Peat in the mountains of New Guinea

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SUMMARY

Peatlands are common in montane areas above 1,000 m in New Guinea and become extensive above 3,000 m in the subalpine zone. In the montane mires, swamp forests and grass or sedge fens predominate on swampy valley bottoms. These mires may be 4–8 m in depth and up to 30,000 years in age. In Papua New Guinea (PNG) there is about 2,250 km^2 of montane peatland, and Papua Province (the Indonesian western half of the island) probably contains much more. Above 3,000 m, peat soils form under blanket bog on slopes as well as on valley floors. Vegetation types include cushion bog, grass bog and sedge fen. Typical peat depths are 0.5–1 m on slopes, but valley floors and hollows contain up to 10 m of peat. The estimated total extent of mountain peatland is 14,800 km^2 with 5,965 km^2 in PNG and about 8,800 km^2 in Papua Province. The stratigraphy, age structure and vegetation histories of 45 peatland or organic limnic sites above 750 m have been investigated since 1965. These record major vegetation shifts at 28,000, 17,000–14,000 and 9,000 years ago and a variable history of human disturbance from 14,000 years ago with extensive clearance by the mid-Holocene at some sites. While montane peatlands were important agricultural centres in the Holocene, the introduction of new dryland crops has resulted in the abandonment of some peatlands in the last few centuries. Despite several decades of research, detailed knowledge of the mountain peatlands is poor and this is an obstacle to scientific management.

KEY WORDS: fire history; mire; montane swamps; Papua; peatland; subalpine; vegetation change

INTRODUCTION

The main island of New Guinea is the largest, highest and wettest tropical island in the world, being bisected by a cordillera of mountains that extend for 2,200 km north-west to south-east with a maximum altitude of 5,000 m. It lies almost entirely within the broad intertropical convergence zone associated with the Western Pacific Warm Pool. Therefore, monthly water surpluses are experienced by the entire island except for the southernmost plains of the Fly and Digul Rivers and areas of seasonal savanna around Port Moresby in the south-east (Hanson *et al*. 2001). Rainfall is highest in the mid-montane zone because orographic rain from the SE Trades and easterlies and vigorous local thunderstorms drenches the flanks of the ranges with annual totals from 3,000 to 10,000 mm. Some of the intermontane valleys are drier and it is in these highlands at 1,200–1,800 m that intensive agriculture occurs. Rainfall totals may level off above 3,500 m, but the summit areas are wet right to the highest peaks above 4,750 m (Prentice & Hope 2007, Hope 2014).

Peatlands occur at all altitudes on New Guinea owing to generally high rainfall and very high cloudiness. They can be classified into lowland, montane and subalpine types (Whinam & Hope 2005). Mapping of Histosols at medium resolution has been completed for Papua New Guinea (PNG) as part of a national resources database (PNGRIS; Hanson *et al*. 2011) but there is no equivalent dataset for Papua Province, Indonesia (Papua) (Figure 1). Little is known about the stratigraphy of the lowland peatlands and estimates of their area range from 80,000 to 135,000 km^2 (Paijmans 1990, Maltby & Immirzi 1993, Rajagukguk 1997, Hope & Nanson unpublished).

This article reviews the peatlands of the montane (> 1,000 m) and subalpine (> 2,900 m) zones of the main island (Figure 1). Covering an estimated 14,800 km^2, the peat characteristics, stratigraphy and age structure of these mires are better known due to botanical, palaeoecological and archaeological studies, allowing slightly more confident estimates of mean peat depth, volume and possible carbon stocks than for the lowlands. Most of these studies are from PNG but a few are from Papua (Hope 2007a). The main peat-forming vegetation communities are described with some examples of peatlands for which the stratigraphy and age profiles are known. In

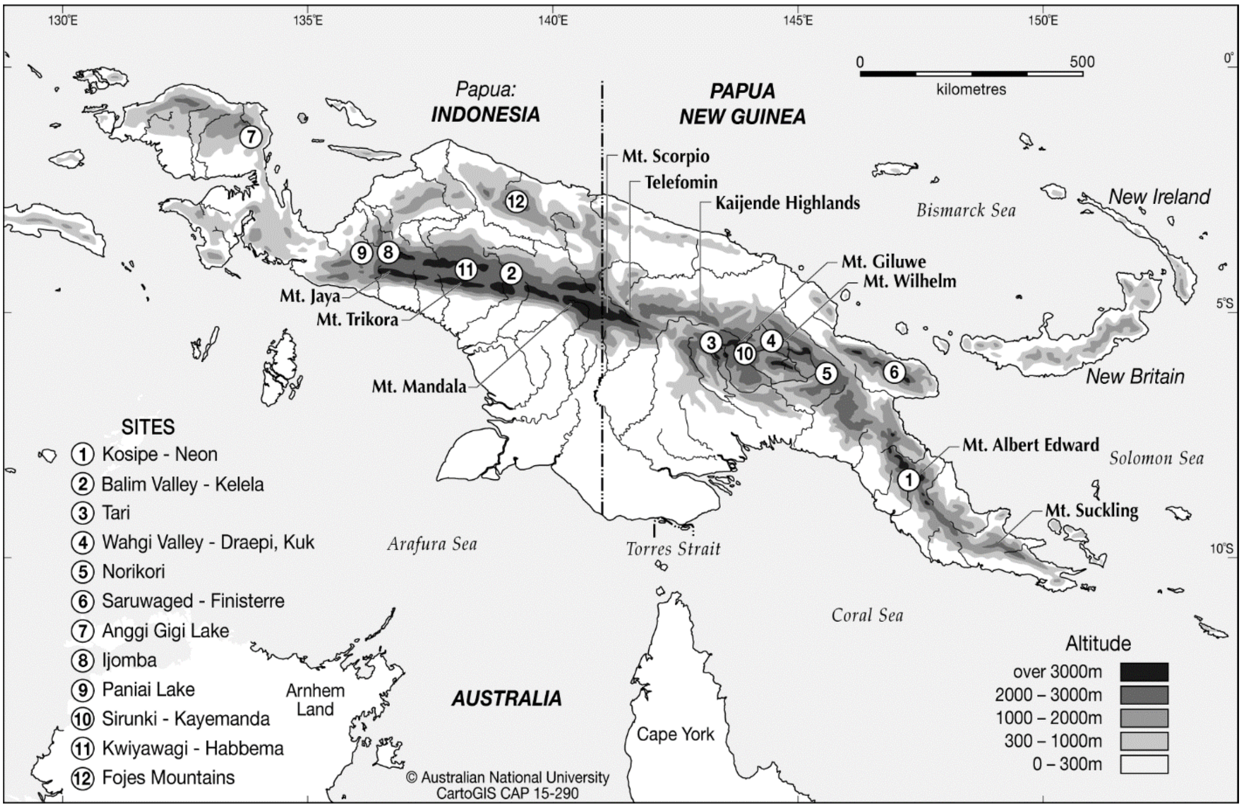

Figure 1. Map of New Guinea showing mountain areas and locations mentioned in the text.

general there are few data on peat chemistry or hydrology. The current management of these peatlands is also described.

