Epiphytes common in crown, moderately common lower down on bole. Tree palms absent or rare. Shrub palms rare. Rattan present. Pandans present to moderately common. Tree ferns present. Buttresses (high rather than wide) present to rare. Stilt roots moderately common, locally very common.

(*b*) *Tall Forest*

(i) Campnosperma *Swamp Forest.*—Canopy very open, about 100 ft high. Emergents to 130 ft high. Lower tree storeys open, locally sago or pandan. Dense shrub layer of *Hanguana* or tall sedge. Herb layer scarce. Thick woody climbers rare; thin woody, fleshy, and ferny climbers very common to abundant. Buttresses common. Stilt roots common. Pneumatophores common.

(ii) *Large-crowned Forest.*—Canopy irregular in height and closure, with many gaps, 100–115 ft high. Emergents to 150 ft high. Lower tree storeys moderately dense. Shrub layer open to moderately dense. Herb layer patchy, averaging 5–10% cover. Climbers generally moderately common to common. Epiphytes in crown present to common, present to rare lower down on bole. Tree palms present to common, occasionally rare or abundant. Shrub palms usually common, often moderately common, locally very common to abundant. Rattan usually present to moderately common, often rare, occasionally common. Pandans present to rare. Buttresses common. Stilt roots present to rare, occasionally moderately common.

(iii) *Open Large-crowned Forest.*—Canopy irregular, with large gaps, about 100 ft high. Emergents 120 ft high. Lower tree storeys moderately dense to open. Shrub layer variable, usually moderately dense, locally dense. Herb layer very scarce. Climbers generally common. Tree palms variable, present to common. Shrub palms common to very common. Rattan variable, present to very common. Pandans variable. Buttresses common. Stilt roots present to moderately common.

INDEX TO LAND SYSTEMS

Fig. 1.—*Nypa* palm fringing tidal creek with *Rhizophora–Bruguiera* mangrove on tidal flats behind (Alele land system). Patches of coconuts occur above high-tide level (right foreground).

Fig. 2.—Mixed *Nypa* and mangrove on tidal flat with abundant crab mounds adjacent to channel (Nipa land system). The small man-made clearing is used as a garden, with bananas, sweet potatoes, sugar-cane, and coconut planted on the crab mounds. The photograph was taken at high tide.

Fig. 1.—Swamp woodland on freshwater tidal flat (Murva land system) adjacent to tidal creek where brackish influence is shown by the *Nypa* palms (left). Note the top of a sago palm frond behind the *Nypa*.

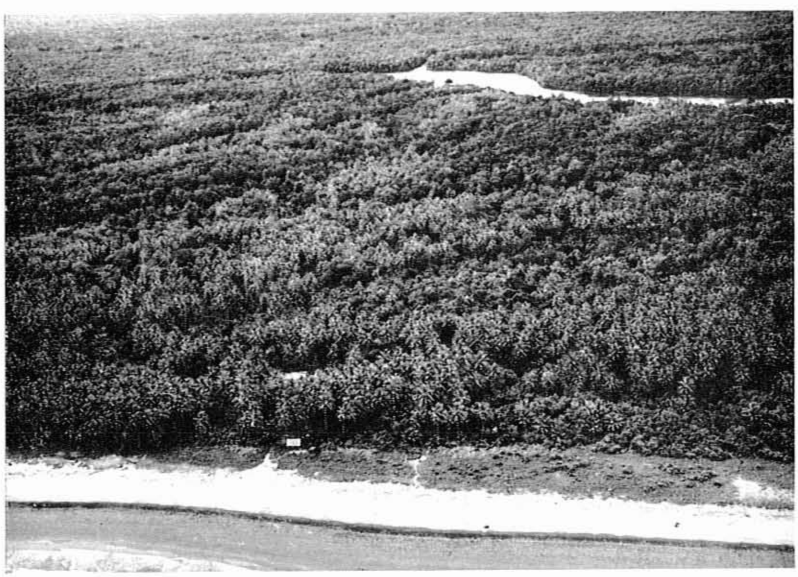

Fig. 2.—Coastal beach ridge barriers (Araimiri land system) showing the present beach and berm with creeping *Ipomoea–Canavalia*, and the linear pattern of beach ridges with indigenous coconut plantings and the intervening swales with swamp woodland. Note the dark-toned mangrove on tidal flats behind (left mid-ground).

