The Peatlands of the Australasian Region

J. Whinam & G. Hope (Eds.)

Abstract: A great variety of peatlands occur throughout the Australasian region from the oceanic sub-Antarctic to temperate and tropical lowland and mountain environments. They include significant areas of blanket bogs on subantarctic islands, southwestern New Zealand and high altitude New Guinea and shallow peat moorlands of maritime Tasmania. More widespread but less extensive are topogenic swamps including coastal peatlands, which are often dominated by shrubs and include tropical swamp forests in northern Australia and throughout the Pacific. Upland and closed basin peatlands occur as well, large examples occurring in New Zealand and New Guinea together with smaller montane and subalpine fens and bogs.

Although some of the peatland types have northern hemisphere counterparts (e.g. *Sphagnum* bogs, sedge fens, *Phragmites-Typha* riparian fens), some appear to be peculiar to the Australasian region (e.g. the Tasmanian buttongrass moorlands, the Restionaceous-sedge peatlands of New Zealand, *Melaleuca* swamp forests in northern Australia and hard cushion bog in New Guinea). Some peatlands are restricted to unusual hydrologic sources, such as the inland Australian spring mounds and the *Melaleuca* swamps on King Island, Tasmania. As with peatlands generally, there is a close link between the biota present, the occurrence of peat, the hydrology of sites and evapotranspiration effects on humification. In general Australasian peatlands are not dominated by *Sphagnum* or other moss taxa but some monocot taxa are very widespread.

Peat sections are often Holocene or younger although long sequences are known extending back over a glacial cycle. The age of initiation can be quite variable, reflecting humidity and disturbance by fire in the past. Peat growth may be rapid, with up to six meters being formed in the last 3.000 years, but many sections are oxidised and hemic and typically 1-2 m deep. The long term build up of organic profiles occurs under sedgelands (predominantly Cyperaceae and Restionaceae) and tropical forest. Lake mud-peat sequences are also common eg in Western Australia, where diatomaceous soils are sometimes found.

The current condition of peatlands covers the full range from natural and undisturbed (e.g. the subantarctic peatlands, the *Sphagnum* peatlands of alpine and sub-alpine New Zealand and Tasmania), through to disturbed sites where either historical or current land use patterns threaten the integrity of the peatlands. This includes former grazing in the montane swamps of eastern Australia, the impacts of land subdivision and drainage on the temperate and tropical coastal peatlands which have modified once large peatlands to tiny remnants. Peatlands in the Australasian region are also affected by burning regimes, agriculture, moss harvesting and peat mining, with climate change likely to have broad implications due to the marginal nature of many of the peatlands. Knowledge of peatland function and value across the region is generally poor, although wetlands are better recognised for their conservation values. This situation must be improved if long term peatland integrity is to be maintained.

Key words: Australasian peatlands, subantarctic peatlands, Tasmanian blanket bogs, moorlands, Sphagnum, restiad bogs, carbon budgets, montane swamps, temperate coastal peatlands, inland spring mounds, Australian tropical peatlands, Pacific mires, New Guinea mires, peatland management, climate change, fire histories, carbon budget, conservation.

Introduction

Peatlands occur throughout the Australasian region, ranging from the blanket bogs of subantarctic islands such as the Auckland Islands and southwestern New Zealand, and the buttongrass moorlands of maritime Tasmania to widespread topogenic swamps of eastern Australia and New Zealand. Coastal peatlands, often dominated by shrubs, are also common in Australia and New Zealand and these extend through to the tropical swamp forests of northern Australia and the Pacific. Rarer peatlands