PEATLAND SETTINGS

The peatlands of the montane zone are largely minerotrophic fens infilling valley floors and these include some very extensive peatlands occupying tectonic depressions or surrounding lakes. For example, a huge wetland of 419 km^2 occurs on the eastern side of Paniai Lake and has unknown depths of peat and lake sediments (Johns *et al*. 2007). Impeded drainage basins are common due to the active orogeny and lateral faulting that occurs throughout the island. The Tari basin in the western highlands of PNG has a complex of large montane swamps with deep peats developed due to tectonism and some volcanic flows (Haberle 1998). Because vulcanism has been extensive in eastern PNG, lava or tephra has blocked valleys in some places, allowing large areas of peatland to infill the basins. One example is the upper Wahgi River near Mount Hagen where mid-Quaternary volcanic lahars have reversed river drainage and extensive sedge-grass peatlands up to 15 m thick have formed in the last 50,000 years (Powell 1981). In some cases extensive peat sections are preserved but peat is no longer actively forming.

Soils containing volcanic ash are notably high in organic matter. This is attributed to the large amounts of allophane and aluminium oxides, which form stable compounds with organic matter (Bleeker 1983, Wood 1987, Hope & Hartemink 2007). This, in conjunction with the cool, wet climatic conditions, slows down the rate of organic matter mineralisation by soil micro-organisms. Palaeosols with buried organic horizons representing periods of greater organic accumulation in the past are also common in areas exposed to tephras. For example, on gentle slopes at Kosipe, a 40–80 cm thick dark band which is prominent in most profiles formed during a period of probable cooler temperatures *ca*. 50,000–15,000 cal. yr. BP. This horizon has been identified palynologically as the remnant of a peatland that formed under grass bog vegetation (Hope 2009).

Large river systems built levées behind which peats accumulated, as at Kelela swamp in the Baliem Valley of Papua (Haberle *et al*. 1991). This swamp infills an abandoned meander of the Baliem River and contains 5 m of fibrous peat that has formed in the last 7,000 years. At Kosipe (PNG) a shallow lake formed behind a levée and developed into an extensive peatland up to 7 m deep covering 18 km^2 (Hope 2009) (Figure 2). Karstic basins are also widespread in both limestone and ultramafic rocks, and many of these are infilled with peat. An example is 4 m of marginal peat near Anggi Gigi Lake in Papua dating back 15,000 years (Hope 2007b).

Away from waterlogged sites, high temperatures and abundant radiation assist with rapid organic breakdown, but this effect reduces with altitude due to lower temperatures and increased duration of daily fog. At altitudes around 2,700–3,100 m, with mean temperatures around 11 °C, organic breakdown can be less rapid than litter accumulation. Slopes are mantled by organic soils which thicken to peat where water seepages or spring lines are common. Above 3,600 m large areas of blanket mire occur on substrates with poor drainage such as volcanic, granitic and sandstone deposits. The 200 km^2 summit zone of the extinct stratovolcano Mount Giluwe has an estimated peat soil cover of 60 % with depths of 0.5–3 m. (Figure 3).

At the last glacial maximum, ice covered about 3,770 km^2 of land above 3,450 m on New Guinea (Prentice *et al*. 2011, Hope 2014). An array of topogenic mires has built up around glacial tarns and behind moraines. At Laravita Tarn at 3,650 m on Mount Albert Edward, 4 m of fibrous grass bog peat has infilled a tarn basin that formed *ca*. 15,000 cal. yr. BP. The ice which formed that basin also created an outwash fan that blocked the Neon Basin, a broad valley at 2,900 m altitude. An extensive *Astelia* cushion bog built up 2 m of peat over the past 9,000 years, but downcutting by the present-day stream is eroding the peat (Hope 2009). A complex of sedge fens is colonising lake sediments at Brass Tarn, a glacial basin on Mount Wilhelm (Wade & McVean 1969).

PEAT-FORMING VEGETATION

No comprehensive account of wetland vegetation exists for the entire island of New Guinea, as only scattered ecological survey work has been carried out. Although peat-forming communities are quite variable across the island, they can be described in broad terms. While many mire species are widespread, there are also intriguing patterns of endemism amongst currently-evolving taxa such as

Figure 2. Swamp forest, tall sedge and sedge-grass fen at Kosipe Swamp (2,000 m). The swamp and forest were burnt in 1998.

Xanthomyrtus, *Vaccinium*, *Gentiana*, *Eriocaulon* and *Ranunculus* (van Royen 1979–83, Johns *et al*. 2006). Hence, the vegetation units listed below probably cover a range of regional variants, and both floristics and community structures can vary with altitude. The terms fen and bog are used to indicate peat-forming vegetation with or mainly without access to mineral nutrients, respectively, but this has not been tested with nutritional studies (Whinam & Hope 2005).

The key ecological work on the large sedge-grass fens of the New Guinea Highlands was carried out 40 years ago by Flenley (1969), Powell (1970) and Walker (1972), with later studies at Tari and Norikori by Haberle (1996, 1998) and at Kosipe by Hope (2009). The first classification of subalpine and alpine mire vegetation associations based on relevé data was by Wade & McVean (1969) on Mount Wilhelm. That work has formed the basis for defining subalpine peatland communities on other mountains such as Mount Jaya (Carstensz) (Hope 1976b) and Mount Albert Edward (Hope 1975), and was summarised for the island by Hope (1980). Mount Trikora mires were also later compared to the Wade & McVean scheme (Mangen 1993).

Montane vegetation types (1,000–2,800 m)

In the montane zone, sedge- and grass-dominated communities form the most extensive peatlands but swamp forests with podocarps, oaks and pandans also occur. Although several *Sphagnum* species are known from New Guinea (Whinam *et al*. 2003), *Sphagnum*-dominated mires are rare and found mainly at the montane–subalpine transition (2,400–3,000 m).

1. Montane swamp forests

This forest complex of possibly several communities usually has an open low canopy which becomes more open and stunted in the wettest areas. Important species include the gymnosperms *Dacrydium nidulum* and *Dacrycarpus cinctus*, while *Podocarpus imbricatus* and *Pandanus* spp. are usually present as an understorey. Examples are described in more detail in Box 1. Swamp forest has been severely affected by fire, and Walker (1972) considers it to be preserved in only a small portion of its original range in the PNG highlands. Areas of former forest sometimes persist as an open woodland of stunted *Pandanus* spp.

Figure 3. The summit plateau of Mount Giluwe, with extensive blanket bog. The patches of subalpine forest, now tiny, were much more extensive 1,500 years ago.

2. Tall grass fen

This fen is dominated by tall grasses such as *Phragmites karkar* and sedges, which form dense stands up to 4 m in height with only a few sub-canopy species. The community forms coarse fibrous peat often intercalated with silt or clay. The fibrous peat may be several metres thick but is more usually only 1–2 m thick and not of great age. Similar peatlands occur at 1,000–2,500 m across the montane region. These have been termed mid-montane grass swamp by Paijmans & Löffler (1972), who list *Arundinella furva*, *Isachne* sp. and *Dimeria* sp. as the common grass species and *Macherina rubiginosa* as a prominent sedge in addition to *Phragmites*.