Fig. 1.—Raised level beach plain (Malalaua land system) with tall large-crowned forest partly cleared and burnt to form mid-height *Imperata* grassland. The low undulating hills of Hauta land system are in the background.

Fig. 2.—Permanent non-tidal freshwater herbaceous swamp (Waigani land system) with tall *Hanguana* and abundant *Cyclosorus* fern. Beyond is freshwater swamp woodland (Movori land system) with scattered low trees overgrown with climbers.

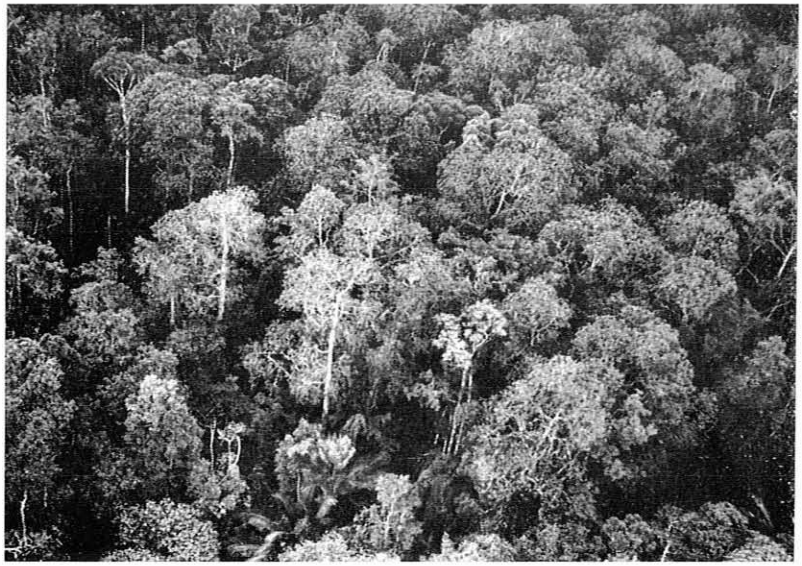

Fig. 1.—Permanent, stagnant, non-tidal freshwater swamp forest (Campnosperma land system) with tall *Campnosperma* trees and an undergrowth of sago.

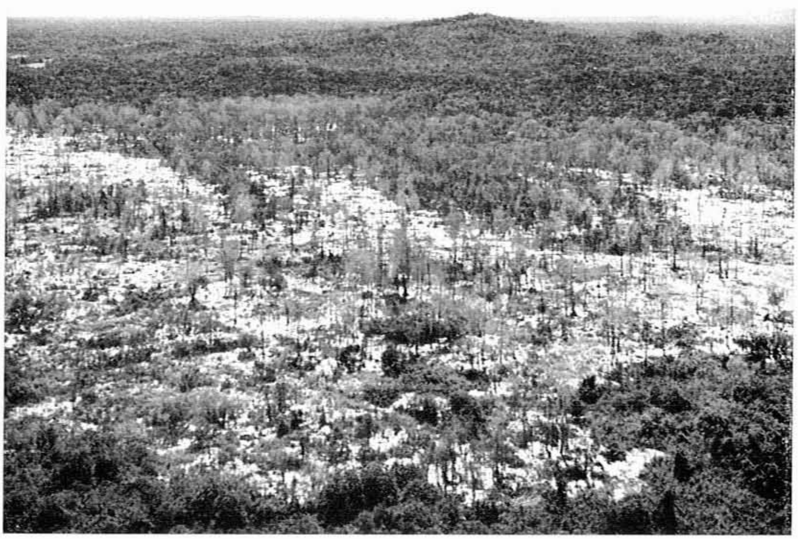

Fig. 2.—*Melaleuca* swamp savannah (Melaleuca land system) showing the blackened trunks of burnt trees inundated under several feet of water. These swamps are confined to the south-east of the area where the climate is strongly seasonal. The low undulating hills of Hauta land system are seen in the background.

Fig. 1.—Terminal part of the meander tract of the Tauri River showing open water and herbaceous and woodland swamp transitional to tall forest (Terapo land system). The taller vegetation occurs on embryonic levees fringing the river, on prior levees (foreground) where coconuts, sago, and bamboo are seen, and on prior scrolls (right background). This land is frequently flooded.

Fig. 2.—Prior levee and back plain of the meander tract of the Tauri River with dryland rice in the foreground and marginally disturbed tall open-canopy forest in the background (Tauri land system). This land is occasionally flooded.