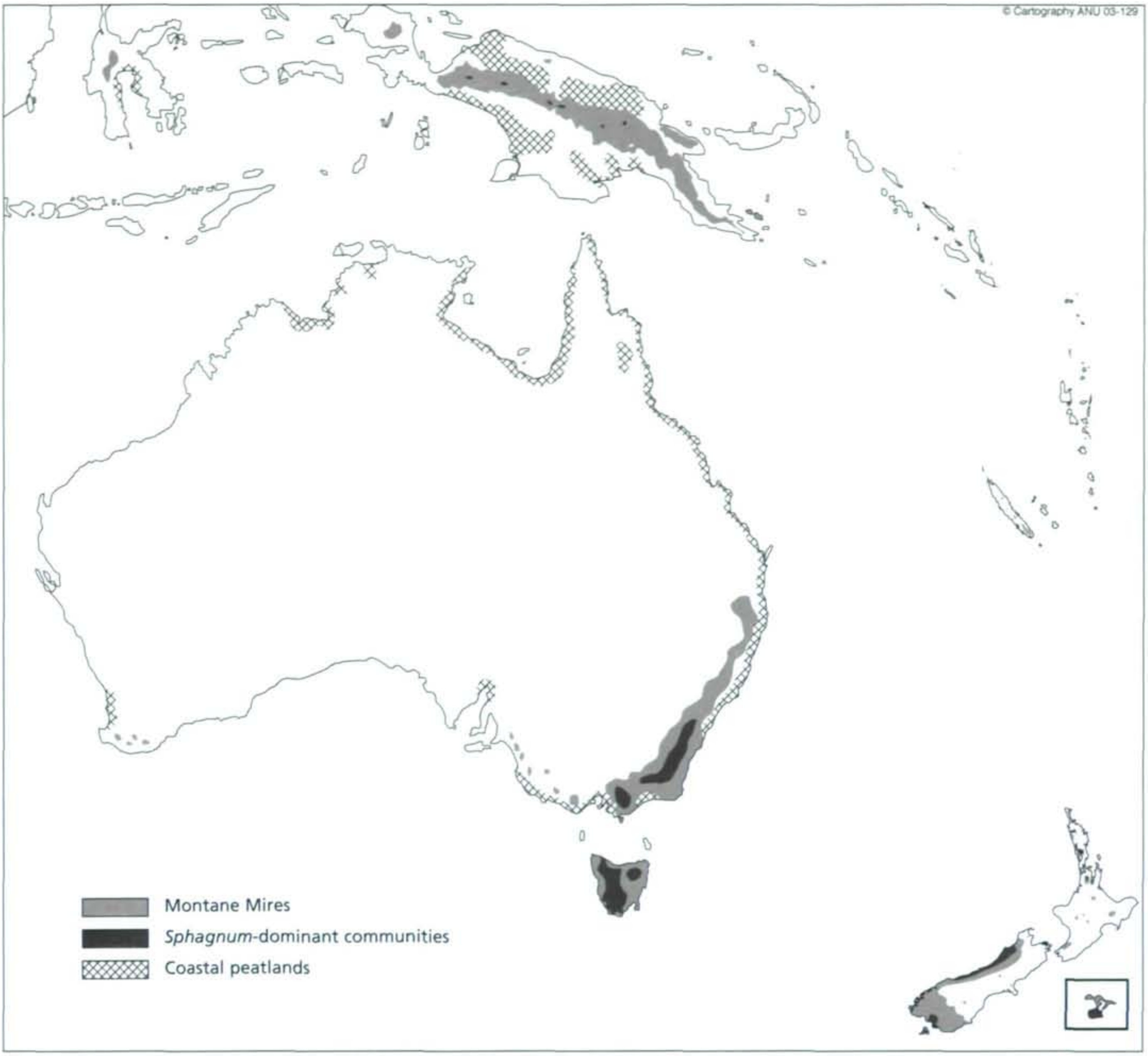

Fig. 1: Map of the Australasian region.

include the high altitude peatlands of New Guinea, which curiously mimic the sub-Antarctic in some ways, and the spring peats of arid Australia (see Fig. 1).

While peatlands do occur throughout the region, they tend to be comparatively small in size and most commonly occupy specific habitats that compensate for the generally arid conditions of Australia, the high temperatures associated with the tropics and the geologically young and unstable landforms of New Zealand.

Although some of the peatland types that occur throughout parts of Australasia have northern hemisphere counterparts (e.g. *Sphagnum* bogs, sedge fens, *Phragmites*-*Typha* riparian fens), some appear to be peculiar to the Australasian region (e.g. the Tasmanian buttongrass moorlands, the Restionaceous-sedge peatlands of New Zealand, *Melaleuca* swamp forests in northern Australia and hard cushion bog in western New Guinea). Some peatland types are very restricted and occur at unusual hydrologic sources, such as the inland Australian spring mounds and the *Melaleuca* swamps on King Island, Tasmania. As with peatlands generally, there is a close link between the biota present, the occurrence of peat, the hydrology of sites and evapotranspiration effects on humification. However, unlike much of the northern hemisphere, Australasian peatlands are not generally dominated by species of *Sphagnum* moss.

Research work on the peatlands of the Australasian region is relatively young, with publications appearing from the 1950s (e.g. COSTIN 1954, MILLINGTON 1954, BARTRAM 1957) and increasing from the 1970s (WALKER & GUPPY 1968, JACKSON 1973, HOPE 1980, HOPE & SOUTHERN 1983, WARDLE 1991, MUELLER-DOMBOIS & FOSBERG 1998) through to the present. The research includes: general descriptions of specific peatland types and their distribution, the associated biota (e.g. ROMANOWSKI 1998), aspects of hydrology, palaeoecology, the impacts of fire, threats to the conservation of peatlands, restoration ecology (CLARKSON et al. 1999) and the likely impacts of climate change on this restricted biome. A relative absence of lakes in the landscape has resulted in many peatlands being investigated for palaeoecology and palaeoclimate studies.