Box 1. Montane swamp forests: some examples.

Described by Walker (1972) from Kayemanda at 2,550 m as an open low forest, montane swamp forest also occurs with a closed canopy in the Southern Highlands of PNG (Johns 1980). At Kosipe the *Dacrydium* is co-dominant with *Podocarpus, Dacrycarpus, Castanopsis, Pandanus, Xanthomyrtus, Sericolea, Vaccinium* and *Dimorphanthera* with scattered *Cyathea* tree ferns (photograph below and Figure 2). A small aquatic *Pandanus* is common as an understorey shrub and *Freycinetia* is a common climber. The forest grows where some silts are present in the upper layers of the peat (Hope 2009).

On Mount Wilhelm at Komanimambuno (2,750 m), *Dacrydium* is absent and the low and stunted forest contains *Cryptocarya* sp., *Dacrycarpus cinctus*, *Decaspermum forbesii*, *Elaeocarpus ptilanthus*, *Pandanus giulianettii*, *Pittosporum ramiflorum*, *Prunus pullei*, *Syzygium* sp., *Timonius belensis* and *Weinmannia trichophora*. A *Vaccinium* species clambers into the canopy, and festoons of the climbing bamboo *Nastus productus* cover the lower branches up to 8 m. Open wet areas are dominated by *Isolepis subtilissimus* with scattered occurrences of *Deschampsia klossii* and *Ranunculus pseudolowi*. On drier parts of open areas there is profuse growth of *Alpinia* sp., grasses, *Gunnera macrophylla*, *Lycopodium* spp. and terrestrial orchids, and some shrubs such as *Coprosma papuensis* and *Rhododendron maius* (Hope 1976a)

Bog or swamp forest occurs near Tari and in the Levani Valley at 1,500–2,000 m (Johns 1980). It is floristically rich, with trees such as *Dacrydium, Podocarpus, Carpodetus*, Myrtaceae, *Glochidion*, *Homolanthus*, *Maesa*, *Pandanus* and *Nothofagus pullei* forming a variable canopy. A dense layer of small trees and shrubs is found beneath the canopy. The forest floor is relatively open with irregular sedge hummocks separated by pools. Similar forests occur east of Paniai Lake at 1,450–2,300 m with nearly pure stands of *Dacrydium* up to 34 m in height and occurrences of *Araucaria cunninghamii*. Bryophytes are abundant, including areas of *Sphagnum* around the tree bases. *Rapanea communis* and *Dacrycarpus imbricatus* are in an understorey with *Melicope* common in disturbed areas (Rappard & van Royen 1959).

3. Short grass fen

Many parts of the upper Wahgi valley are covered with pure or mixed stands of short grasses up to 1 m tall; *Leersia hexandra* may be the sole dominant or may share dominance with *Ischaemum barbatum* and *Callipedium parviflorum.* In other cases it is associated with *Phragmites karka*. The water table is near or at the surface during most of the year and a fibrous peat develops below the grasses (Powell 1970). This swamp type has also been found at Telefomin (Hope 1983) where *Leersia hexandra* and other grasses and sedges are about 30 cm high, with occasional shrubs or saplings of *Schefflera*, *Rhododendron***,** Sterculiaceae, *Eurya,* and *Macaranga* species present. Several ground ferns, including *Sticherus* sp. and *Blechnum* sp., are common along drainage lines while *Alpinia* sp., *Xyris* sp., *Eriocaulon* sp. and *Nepenthes* sp. occur within the grass tufts and *Eriocaulon* spp. dominate small wet depressions. Abundant buried logs and several stumps show that the area formerly supported trees.

4. Mixed sedge-grass fen

Sedge-grass fen borders small ponds in the volcanic landscape of the Wahgi-Baiyer River divide. Pure stands of the sedge *Machaerina rubiginosa* often grow as floating mats of vegetation, 0.5–1 m high, over several metres of water; or, where the water is shallower, as tall fen with other sedges and grasses (Box 2). A dark peat develops beneath the vegetation. At Kelela Swamp in the Baliem Valley, Haberle *et al*. (1991) studied a sedge-grass swamp with a similar assemblage of low sedges (*Carex brownii*, *Elaeocharis* sp., *Fimbristylis dichotoma*, *Lipocarpha chinensis*, *Machaerina rubiginosa*, *Schoenoplectus* sp., *Schoenoplectiella mucronata*) and grasses (*Echinochloa crusgalli*, *Imperata* sp., *Isachne* sp., *Ischaemum* sp., *Leersia hexandra*, *Phragmites karka*).

5. Tall sedge fen

A mosaic of grass and sedge fens at Kayemanda Swamp (Walker 1972) includes pure sedge fens of *Machaerina, Isolepis* and *Eleocharis spp.* Although scattered tall grasses (*Sacharum* spp.) may be present, Walker distinguished eight swamp species associations with *Machaerina rubiginosa* acting as an important component in each. This is one of the few studies to consider successional directions in mire vegetation (Box 3). At Kosipe, in the Ivane Valley, tall sedge fen of *Isolepis* sp. dominates the wettest areas as a tall sedgeland up to 2 m in height (Box 3), while a zone of *Eleocharis sphacelata* follows stream lines. Low shrubs of *Melastoma* and *Gonocarpus,* ferns and fern allies including *Blechnum, Gleichenia* and *Lycopodium spp.* are common (Hope 2009).

Box 2. Mixed sedge-grass fen at Woitape.

In the Wahgi Valley, e.g. at Woitape near Kosipe (1,500 m) (right), in addition to the sedge *Machaerina rubiginosa,* other sedges such as *Cyperus globosus* and the rush *Juncus* cf. *prismatocarpus* are important, together with the grasses *Dimeria dipteros* and *Leersia hexandra*, and herbs such as *Eriocaulon hookerianum* and *Limnophyla aromatica*. Other species are present at lower frequency, including *Arthraxon hispidus, Isachne globosus*, *Ischaemum barbatum, Phragmites karka* and *Sacciolepis indica* among the grasses; and *Cyperus haspan*, *Eleocharis* sp., *Lipocarpha* sp. and *Rhynchospora rugosa* among the sedges. The forbs *Emilia renanthoidea, Lactuca* sp., *Dysophylla verticillata*, *Plectranthus* sp. and *Viola arcuata* are present, and *Xyris* sp. and *Thelypteris palustris* are also recorded. The shrubs *Melastoma affine* and *Glochidion* sp. and the scrambling *Nepenthes* sp. and *Geitonoplesium cymosum* appear in less wet areas while the fern *Dennstaedtia* sp. and *Lycopodium cernuum* are common in all sample plots (Powell 1970).

Subalpine vegetation types (2,700-4,550 m)
The greatest diversity of mire communities is found in the subalpine zone where a range of mat- or cushion-forming lilies and other herbs, shrubs, ferns, and bryophytes form specialised herbfield and hard cushion fens and bogs. Shrubs sometimes form an open heath with some of the non-woody plants.