Fig. 1.—Tall large-crowned forest with moderately closed canopy on the levee banks of the Vailala River, with lower open forest on an infilled prior meander in the centre foreground (Hepea land system). Note the *Octomeles* on the scroll (right mid-ground). The tall forest merges into mid-height basin forest on the poorly drained back plains in the background (Vailala land system).

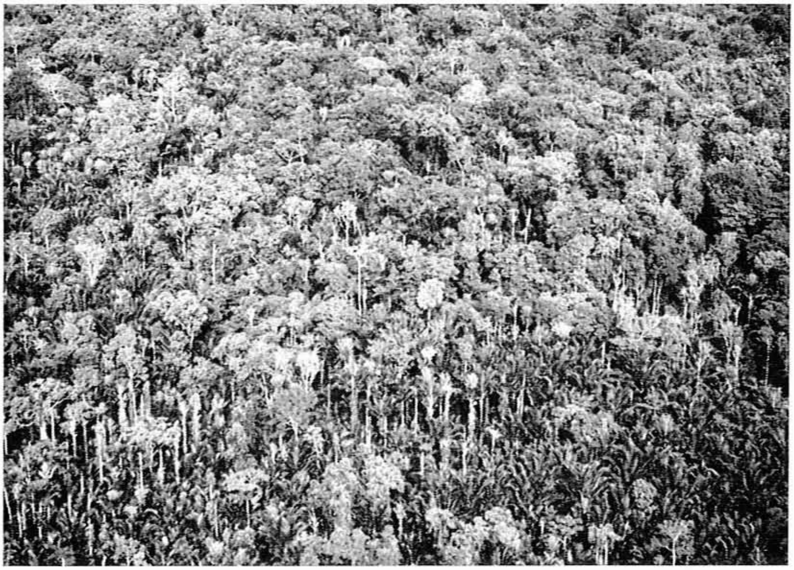

Fig. 2.—Mid-height medium-crowned basin forest with moderately closed canopy on an alluviated basin plain with swampy patches with sago in the foreground (Vailala land system).

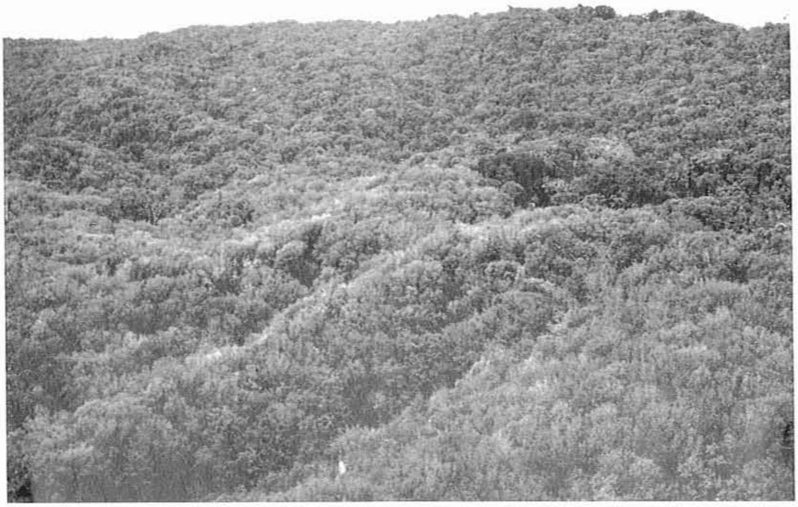

Fig. 1.—Undulating low hills with moderate slopes (Hauta land system) and tall large-crowned hill forest (mid-ground) partly replaced by rubber plantation near Epo (foreground). The steeper slopes of the ridge in the background are part of Maipora land system.

Fig. 2.—The gap in Rim Ridge cut by the Tauri River (mid-ground). The low hills with very steep slopes in the foreground, and Rim Ridge, form part of Maipora land system and bear mid-height small- to medium-crowned hill forest. The tall large-crowned forest adjacent to the river belongs to Hepea land system.

Fig. 1.—Benched spurs on the side of Wenna Creek at 5000 ft altitude showing an intensive pattern of garden regrowth (Kwambega land system) and several Kukukuku settlements. The steeper slopes at the back have scattered recent garden clearings and form part of Eruki land system.