Typology – a plea for understanding

Unlike the northern hemisphere, there has not been any major research emphasis on peatland typologies and peatland definitions (but see JOHNSON & GERBEAUX 2004 for New Zealand). Many of the definitions and typologies applied to northern hemisphere peatlands are not appropriate to Australasian peatlands. We use the term '**peatlands**' to indicate terrestrial sediments in which organic matter exceeds 20% dry weight and with a depth generally greater than 30cm. However some mires, such as Tasmanian buttongrass moorland, are usually more shallow, but must be included as they form extensive organic terrains. Also oxidised (humic) peats are not readily distinguished from muds forming in shallow water so some limnic organic sediments may be mapped as peatland.

Very less work has been carried out on the nutritional status of peatlands so that this criterion has not generally been used in classification, and neither has the supposed origin of the peat been considered. The practical distinction between ombrotrophic and minerotrophic is blurred, as dramatically infertile sites (e.g. on Precambrian quartzite in Tasmania) may have lower levels of fertility than some purely ombrotrophic sites, given relatively high salt and dust accession levels in the region. Thus general Australian usage expands the restricted trophic definition of **bog** from purely ombrotrophic vegetation communities, to include a range of peatlands with shrub-moss-cushion plant vegetation with complex structure that raises large parts of the surface above the average water table. This includes large areas of partially topogenic mires in addition to raised and blanket bogs. In contrast, **fen** has a rather restricted meaning by comparison with the catch-all meaning ascribed by some European authors (see for example CHARMAN (2002: 6)), being used for mostly graminoid (Cyperaceae, Juncaceae, Poaceae, Restionaceae, Typhaceae and Xyridaceae) dominated mires in which the average water table is generally at the surface. Peatlands dominated by tall shrubs and trees are generally termed **swamp forest. Moorland, marsh** and **salt marsh** are also used for particular vegetation types on wet slopes and coastal inundated plains respectively.

Thus in Australasia, peatland classification is primarily concerned with the structure and life forms of the peat-forming vegetation. This approach (which follows other vegetation classifications in the region, e.g. SPECHT et al. 1974) has the considerable merit of not attempting to pre-judge trophic or causative factors that cannot be readily measured. The terms bog and fen are used here in simply a vegetational structural sense.

Origins of the mires

The great majority of peatlands that have been investigated have proven to be no older than the late Pleistocene and many are mid-Holocene or younger. Upland and subantarctic basins respond to increasing temperature and humidity after 15.000 yr BP, with a decrease in mineral deposition and the spread of sedge and grass onto valley fills. This vegetation seals the valleys and intercepts water, allowing peat to form. However the age of initiation can be quite variable, as shown for southeastern Australian swamps by KERSHAW & STRICKLAND

(1989). The site and its substrate appeared to be a major control, there being little correlation of age with altitude. Site characteristics also control peat stability as sites on erodible sandstones had a tendency to collapse, probably by headward erosion possibly initiated by fire. Thus a range of basal dates was found on Sydney sandstone and attributed to random chance of erosion by Young (1986).

The topogenic peatlands often preserve black and grey clay beds beneath the peat and in a few cases these overlie pre-glacial peats, as at Wyrie Swamp (Dodson 1977) and Caledonia Fen (McKenzie et al 2001). Thus peatland occurrence in a given region tends to be a measure of changing regional climates. There are some exceptions to the limited age of peat sections where the topographic setting, for example volcanic or tectonic barriers, have permitted long periods of peat formation such as at the meteorogenic Darwin Crater, Tasmania (Colhoun & van der Geer 1988), the volcanic crater of Tower Hill, Victoria (D'Costa et al. 1989), and tectonic basins at Sirunki, Kosipe and Tari, New Guinea (e.g. Walker & Flenley 1979, Haberle 1998). These deposits extend back 50-several hundred thousand years.

A second major event that initiated peat formation was the flooding of former valleys by sea level rise about 6.000 yr BP. Sequences that reflect succession from open estuarine conditions to freshwater peats are frequent and commonly extensive, often with a phase of mangrove or salt marsh peats. Interdune swamps that reflect rising water tables are also widespread on most coasts in the region. Because sea level is an effective base level, some peat formation reached a limit after a few thousand years and did not form in the late Holocene. This has been noted in tropical sites in Fiji and Vanuatu where alluvium from human disturbance of slopes has buried peatlands that had ceased to form after 3.000 - 4.000 years ago, perhaps due to regional sea level falls (Hope et al. 1999).

Pollen and charcoal studies have been made on more than 400 swamps in the region (Hope et al. 1999, Pickett et al. 2004). These have allowed broad pathways of development to be established, and hinted at a range of fire and other disturbance regimes experienced by mires. A third group of mires has emerged from these studies, those initiated following forest clearance. This changes the water availability and peats form over the top of garden beds and fallen logs. One example is Kuk Swamp, in highland New Guinea, where up to 4 m of grass and sedge peat has formed in several phases following forest clearance in the catchment (Denham et al. 2003).