6. Sphagnum-Gleichenia *bog*
Sphagnum species in New Guinea do not form cushions and the moss generally contributes as a ground layer in sedge or fernlands rather than dominating. It is only a minor contributor to peat formation. Various occurrences of this community are described in Box 4.

7. Gleichenia vulcanica *bog*
Fronds of the rhizomatous fern *Gleichenia vulcanica* can form a dense sward in which few other species are present. Although the community is described from Mount Wilhelm it is far more common on Mount Giluwe and Mount Scorpio where it is the most extensive subalpine community. Like *Astelia* bog (see *10*), *Gleichenia* bog does not tolerate inundation, and forms a blanket bog on gentle slopes. The fern readily colonises wet seepage areas on bare rock and consequently can be found on very steep slopes as well, in an association which Wade & McVean (1969) distinguish from the mire association. Many of the fronds in a mature stand are dead or dying, giving a sombre grey-black appearance and making the community vulnerable to fire. The community regenerates quickly after a light fire by shooting from the rhizomes and this ability may explain its great extent on Mount Giluwe compared to grasslands. Severe fires following drought can burn the peat soil and kill the fern completely and since the fronds seem to be sterile, such sites are colonised by grassland which will only slowly be invaded by fern. The importance of *Gleichenia* bog on Mount Scorpio (which is almost devoid of grassland) reflects very wet conditions (> 11,000 mm pa) and widespread rock exposures which are due to a very low weathering rate of the

Box 3. Tall sedge fen.

Describing the eight tall-sedge swamp associations at Kayemanda Swamp, Walker (1972, pp. 492–493) states that "*Machaerina rubiginosa* is important to greater or lesser degree, throughout this sequence. It may be thought of as beginning in water usually > 25 cm deep, which *Eleocharis sphacelata* shares with *Machaerina rubiginosa*, *Schoenoplectiella mucronata* and a *Juncus* sp. As the deeper water is occluded, *Machaerina rubiginosa* becomes more consistently plentiful and several aquatic dicotyledons (e.g. *Nymphoides* sp., *Limnophila aromatica*) establish. These remain as the water becomes still shallower (most of it now between 5 and 25 cm depth) but more species are added including *Hydrocotyle* sp., *Carex gaudichaudiana* and, where the water is shallowest, *Lobelia angulata*, *Fimbristylis dichotoma*, *Thelypteris* sp., and even *Sphagnum* sp. Despite this there is no change in the appearance of the deposit, which is usually a brown coarse detritus peat. The next development is associated with the accumulation of peat and litter, especially around the tussocks of *Machaerina rubiginosa* and *Schoenus curvulus*, so that the open water becomes discontinuous, and the loss occurs of some totally aquatic species such as *Eleocharis sphacelata* and *Limnophila aromatica*. Vegetation at this stage virtually ceases to partake of the general circulation of water in areas less advanced elsewhere in the swamp. On balance, this probably leads to more rapid accumulation in the pools and a strong tendency to the establishment of a continuous vegetation cover. The strong tussocks of *Machaerina rubiginosa* act as centres for this and convex hummocks of vegetation are formed through which *M. rubiginosa* continues to grow".

The photograph (right) shows tall sedge fen with *Macharina rubiginosa* at Kosipe (see text).

diorite, rather than disturbance. The bog alliance is rare on Mount Albert Edward and the limestone mountains, but is widespread on Mount Suckling (Stevens & Veldkamp, 1977), south of Mount Victoria (Allen Allison personal communication) and on Mount Trikora (Mangen 1993).

8. Bog heath

This is the only NG subalpine mire community in which shrubs have a significant structural role; an interesting contrast to the widespread occurrence of heath or shrubland bog formations in other parts of the world. This is all the more surprising because some of the characteristic families of woody bog taxa, e.g., Ericaceae and Myrtaceae, are present.

On Mount Jaya, Hope (l976a) describes a *Poa lamii*-*Vaccinium amblyandrum* bog in which a prostrate shrub mat of *Vaccinium*-*Xanthomyrtus klossii* is intergrown by cushion plants and tuft grasses. Scattered erect shrubs of *Rhododendron* spp., *Trochocarpa dekockii* and *Styphelia suaveolens* are present. Mangen (1993) reports a similar open heath on wet valley floors at 3,650 m on Mount Trikora. Also present are *Styphelia suaveolens, Tetramolopium klossii, Trochocarpa dekochii* and abundant large cushions of *Rhododendron saxifragoides*. Grasses and up to 50 % cover of robust tussocks of the sedge *Gahnia javanica*, together with mats of *Thamnolia* lichens, are also characteristic.

A similar structured heath with *Vaccinium* and *Xanthomyrtus* (but not *Poa lamii*) occurs on Mount Scorpio, PNG. Although the heath occupies gentle slopes the substrate is peat with depths commonly over 1 m. Bare areas covered by lichen and clumps of *Gahnia* are again common. Mat-forming shrubs have not been described on bogs in eastern New Guinea but are mentioned for the Kaijende highlands (Takeuchi 2007). The altitudinal range of the *Vaccinium*-*Xanthomyrtus* bog alliance is quite wide as it occurs on paths as low as 3,000 m and up to

Box 4. *Sphagnum*-*Gleichenia* bog: some examples.

On drier sites near sedgelands at Kayemanda, a suite of species including the fern *Gleichenia vulcanica* and shrubby *Vaccinium amblyandrum* are present; whilst *Sphagnum* spp., beginning around the *M. rubiginosa* tussock margins, spread to form a continuous ground layer between the hummocks (Walker 1972).

Farther west, at around 2,850 m in the Kaijende Highlands south of Porgera, Takeuchi (2007) found similar mosaics of *Sphagnum* - *Gleichenia* bog. The *Sphagnum* facies is found in hollows and flats where the water table is at the surface. The species are not stated but possibly include *S. junghuhnianum, S. antarcticum* and *S. cuspidatum.* Takeuchi also observed *Sphagnum* mires in the Fojes Mountains of Papua at 1,400 m north of the Wahgi Valley.

Gillieson *et al*. (1990) report a marginal fen at a small lake at Nurank where *Sphagnum* and sedge peat form a dense floating mat over water.

Hope (1980) describes *Sphagnum* forming a rim around small highly oligotrophic tarns at 3,600 m on Mount Scorpio, Star Mountains (shown in the photograph).

Similar occurrences are noted by van Royen (1967) on Mount Albert Edward, where *Sphagnum* sometimes dominates in a herbfield with *Euphrasia, Plantago aundensis, P. depauperata, P. lanigera, Ranunculus amerophylloides* and *Gentiana ettingshausenii.*

4,000 m on Mount Jaya. The habitat does not seem to be sufficiently wet to exclude tussock grassland, and nutritional factors may play a role. The community is bordered by *Deschampsia klossii* tussock grassland on slopes, and grades to hard cushion bog on more inundated sites.