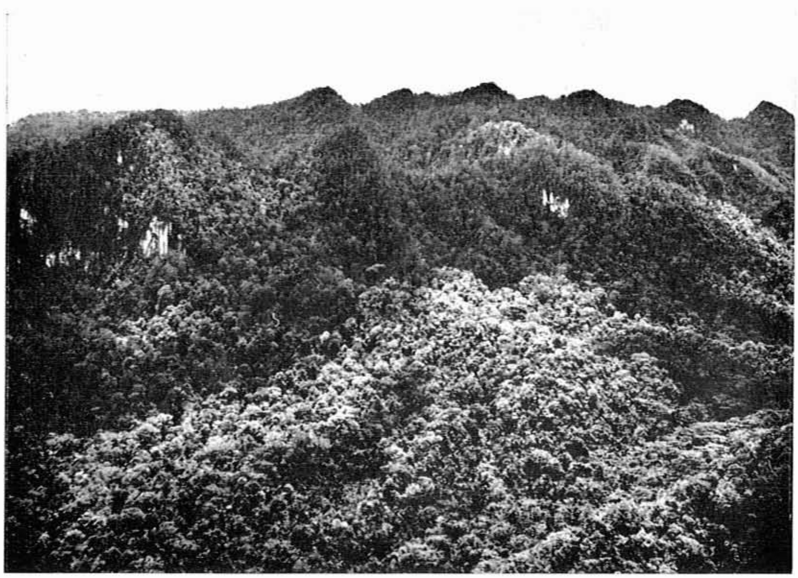

Fig. 2.—The serrated skyline of the karst plateau on the Saw Mountains (Saw land system) showing limestone pyramids with short bare cliffs. The smooth moderate slopes in the foreground, also on limestone, form part of Putei land system. The forest on both land systems is mid-height small- to medium-crowned hill and upland forest which becomes poor with very open canopies on the rockier ground.

Fig. 1.—Very steep and precipitous slopes with mid-height small- to medium-crowned hill forest with open canopies developed on conglomerates are characteristic of part of Kurai land system. Note the landslip on the oversteepened slope of the sharp bend in the Olipai River.

Fig. 2.—High hills with moderate to very steep slopes and tall medium- to large-crowned hill forest with scattered emergent *Koompassia* (Lohiki land system). The canopy is irregular in height and closure.

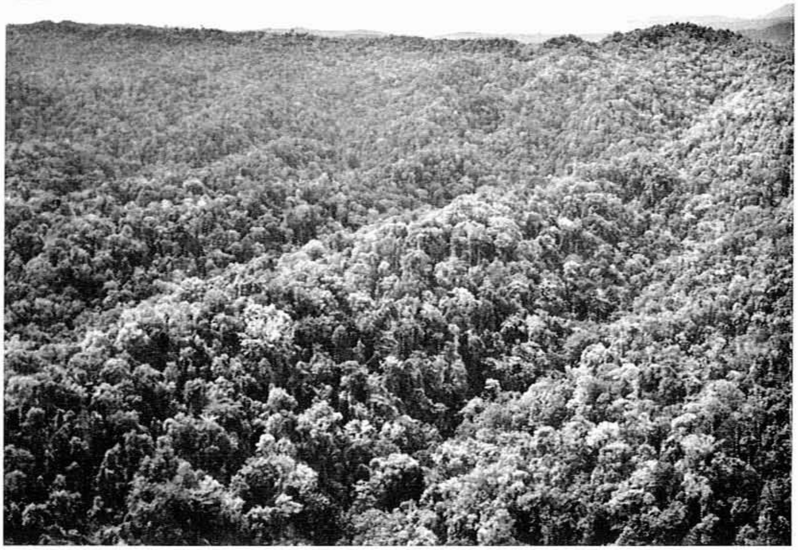

Fig. 1.—Parallel subaccordant high hill ridges with very steep slopes and a dense cover of mid-height small- to medium-crowned hill and upland forest (Nabo land system).

Fig. 2.—High mountain ridges with very steep slopes and small-crowned mid-height upland and lower montane forest (Eruki land system). The forests are much disturbed by past and present shifting cultivation.

Fig. 1.—High mountain ridges with very steep slopes, cliffs, small plateaux, and prominent dip slopes and small-crowned mid-height upland and lower montane forest (Kapau Complex land system).

Fig. 2.—A Kukukuku garden (typically unfenced) on Lohiki land system. Undergrowth is cleared first, then crops (bananas, taro, and sweet potato) are planted and the trees are felled (background). No burning is carried out and the crops emerge through the fallen branches (foreground).