The subantarctic islands

J. M. Selkirk-Bell
& M. S. McGlone

The subantarctic islands of the Australasian region include Macquarie, Heard and McDonald Islands belonging to Australia and Auckland, Campbell, Snares, Bounty and Antipodes Islands belonging to New Zealand (Fig. 2). These islands share landscapes characterised by cool, moist and windy climates and rugged topographies. Most of the islands lie to the south of Australia and New Zealand, however Heard and McDonald Islands lie further to the west.

Tab. 1: Location, basic topographic and climatic data for subantarctic islands. [1] Streten 1988, [2] Allison & Keage 1986, [3] Kiernan & McConnell 1999, [4] Department of Conservation 1997, [5] Campbell 1981, * estimated

Island	Location	Area (km²)	Max. alt. (m)	Mean temp. (°C)	Mean annual rainfall (mm)	Mean wind speed (m s⁻¹)
Macquarie[1]	54°30'S, 158°55'E	122.5	433	4.9	938	9.3
Heard[2]	53°06'S, 73°32'E	372.2	2745	1.0	1.400	8.3
McDonald[2,3]	53°03'S, 72°36'E	1.6	212	1.0	1.400	
Auckland[4]	50°44'S, 166°07'E	626	667	8.0	1.500-2.100	
Campbell[4,5]	52°34'S, 169°09'E	113.3	567	6.8	1.400	9.0
Antipodes[4]	49°41'S, 178°48'E	21.0	366		1.000-1.500*	
Snares[4]	48°01'S, 166°36'E	3.41	152	11.0	1.200	
Bounty[4]	47°45'S, 179°02'E	1.35	88	10 *		

Location, basic topographic and climatic data is shown in Tab. 1. Due to the cool and wet climate, blanket and mire peat deposits are extensive on most of the islands.

While not species rich, the vegetation of these subantarctic islands is noted for its diversity, special forms and unique communities (WARDLE 1991, MEURK et al. 1994b). They are all well vegetated, except for the Bounty Islands which are bare rock, and Heard Island which is dominated by glaciers with only a narrow coastal rim available for vegetation. The vegetation of the Snares is dominated by *Olearia lyalli*, a tree daisy that forms extensive forests. The Auckland Islands are forested by a coastal fringe of southern rata (*Meterosideros umbellata*) and shrublands dominated by *Dracophyllum*, *Myrsine* and *Coprosma* (Fig. 3). Campbell Island has dwarf forests of *Dracophyllum* and scrub of *Myrsine* and *Coprosma*. Macquarie Island, Heard Island, the Antipodes and the uplands of Auckland and Campbell Islands are dominated by tussock grass and herb species. Macrophyllous forbs are important in the subantarctic vegetation in the coastal zone, on fens and in the upland tundra (MEURK et al. 1994b), with three species of *Pleurophyllum*, two species of *Stilbocarpa*, two species of *Aciphylla* and a *Bulbinella* endemic to these islands. There are also considerable areas of cushion herbs (Fig. 4), sedges, rushes, and bryophyte species, especially on oligotrophic, poorly drained peats and in the upland tundra zone (MEURK et al. 1994b), but *Sphagnum* is uncommon, and does not play a significant role in peat formation.

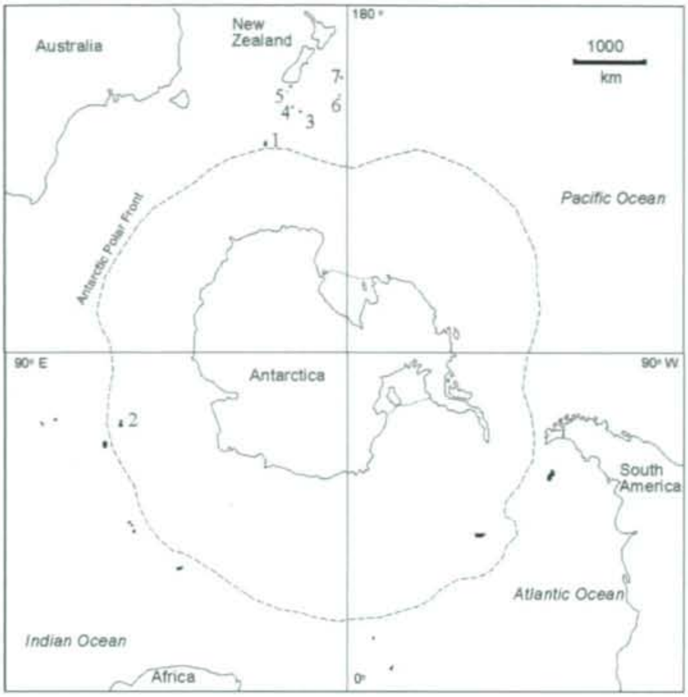

Fig. 2: Location diagram of subantarctic peatlands:
1. Macquarie Island;
2. Heard and McDonald Islands;
3. Campbell Island;
4. Auckland Islands;
5. the Snares;
6. Antipodes Islands;
7. Bounty Islands