9. Hard cushion bog

In very flat areas subject to inundation, cushion-forming plants become dominant and coalesce to form a firm, undulating surface with only scattered tufts of sedges and grasses (Box 5). Takeuchi (2007) found hard cushion bog to be widespread in the Kaijende highlands, where it forms a blanket bog on moderate slopes. Hard cushion bog does not form large stands, but is a distinctive formation above 3,500 m on Mount Albert Edward, Mount Bangeta, Finisterre Mountains and Mount Giluwe (the easternmost locality for *Rhododendron saxifragoides*). It is absent from Mount Wilhelm, probably due to the steep topography.

10. Astelia alpina *bog*

The cushion- and mat-forming lily *Astelia alpina* can occupy a wide range of habitats but it dominates subalpine and alpine bog as robust cushions 30–60 cm in diameter and 10–30 cm thick. It has been described from restricted stands on Mount Wilhelm but is much more extensive on Mount Trikora, Mount Giluwe, Mount Scorpio and Mount Albert Edward. The community has a wide altitudinal range of 2,700–4,250 m, occurring at lower altitudes on poorly drained level areas along the upper Baliem, on the Kaijende Plateau and in the Neon Basin (Hope 1975) (Box 6). At higher altitudes, Wade & McVean (1969) distinguish an alpine *Astelia alpina* community and Mangen (1993) found that *Astelia* is not restricted to peat and but spread onto clay soils. It seems possible that the cushion habit is an advantage in colonising frost-disturbed ground in the alpine zone, but at lower altitudes this role is subordinate to the function of providing microrelief in boggy situations. In either role, the successful *Astelia* cushion becomes liable to invasion by dwarf shrubs or herbs.

11. Grass bog

Grass bog is characterised by a sparse growth of small tussocks and tufts of grasses and an abundant growth of herbs including, particularly, *Ranunculus, Plantago, Potentilla* and *Gentiana* species. Stunted

Box 5. Hard cushion bog.

Gibson & Hope (1986) list the taxa in Papua as *Plantago polita, Oreobolus pumilio, Carpha alpina, Centrolepis philippinensis* and *Astelia alpina* as widespread elements, while species such as *Potentilla foersteriana* var. *brassii*, *Ranunculus* sp., *Trachymene pulvilliforma* and *Isoetes hopeii* are characteristic of the Maoke Range. Various species of *Gentiana, Plantago* and *Eriocaulon* may contribute to the bog in other areas. A prostrate shrub, *Rhododendron saxifragoides*, forms hummocks up to 80 cm in height and mat-forming shrubs are also common (see photograph below; also Figure 6). On Mount Trikora, Mangen (1993) noted that waterlogging-intolerant plants, for example *Danthonia oreoboloides, Deyeuxia brassii, Agrostis rigidula* var. *remota, Carpha alpina, Plantago depauperata* and occasional mosses, would colonise larger cushions.

shrubs of *Styphelia*, *Drapetes* and *Trochocarpa* are usually present and cushion species are common, e.g. *Danthonia oreoboloides, Oreobolus pumilio*, *Centrolepis philippinensis, Eriocaulon* spp. and bryophytes. Tuft sedges are common in the wettest areas between the cushions. Grass bogs have been reported from Mount Wilhelm, Mount Jaya and Mount Albert Edward (Box 7), and grass-dominated mires occur in various forms throughout New Guinea. The habitat is wetter than that of the previous bog types and periodic inundation occurs. Hard cushion bog and tussock grassland merge with this community at its wetter and drier margins, respectively.

Box 6. *Astelia alpina* bog.

The photograph shows *Astelia alpina* bog at Neon Basin (2,950 m). A wide range of small grasses and herbs grow between or in the cushions, and stunted shrubs may be present. Mangen (1993) found that the bog supports *Isolepis subcapitatus* and some of the Hard Cushion Bog taxa such as *Oreobolus pumilio*, *Potentilla forsteriana* var. *forsteriana* and var. *brassii*, *Carpha alpina* and *Plantago aundensis*. The habitat receives abundant surface water but seems to be fairly free-draining, so that the community is common at the bases of slopes and along channel margins. The subalpine bog merges with several mire communities including short grass bog and hard cushion bog. On very wet mountains such as Mount Scorpio, this community forms a blanket bog.

Box 7. Grass bog.

An example of grass bog at Ijomba, Mount Jaya (3,820 m) is shown in the photograph. *Deschampsia klossii* is a widely distributed medium-sized tussock grass found in a range of habitats which often forms a dense grassland over sapric peats that are often over 50 cm deep. At Laravita Tarn, Mount Albert Edward, fibrous grass peat is more than 4 m deep (Hope 2009).

12. Sedge fens

Several simple sedge fen communities are widespread across the mountains; occupying tarn margins, areas of flooding and aquatic habitats. Paijmans (1976) thought these may have been divided into too many community types on Mount Wilhelm by Wade & McVean (1969). There are certainly distinct communities that are widespread across the island and which occupy waterlogged habitats. Some examples are described in Box 8 but much more floristic work is needed to clarify their ecological relationships and environmental gradients.

Box 8. Sedge fens: example types.

Brachipodium-*Carex* fen, found on Mount Wilhelm below 3,450 m (the photograph on the right was taken at 3,420 m) is typical of a group of graminoid-dominated fen associations which have the structural form of closed grassland or sedgeland 20–40 cm in height. These fens occur at relatively low altitudes and may be related to montane rather than subalpine mire vegetation. *Carex capillacea* and several grasses are co-dominant on Mount Wilhelm and there is a sparse herbaceous understorey on the soft peat soils. A similarly structured fen (dominated by an unidentified sedge) occurs between 3,300 and 3,520 m on Mount Scorpion, and analogous fens are known from Mount Albert Edward. Fens in this group have probably been ignored in many mountain areas and the existence of a range of types is very possible.

Carpha alpina fen consists of open tufts and cushions of *Carpha* with tufts of stunted grasses and some other sedges, and abundant bryophytes on bare peat. The community is common on areas subject to inundation over a wide altitudinal range on Mount Wilhelm and is also very common on other New Guinea mountains as high as 4,500 m. Soils may be stony or organic, and the fen plays a pioneer role in colonising lake and pond edges that are subject to flooding.

Uncinia riparia closed sedgeland is reported to dominate a simple alpine fen on Mount Trikora (Mangen 1993) with *Geranium lacustre*, *Ranunculus pseudolowii* and occasional small tussocks of *Deschampsia klossii*.

Wade & McVean (1969) distinguish three simple types of open wet sedge fen, dominated respectively by *Carex echinata*, *C. gaudichaudiana* and *Isolepis crassiusculus* on Mount Wilhelm. All three associations consist of scattered to close-packed tufts of sedge 10–20 cm in height, occupying peaty areas usually flooded by 5–20 cm of water, with relatively few subordinate species. As with the taller closed sedgeland fen, these associations can be regarded as representative of a group of fens which can invade shallow water bodies in the initial stages of hydroseres (see photograph on the right).

Mangen (1993) describes wet sedgelands of *Carex* cf *celebica*, *C. bilateralis* and *C. gaudichaudiana* with occasional grasses such as *Festuca crispato-pilosa*, *Anthoxanthum horsfeldii* and herbs such as *Ranunculus amerophylloides* and *Triplostegia glandulifera* on Mount Trikora.