Most of the ground surfaces of the islands are covered by peat, and can occur as blanket peat, raised bogs and quaking mires (TAYLOR 1955, CAMPBELL 1981, RICH 1996, McGLONE et al. 2000, Fig. 5, Tab. 2). Dopplerite has been identified at the base of some profiles on Macquarie Island (SELKIRK 1996) and dark brown waxy, lignitic peats with conchoidal fracture patterns are abundant in the base of peat blankets on Campbell, Auckland and Snares Islands (FLEMING et al. 1953, LEAMY & BLAKEMORE 1960, CAMPBELL 1981, Mc-

Fig. 3a: View of Hooker Hills, Auckland Island. Red flowered trees *Meterosideros umbellata*. Foreground: mixed scrub including *Dracophyllum longifolium*. (Photo: Janet WILMSHURST)

Fig. 3b: *Donatia* cushions on Auckland Island. (Photo: Janet WILMSHURST)

Fig. 4: Campbell Island, Homestead Ridge Bog, 50 m altitude. *Oreobolus pectinatus* cushion bog, with stunted shrubs of *Dracophyllum scoparium*. This association is typical of poorly drained, rolling to flat lowlands. Animal is Hooker's sealion (*Neophoca hookeri*). (Photo: Janet WILMSHURST)

GLONE 2002). Upper peat layers tend to be more fibrous and less humified.

Nutrient status of the peats is generally low, but coastal exposure to wind-blown spray considerably changes the nutrient input, for example, leading to luxuriant coastal communities on Auckland and Campbell Islands (MEURK et al. 1994a). Wind exposed peats often incorporate large percentages of mineral material, such as on Macquarie Island where peats can incorporate up to 50% windblown sand (TAYLOR 1955, JENKIN 1975, SELKIRK et al. 1988). There are 7.000-year long records of wind blown sand and pebbles in cliff top peats from both Campbell and Auckland Islands (MCGLONE et al. 1997, MCGLONE 2002).

The maximum depth of peat accretion varies considerably, with peat depths of up to 5m recorded on the Antipodes Islands (HIGHAM 1991), nearly 10m on Campbell Island (MCGLONE et al. 1997) and the maximum known depth of mire peat on Macquarie Island is 5.9m (RICH 1996). Blanket peats generally are 1-4 m deep (MCGLONE 2002). The slope of the surface upon which the peat forms is important in determining the maximum depth of the peat. On the steep slopes of Macquarie, Campbell, Auckland and Antipodes Islands peat accumulations are periodically removed by mass failure (CAMPBELL 1981, SELKIRK 1996). The oldest dated peats from Auckland Island are c. 15.000 years old and Campbell Island c. 13.000 years old, but widespread peat accumulation only occurred after 12.000 years ago (MCGLONE 2002). The oldest Macquarie Island peats are c. 10.000 years old (SELKIRK et al. 1988).

Tasmanian Blanket Bogs: Geo- and Biodiversity of these Unique Mires

M. PEMBERTON, J. BALMER, M. DRIESSEN & A. RICHARDSON

Tasmanian blanket bogs or buttongrass moorlands are unique to Tasmania and have contributed to the listing of the Tasmanian Wilderness World Heritage Area. They provide examples of long-ongoing ecological processes initiated in late Pleistocene to early Holocene times, which have resulted in the development and survival of highly distinct communities of plants and animals.

Tab. 2: Examples of profile descriptions of peats from Macquarie Island (after TAYLOR 1955) and Campbell Island (after CAMPBELL 1981)

	highmoor peat – Macquarie Island	**thick peat soils – Campbell Island**
vegetation	*Poa foliosa* grassland	*Dracophyllum* scrub, *Poa* tussock grassland
profile description	0-23cm: very fibrous peat. Leaves and roots barely decomposed. pH 5.4 23-43cm: very fibrous peat. Plant remains easily distinguished. pH 4.4 43-69cm: dark brown fibrous peat. Occasional large rocks to 30cm diameter. pH 4.2 69-86cm: brown peat, few fibres, margins fairly sharp. pH 4.4 86- 119cm: Dark brown amorphous peat. Occasional decomposing pebbled to 5cm diameter. pH 4.5 119-147cm: as above but slightly darker colour. pH 4.2 147-152cm: very dark brown peaty loam, with many decomposing pebbles. PH 4.5 152-178cm: brown loam with little peat. pH 4.4 178-238cm: yellow gravely loam with many brown mottlings.. Increasing gravel content with depth. pH 4.7 – 6.0	0-25cm: very dusky red (5YR 2.5/2) peat; weakly decomposed (D4); friable; moderately developed fine crumb structure; many fine fresh roots; distinct boundary 25-60cm: dusky red (10R 3/4) peat; moderately decomposed (D5); weakly developed platy structure; some black streaks of humus; few seal gastroliths; a few fresh roots; indistinct boundary 60-85cm: black to very dusky red (2.5YR 2.5/0-2.5/2) peat; strongly decomposed (D7); firm; weakly developed blocky structure; indistinct boundary 85-185cm: black to very dusky red (2.5YR 2.5/0-2.5/2) peat; strongly decomposed (D6); firm; massive; few stone fragments and seal gastroliths; distinct boundary 185-215cm: very dusky red (2.5YR 2.5/2) peat; moderately decomposed (D5) mushy; slightly fibrous; distinct boundary *on*: black and very dusky (2.5YR 2.5/0-2.5/2) strongly decomposed (D8) peat