Carex gaudichaudiana fen, at least, appears to be common on Mount Jaya and Mount Scorpio as well as on Mount Albert Edward, and more detailed surveys will probably demonstrate several new associations occupying particular niches and altitudes. This species of *Carex* forms extensive and deep peatlands in southern Australia and New Zealand (Whinam & Hope 2005).

13. Aquatic vegetation

Several aquatic vegetation communities are known, although few have been fully described. Most contribute to organic deposits or merge with peatland vegetation.

Isoetes tarn community

A distinctive aquatic community occupies tarn and lake floors in water depths averaging 50–100 cm. Large rosettes of *Isoetes habbemense* (Mount Trikora, Mount Scorpio), *I. stevensii* (Mount Giluwe) and *I. neoguineensis* (Owen Stanley and Saruwaged Ranges) up to 30 cm in diameter form an open and usually rather regular cover in the soft organic oozes (Croft 1980). The community is rare on Mount Jaya and absent from Mount Wilhelm. The spores possibly arrive in new tarns with water birds.

Callitriche palustris and *Isolepis crassiuscula* aquatic community

Wade & McVean (1969) found these species in shallow water in tarns on Mount Wilhelm. Hope (1975) observed *Callitriche palustris* in deeper parts of a tarn at 3,650 m on Mount Albert Edward. Brass (1941) notes *Isolepis crassiuscula* in the water, and *Carex fascicularis* as riparian stands up to 80 cm tall, in the outlet stream and on the shores of Lake Habbema at 3,250 m.

Other aquatic vegetation

Mangen (1993) notes shallow pond vegetation of *Isolepis fluitans, Schoenus maschalinus* and *Isolepis* sp. Hope (unpublished) observed abundant aquatic plants in Lake Habbema forming a dense layer of macrophytes that included *Potamogeton* sp. together with bottom-rooted rosette *Isoetes habbemense* and a charophyte forming an aquatic community in water depths to 3 m. An unidentified sedge occupies some stream channels on Mount Scorpio. Van Royen (1967) remarks on an *Isolepis fluitans* stream community on Mount Albert Edward and in the Neon Basin. Hope (1975) has noted a *Gonocarpus micrantha* community forming mats on the floors of ephemeral ponds in this area.

14. Alpine mosslands

Wade & McVean (1969) described moss-dominated communities from the highest and most shaded summit area of Mount Wilhelm. Mangen (1993) describes a mossland on Mount Trikora with *Ranunculus bellus*, *Centrolepis philippensis, Keysseria pinguiculiformis* f. *nana*, *Potentilla forsteriana* var. *brassii* and *Uncinia compacta* var. *alpina*. Only a small area of wet mossland was found on Mount Jaya (Hope 1976b), but the association was probably an alpine mire (Box 9).

This mossland community is found on areas that were formerly ice- or snow-covered and is probably successional to grass bog. On Mount Wilhelm the mosslands occupy sandy peats which have buried deeper peats (Hope 1976a).

Box 9. Alpine mossland on Mount Jaya.

Alpine mossland with *Ranunculus* at 4,450 m on Mount Jaya. This area has been deglaciated within the last century. Plant cover is incomplete and consists of small mats of moss with scattered small tuft or cushion species, including *Poa callosa Potentilla foersteriana*, *Uncinia* sp. and abundant cushions of *Ranunculus saruwagedicus*.

PEATLAND EXTENT

Table 1 shows the extent of peatland in the mountains of New Guinea, and estimates the possible volume of organic soils and sediments. Data for PNG are based on selected classes of Histosols that have been mapped in PNGRIS, a Resource Information System prepared by the CSIRO (Australia) that compiles soil and land-use categories. The data on wetland soils (mainly Histosols such as Tropohemists and Tropofibrists) were compiled for the montane zone of PNG. An estimate of total area was made for the montane peatlands of Papua Province based on relative frequency of the swamp types compared to PNG. The estimates of peat thickness for Papua were based on just a few stratigraphic investigations and some observations in four regions of the main range (Mount Jaya, Kwiyawagi, Mount Trikora, the Baliem) and reports from two other regions (Paniai Lakes, Anggi-Gigi Lakes). The extent of subalpine peatlands is calculated for the area above 2,900 m because topogenic mires and blanket bog become very frequent in this altitudinal zone.

A recent estimate of the subalpine area above 2,900 m based on a 60 m DEM gives values of 11,771 km^2 in Papua and 6,705 km^2 in PNG (Prentice *et al*. 2011). A tentative estimate is that 22 % of these areas are mires or have deep organic soils. Conservative estimates of mean depths provide approximations for the volume of peat in montane New Guinea, noting that the area of montane habitat is about 2.5 times larger in Papua than in PNG.

It can be seen that the area of montane peatlands is around 50 % of the area of the organic terrains of the high mountains above 2,900 m; yet the subalpine area contributes about the same peat volume (and carbon store) as the deeper but less extensive montane swamps. However, a single area such as the 410 km^2 wetland east of Paniai Lake may have much thicker peat than the average used here, so the relative importance of montane peatlands may increase with further research.

Table 1. Estimates of the extent and possible volume of organic soils and sediments of montane and subalpine peatlands on the main island of New Guinea, for Papua New Guinea (PNG) and the whole island (NG).

Dominant vegetation	Peat types	Altitude range	Peat thickness (m)	PNG area (km^2)	PNG volume (Mm^3)	NG area (km^2)	NG volume (Mm^3)
Montane swamp forest	fibrous wood peat	500–3000	1.5–8.5	1,419	3,548	2,900	7,250
Tall and short sedge - grass fen	fibrous peat, humic clays	500–2900	2.0–9.0	839	3,356	1,780	7,120
Subalpine moorlands and fens: e.g. *Astelia* - *Gleichenia* blanket bog, hard cushion bog, grass bogs and fens, sedge fens, mosslands	humic and fibrous peats	2900–4500	04–3.0	3,707	5,561	10,200	15,300
Totals				**5,965**	**12,465**	**14,800**	**29,670**

PEAT CHARACTERISTICS

The montane sedge-grass peats are coarsely fibrous to partially decomposed with pH in the range 6–6.5 (Walker 1972). *Sphagnum* peats and other high-altitude ombrotrophic mires have pH values in the range 3.4–5.5 (Hope 1976b, Mangen 1993). These peats vary from fibrous to humic in texture. Bulk density has not been generally measured although Wood (1987) obtained values of 0.71– 0.83 g ml^{-1} for 'Humic Brown Soils'. These values probably reflect a substantial clay component derived from weathered tephra. Water content of most montane peats is 92–98 % (Haberle 1998) with loss-on-ignition values consistently above 70 % (Powell 1970) except where diluted by tephra. Most subalpine peats are similar.

Little work has been carried out on peat chemistry in New Guinea. The humic brown soils have a carbon content of 5–15 % and pH averaging 5.1, and other PNG highland Histosols are described in survey work by Haantjens (1970). Subalpine peats have been chemically analysed from Mount Jaya (limestone), Mount Trikora (sandstone), Mount Wilhelm (granidiorite) and Mount Albert Edward (schist) (Wade & McVean 1969, Hope 1975, Hope 1976b, Mangen 1993). Table 2 shows similar features in the peats with organic C content 20–35 % and moderate acidity (pH 5–6). The peats on limestone are slightly less acid (pH 6–6.5).

Peats in the PNG Highlands and at Mount Wilhelm and Mount Albert Edward contain tephra throughout, including discrete bands (Figure 4). Wood (1987) found that the reaction to sodium fluoride was strongest in the surface horizon, suggesting a higher content of allophane and non-crystalline material such as glass. Although tephra is absent from Papua the values for extractable nutrients from Mount Jaya are similar to those for the PNG mountain peats. Phosphorous content is low but concentrations are variable in different peats. Total base cations average 58 me 100 g^{-1}, with calcium being the dominant exchangeable cation. Levels of sodium are surprisingly high in some samples, perhaps reflecting inputs of marine aerosols in rain.

Peat accumulation rates for fresh red fibrous peat fall in the range 3–17 cm 100 yr^{-1} with slower rates of 2.5–6 cm 100 yr^{-1} for humified peats and some exceptions such as Norikori Swamp where rates of 20.8 cm 100 yr^{-1} were observed in the late Holocene (Haberle 1996, 1998). Subalpine peat sections such as Imbuka (Hope 1976a), Laravita Tarn (Hope 2009) and Ijomba (Hope 1976b) have long-term accumulation rates of 2.9, 3.7 and 4.2 cm 100 yr^{-1} respectively.

PEAT FORMATION HISTORIES

The history of the subalpine mires reflects both glacial and post-glacial changes. On Mount Wilhelm at Komanimabuno (2,740 m), 300 cm of grass-sedge peat accumulated under cold conditions from 22,000–14,000 cal. yr. BP after which the site was invaded by swamp forest with a much slower organic accumulation rate, presumably reflecting increased water use by the forest under warmer conditions (Hope 1976a). Twelve peatlands that formed on formerly glaciated sites have been analysed for pollen and are listed by Prentice *et al.* (2005). Initial peat formation ages are *ca*. 14,000–18,000 cal. yr. BP but the highest sites above 4,200 m (Mount Giluwe and Mount Wilhelm) only form peat after 12,000 cal. yr. BP. An example on limestone terrain is Ijomba Mire on the Kemabu Plateau which was deglaciated *ca*. 16,500 cal. yr. BP. At first the site was free-draining but finally sealed with peat around 7,300 years ago. It has accumulated 3 m of peat under a mixed shrub - sedgeland since then (Hope & Peterson 1976). The glacial times seem to have allowed an extension downslope of moorland peat and humic build-up, as an organic-rich layer is preserved in soil profiles down to 2,000 m as at Kosipe (Hope 2009).

In contrast, the montane swamps have a wide range of ages related to the formation of basins by tectonic or other processes. Peat formed on volcanic lahars at 1,500–1,800 m altitude around Mount Hagen more than 50,000 years ago and developed on valley floors under swamp forest to considerable thickness. Powell (1981) analysed peats formed in hollows in the ashfield at Draepi (1,885 m) with an age range of 38,000–17,000 cal. yr. BP and found they had formed under swamp forest. Other old montane peatlands include Sirunki Swamp at 2,500 m altitude with more than 25 m of sediment dating back more than 35,000 years (Walker & Flenley 1979). At Kosipe Swamp at 1,932 m a stream levée created a wetland about 50,000 years ago and this peatland expanded up-valley. A second core close to the head of the swamp (Figure 2) has a younger initiation date of 26,500 cal. yr. BP (Hope 2009). The swamp now contains > 5 m of peat over an area of 18 km^2.

Löffler (1972) reports a bed of peat > 20 m thick dammed by a volcanic lahar and underlying the 50,000 year old Tomba ash at Alkena in the Tambul Valley near Mount Hagen. Lava-dammed basins near Tari in PNG contain 100,000-year sequences of peat (Haberle 1998). Similar peats, which contain bones of extinct megafauna, are known from Telabo Swamp south of Tari (Flannery 1994) (Figure 5).

Table 2. Chemical characteristics of montane and subalpine peats. CEC = cation exchange capacity. CEC, Ca, Mg, K and Na values are *per* 100 g of dry soil.

Sample	Rock substrate	pH	Organic C (%)	Total P (ppm P_2O_5)	CEC (meq)	N (%)	C/N	Ca (meq)	Mg (meq)	K (meq)	Na (meq)	% base saturation	Source
Gogimp peat	Volcanic ash	4.0	14–22.2	24	28.0	0.6	22–37			0.8		6	Haantjens (1970)
Tambul brown earth	Volcanic ash	4.0	13.4	3.2	36.3	0.9	15					6	Wood (1987)
Pinde (alpine humus)	Granite	5.8	21.0	12	64	0.5	21					6	Haantjens (1970)
Pompameiri sedge fen - swamp forest	Granite	5.0	10–13	4–8	41–46	0.85				0.5		17–28	Haantjens (1970)
Tussock grass bog	Limestone	6.7	35.4	16	70	1.4	25	111	20	37	32	9	Hope (1976b)
Tussock grass bog	Schist	6.4	31.2	86	64	1.1	28	50	10	72	80	14	Hope (1975)
Astelia cushion bog	Granidiorite	5.4	16.8	40	45.4	0.9	18.1					6	Wade & McVean (1969)
Short grass bog	Granidiorite	5.7	18.8	10	71	1.3	15	144	20	25	4	23	Hope (1976a)
Short grass bog	Schist	6.0	35.2	97	90	0.9	38	10	7	16	74	5	Hope (1975)
Subalpine bog heath	Sandstone	3.4	22.65			2.26	10.2						Mangen (1993)
Hard cushion bog	Limestone	6.1	37.0	29	56	1.6	24	55	15	29	41	8	Hope (1976b)
Hard cushion bog	Schist	5.9	29.5	70	48	1.0	29	44	7	12	100	16	Hope (1975)
Gleichenia vulcanica bog	Granidiorite	5.6	13.9	34	51.8	0.8	16.4	5.9				16	Wade & McVean (1969)
Carex gaudichaudiana fen	Granidiorite	5.6	15.8	14	56.2	0.8	19.0					16	Wade & McVean (1969)
Means		**5.7**	**23.4**	**37.4**	**58.1**	**1.0**	**22.0**	**60.0**	**13.2**	**27.4**	**55.2**	**12.3**	

Figure 4. A peat core from grass bog on Mount Wilhelm showing a discrete band of olive-grey tephra, probably Tibito (285 cal. yr. BP).

Figure 5. Buried peat near Tari, 1,400 m. This fossil peat underlies a large tephra which may be the 50,000 year old Tomba horizon.

Other peats formed under swamp forest and subsequently buried by outwash fans occur in the upper Balim Valley near Kwiyawagi at 2,800 m (Hope *et al.* 1993).