Tasmanian blanket bogs cover about 1,000.000 ha of undulating terrain in the western part of the State (Fig. 6). They occur in regions which experience more than 1600 mm of rainfall per annum, have high humidity (typically greater than 80%) and low evaporation (PEMBERTON 1989). From a world perspective they appear to be very marginal mire systems mainly as a consequence of relatively dry and mild summers and could be further impacted by climate change. They occur on a range of geological types, but appear best developed on inert siliceous substrates where mineral soil development is minimal. They extend from close to sea level to altitudes of just over 700 m and from relatively flat ground to slopes of over 40 degrees (Fig. 7). The deepest peats occur in lowland depressions and can be up to 4 m deep whilst they shallow to less than 0.3 m on slopes. In these locations it is arguable whether they qualify as organosols (ISBELL 1996), but with virtually no other soil development it is impossible to classify them as any other soil type. This, together with marginal organic contents in some instances, make them quite distinct peatlands on a world scale.

Palynological and palaeobotanical investigations suggest that the current flora of the bogs has contributed directly to their development over about the last 10.000 years (MacPHAIL et al. 1999). It also appears that the bogs started to form following deglaciation of mountains in the west about 12.000 years ago. Development probably started at the lowest elevations closest to sea level where conditions were relatively mild and they gradually expanded inland.

Peat mounds have developed on the blanket bogs on lowland plains (Fig. 8). The reason for their development is unclear (MacPHAIL et al. 1999), but could result from differential expansion and contraction of the peat, development above a spring, or from firing. One of the first two is the more likely explanation. They can be up to 2 m high and between 1 and 30 m in diameter. In a world context they appear to be rare with the only similar examples described from Scotland (LINDSAY et al. 1988).

Fig. 5: *Pluerophyllum hookeri* – patterning in quaking mire, Handspike Point Macquarie Island. Crouched human figure gives scale. (Photo: Patricia SELKIRK)

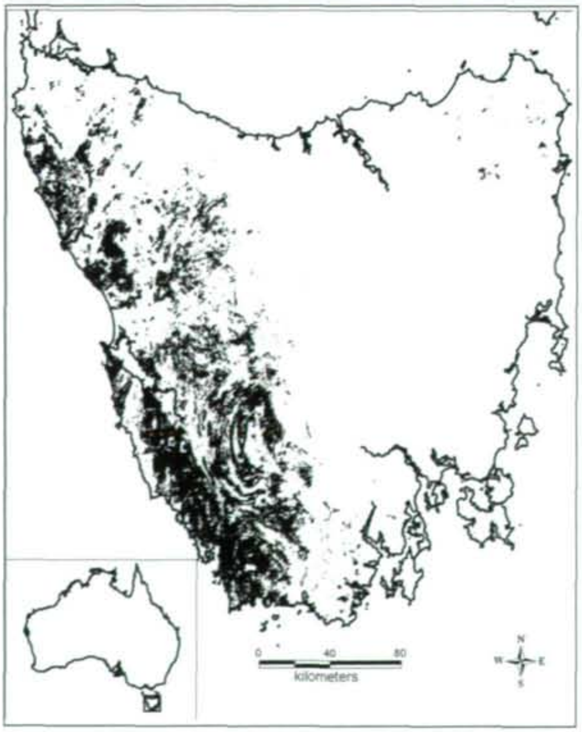

Fig. 6: Distribution of Tasmanian Buttongrass Moorlands/Blanket Bogs

Fig. 7: A peat landscape in south western Tasmania. The blanket bog/buttongrass moorland complex extends from the undulating plains in the foreground to the steeper slopes and ridges in the background. Peat mounds are scattered across the plain. (Photo: Michael Pemberton)

Fig. 8: A peat mound formed on the blanket bog in south western Tasmania. They have different hydrological characteristics and deeper less decomposed peat horizons compared to surrounding peatland. (Photo: Michael Pemberton)

Tab. 3: Vertebrate fauna that spend their whole life-cycle within buttongrass moorlands. *Endemic to Tasmania.

Group	Common Name	Scientific name	% of Tasmanian Total
Mammals			**12**
	Broad-toothed mouse	*Mastacomys fuscus*	
	Swamp rat	*Rattus lutreolus*	
	Swamp antechinus	*Antechinus minimus*	
Birds			**2**
	Ground parrot	*Pezoporus wallicus*	
	Striated field wren	*Sericornis fuliginosus*	
	Southern emu wren	*Stipiturus malachurus*	
Reptiles			**19**
	Tiger snake	*Notechis ater*	
	White-lipped snake	***Drysdalia coronoides***	
	Metallic skink	*Niveoscincus metallicus*	
	She-oak skink*	*Cyclodomorphus casuarinae*	
Frogs			**45**
	Tasmanian tree frog*	*Litoria burrowsae*	
	Brown tree frog	*Litoria ewingi*	
	Tasmanian froglet*	*Crinia tasmaniensis*	
	Brown froglet	*Crina signifera*	
	Smooth froglet	*Geocrinia laevis*	
Fish			**4**
	Swamp galaxias*	*Galaxias parvus*	

Flora

The blanket bogs and related peatlands are formed under a heathy-sedgeland or sedgeland-heath vegetation typically referred to as 'buttongrass moorland'. The moorland is a unique vegetation type in a global context, being the only extensive vegetation type dominated by a hummock forming, tussock Cyperaceous sedge, *Gymnoschoenus sphaerocephalus*. The presence of this species, or the Restionaceous species with which it typically associates, defines this vegetation. It is highly variable in structure, ranging from low closed sedgeland, through heathland, and low open scrub to open woodland (Jarman et al. 1988).

The buttongrass flora is comprised of 272 vascular species including adventitious species. About 202 species from 50 families are typical of buttongrass moorlands, of which 30% are endemic to Tasmania (Jarman et al. 1988, Balmer unpublished data 2003). Only five families have more than ten species typical of moorlands: Cyperaceae (26), Epacridaceae (17), Myrtaceae (15), Restionaceae (12), and Poaceae (11). Graminoid species make up 39% of the flora, woody species 32%, forbs 25%, and ferns and their allies just 4% of the flora.

Edaphic factors strongly influence the vegetation floristics and structure (Bowman et al. 1986). The high degree of scleromorphy is an adaptation to low nutrients but increases the flammability of the vegetation. Dead graminoid leaves and culms are slow to decompose and are retained within and below the plant canopy, accumulating over time to create fuel loads in excess of 20 tonnes per hectare in some situations (Marsden-Smedley & Catchpole 1995, 2001). These fine fuels dry quickly after rain and fires can burn in this vegetation after as little as one rain free day, even in winter.

Fauna

Buttongrass moorlands are difficult places for animals to live due to soil condition, the nutrient status of vegetation and the flammability of the vegetation. Consequently, relatively few of Tasmania's vertebrate species spend their whole life cycle within buttongrass moorland (Tab. 3). The moorlands are the primary habitat for four species: the broad-toothed mouse, ground parrot, striated field wren and southern-emu wren. The endangered orange-bellied parrot is dependent on moorland habitat for feeding during its breeding season. The ground parrot is one of only three ground-dwelling parrots in the world and buttongrass moorlands are the stronghold for the species in Australia

Frogs are well represented in buttongrass moorlands with nearly half of Tasmania's frogs recorded in this habitat, but only the brown tree frog and common froglet are widely distributed. Several mammal and bird species regularly use moorland habitats for feeding, particularly the wombat, Bennett's wallaby, eastern quoll, echidna, marsh harrier and brown falcon, but they typically shelter in adjacent habitats.

The terrestrial invertebrate fauna of buttongrass moorlands is numerically dominated by Collembola (Katiannidae, Isotomidae, Bourletiellidae Katiannidae), Diptera (Chironomidae, Muscidae, Ceratopogonidae, Sciaridae), Araneae (Tetragnathidae, Araneidae, Thomisidae), Acarina (Parakalummatidae, Uropodidae), Formicidae (Dolichoderinae, Myrmeciinae) and Orthoptera (Gryllidae, Acrididae). Unusually, the abundance of Coleoptera appears to be relatively low. The most biodiverse groups recorded are Diptera (36 families, 290 species), Araneae (29, 214), Coleoptera (25,98), Acarina (35, 68), Lepidoptera (17, 62) and Collembola (12, 51).

Perhaps the most conspicuous invertebrates in Tasmanian buttongrass moorlands are the burrowing crayfish (Fig. 9) in the endemic genera *Ombrastacoides* and *Spinastacoides* (HANSEN & RICHARDSON in press). Their burrows are significant landscape features, and the presence of crayfish in such acid peats is highly unusual world-wide. Another conspicuous invertebrate feature of buttongrass moorlands are the large (up to 0.5 m tall) nesting mounds created by jack jumper ants (*Myrmecia pilosula* group).

Fig. 9: Burrowing crayfish (Photo: K. ATKINSON)

Conclusion

Tasmania has the most extensive blanket bogs in the Southern Hemisphere and arguably some of the most pristine in the world. (SHARPLES in press). Despite this peat fires have destroyed considerable areas of peatland (PEMBERTON & CULLEN 1995) and there appears to be a delicate balance between vegetation which has adapted to fire and the soil it produces which is vulnerable to fire.