By contrast, the large montane swamp at Norikori (1,420 m) is late Holocene in age and peat formation has possibly accelerated due to the removal of forest (Haberle 1996). Similarly, peatlands at Kindeng and Draepi (Powell 1981) and Kelela (Haberle *et al*. 1991) show rapid peat accumulation when forest is removed from the local catchment.

HUMANS AND FIRE IN PEATLANDS

People have been in the mountains of New Guinea for 45,000 years and their earliest known sites are on the margins of the large peatland that infills the Ivane Valley at Kosipe (Summerhayes *et al*. 2010). Charcoal indicates that the fen surface was burnt frequently, with charcoal increasing as the peatland transitioned from short to tall sedgelands at the start of the Holocene (Hope 2009). Even subalpine peatlands on some mountain areas such as Mount Jaya, Mount Trikora and Mount Albert Edward (Hope 2014) were being burnt by people despite being distant from permanent settlement.

Fire becomes more prominent in most swamp pollen records after human occupation commences (Haberle *et al.* 2001, Hope & Haberle 2005, Fairbairn *et al.* 2006, Haberle 2007) and disturbance of montane peatlands and surrounding catchments becomes widespread in the Holocene. Despite the high fire activity at the end of the last glacial period, the driving force behind forest expansion into grassland overrides the persistence of fire activity. In all montane mire records that cover the early Holocene, we find swamp forest dominated by *Syzygium*, *Pandanus* and some gymnosperm taxa occupying wetlands in the valley floors (Haberle 2007). The relatively high biodiversity and resource value associated with swamp forests, including the high density of utilisable *Pandanus* species (*P. antaresensis, P. brosimos/julianettii* complex (Haberle 1995) may have led to these environments being a focus for human activity throughout the Holocene.

The appearance and spread of agriculture in the highland valleys occurs in the montane valleys in the early Holocene. The earliest indications of the ditching of Kuk Swamp, near Mount Hagen, occurs around 9,000 BP (Denham & Haberle 2008, Haberle *et al*. 2012) and swamp agriculture (Denham *et al.* 2004) led to truncations in peat growth. The timing accords remarkably well with the transition to "modern" Holocene climates and points to the possibility that expansion of clearing and plant manipulation was partly environmentally controlled. It is possible that the early Holocene was a time of more reliable climates. El Niño related drought and frost episodes may have been much rarer (Groves & Chappell 2000). This would have rewarded experimental taro and banana planting and water manipulation (Denham *et al.* 2004, Ballard *et al*. 2013). By 7,000–5,000 years ago the lower parts of the major highland valleys had been cleared and peatland agriculture involving water control by ditching and mounding was widely practiced. The valley floors would have looked similar to when the first outside observations were made in 1933 with the exception that sweet potato had become widely cultivated in the last few centuries, reducing the reliance on the swamp horticulture of taro.

The expansion of montane agriculture resulted in forest loss and increased wetland burning at higher altitudes as hunters started to utilise higher-altitude resources. Mount Wilhelm experiences a transition from subalpine forest to grasslands in the last 1,000 years (Corlett 1984) and new evidence from high altitudes on Mount Giluwe suggests that it, too, was cleared after 1,500 cal. yr. BP (Hope unpublished).

CURRENT PEATLAND MANAGEMENT

Limited conversion of montane peatlands for commercial agriculture has occurred, for example for small tea plantations near Mount Hagen. Such enterprises often utilise areas that were formerly ditched and used for taro cultivation but abandoned due to the spread of dryland crops such as sweet potato. Deep drainage and associated planting of dryland trees such as *Eucalyptus deglupta* has resulted in significant peat subsidence, with up to 4 m of grass-sedge peat altering to a sapric Histosol 0.5 m in depth. Increased land pressure has led to more cropping of swamp margins and removal of swamp forest where this is accessible. For example, during the severe drought of 1997–8 peatlands around Lake Kopiago were ditched and mounded as the lake retreated in order to grow a range of vegetables. Drainage is often associated with these agricultural practices. However, peat is not exploited by mining for soil improvement material or fuel.

In general, the subalpine peatlands have only been utilised for hunting and as open corridors for tracks. Fauna hunted in grassy mires includes water birds such as Salvadori's Teal (*Salvadorina waigiuensis*) and the Snow Mountains Quail *(Anurophasis monorthonyx)*. The Eastern Long-beaked Echidna (*Zaglossus bartoni*) can be found searching for worms in peatlands at high altitudes, but is now rare. Given the cold and rainy environment it is not surprising that signs of fire damage are concentrated along trackways across mires. Attempts have been made to discourage fire in the subalpine, for example in local management of Mount Wilhelm (Hope 2014). However, destructive fires associated with El Niño events in 1972, 1984 and 1997–8 burned large areas of the peatlands. In most cases this resulted in only minor losses of peat, but some peat fires did occur at Kosipe and Mount Giluwe that reduced 0.3–0.4 m deep peat soils on drier sites to mineral horizons.

The limited economic development at high altitudes includes roading to 3,200 m on Mount Trikora, mining to 4,300 m on Mount Jaya, and the establishment of radio repeater stations serviced by helicopter. These activities have drained or buried existing peatlands and provided increased access to visitors (Figure 6). Development for tourism has been limited because of the difficulties of access to the subalpine, though both Mount Wilhelm (PNG) and Mount Trikora (Papua) are the targets of treks. On the other hand, the development of sedentary highland populations linked to roads and towns seems to have lessened traditional use of the mountains. Some areas exhibit successional recovery of wetlands (Hope 2014).

CONCLUSION

In global terms the mountains of New Guinea support significant montane peatlands and remarkably diverse subalpine mires. The environment differs from tropical Andean and African mountains in being relatively wetter and more equable, with higher minimum temperatures than the afroalpine or páramo. This has probably encouraged long-distance migration by cool temperate plants from both hemispheres and adaptation of local elements from the montane belt. Given the wide range of peat sections spanning at least the later Pleistocene to the present that are already known, there is great potential for studying past biogeographical and environmental changes of the mountain biota as well as diversity changes.

It is clear from this review that knowledge about peatland extent, peat characteristics, processes and

Figure 6. A new road cutting through hard cushion bog near Lake Habbema, 3,200 m. Photo: Peter Hitchcock.

management in the mountains of the great island of New Guinea is at a very rudimentary stage. Floristics and ecology have received some attention, and limited areas have been investigated for stratigraphy and chronology. For the highlands there have been scattered stratigraphic studies that indicate the kinds of peat present and age-depth profiles. However, there are no comprehensive studies of peatland chemistry or of the potential of peatlands as carbon stores, nor of their role in hydrology and carbon sequestration. These aspects urgently need more comprehensive surveys and analyses on both sides of the island.

Overall, the montane and subalpine peatlands of New Guinea are not currently threatened by direct utilisation. Given the perhumid conditions, even climate change may not be a critical threat at present; although the widespread peatland fires during the 1998 El Niño drought show that even occasional dry periods can be damaging. However, efforts towards any kind of management of the peatland resource in New Guinea are hampered by our poor understanding of the mountain peatlands. This aspect should have priority in planning future research.

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