Sphagnum peatlands of Australasia

J. WHINAM

An overview of the *Sphagnum* peatlands of Australasia has recently been published (WHINAM et al. 2003) and the following is a summary of that overview.

In comparison with peatlands in the northern hemisphere, Australasian peatlands dominated by *Sphagnum* (typically *S. cristatum*) are generally small in area, restricted in distribution, and have low species richness. Peatlands are generally dominated by Restionaceae, Cyperaceae, and Epacridaceae species, but *Sphagnum* is frequently an important component. Throughout Australasia, 25 species of *Sphagnum* have been recorded (Tab. 4).

Sphagnum peatlands are defined as having *Sphagnum* species as the dominant peat

Tab. 4: Distribution of *Sphagnum* species in Australasia (from Whinam et al. 2003. Australia (Aus, Mainland Australia; Tas, Tasmania), New Zealand (NZ, New Zealand; Chat, the Chatham Islands), Subantarctic Pacific islands (AI, Auckland; An, Antipodes; C, Campbell; M, Macquarie), Pacific (NG, New Guinea; VFJ, Viti Levu, Fiji; TaFJ, Tavieuni, Fiji; NCal, New Caledonia; HAW, Hawaii; Sam, Samoa), and Malesia (Sul, Sulawesi, Indonesia; BM, Borneo, Malaya; M, Malesia; WM, Western Malesia. Based on Streimann & Curnow (1989), Fife (1996), Seppelt (2000) and Touw (unpubl. data)

Species	**Australia**	**New Zealand**	**Subantarctic islands**	**Pacific**	***Malesia* (other than New Guinea)**
S. australe	*Aus, Tas*	NZ, Chat	AI, An, C		
S. antarense				*NG*	Sul
S. compactum		NZ		NG	M
S. cristatum	Aus, Tas	NZ, Chat		NCal	
S. cuspidatulum				NG	M
S. cuspidatum				NG, NCal	M
S. cuspidatum ssp. *subrecurvum*				NG	BM
S. efibrillosum				NG	
S. falcatulum	Aus, Tas	NZ, Chat	AI, An, M		
S. fuscovinosum	Tas				
S. junghuhnianum var *semiporosum*				NG	
S. luzonense					WM
S. novo-caledoniae				NCal	
S. novo-guineense				NG	
S. novo-zelandicum	Aus, Tas	NZ	C		
S. palustre				VFJ, HAW	
*S. perichaetiale (*incl. *S. beccarii)*	Aus	NZ		NG	M
S. reichardtii				VFJ	
S. seemannii				TFJ, Sam	
S. sericeum				NG	M
S. simplex		NZ			
S. strictum ssp. *pappeanum*				NG	M
S. squarrosum		NZ			
S. subnitens		NZ			
S. subsecundum				NG	M

forming vegetation and where the peatland area is greater than 1.000 m^2 to form a distinct ecosystem. They occur in Australia most frequently between 600 to 1.000 m altitude, while in New Zealand they range from sea level to 1.500 m. Examples of these mires are described for southern Victoria by Mackenzie (1997, 2002). The importance of *Sphagnum* peatlands in the landscape generally increases from north to south and with increasing altitude. *Sphagnum* occurs mainly on humic acid peats and deep accumulations of *Sphagnum* peat are unknown, suggesting that it is always a subsidiary taxon in Holocene mire communities. One of the major factors limiting the development of *Sphagnum* peatlands in Australia and New Zealand is moisture availability, in particular evapotranspiration in the driest month. While rainfall may be less important in peatlands that receive significant catchment runoff, the generally small size of the peatlands affects their sensitivity to hydrologic changes. They tend to be partly minerotrophic in Australia but fully ombrotrophic in New Zealand.

The major geomorphic types of *Sphagnum* peatlands in Australasia include: kettle holes and moraine-dammed valleys of the depositional zone; glaciofluvial outwash or colluvial valley fill deposits; riparian or lacustrine environments (Fig. 10 - 13); horizontally-bedded sandstone shelves; karst sinkholes (Whinam & Buxton 1997). The major structural types include: snowpatch, subalpine coniferous; sedgelands; shrublands (including New Zealand pakihi wet heath (Mew 1983)); rainforest; grassy tussock and aquatic. Descriptions of *Sphagnum* communities in New Zealand are included in Wardle (1991) and for Tasmania in Whinam et al. (1989, 2001). On mainland Australia *Sphagnum* is most common as a component of shrub bogs dominated by epacrids and restionaceous species (Costin 1954,

MILLINGTON 1954, ASHTON & HARGREAVES 1983, HOPE & SOUTHERN 1983, KERSHAW et al. 1997, CLARKE & MARTIN 1999).

There is little evidence of extensive patterned mires (CAMPBELL 1983, KIRKPATRICK & GIBSON 1984, WHINAM & KIRKPATRICK 1994, MARK et al. 1995) and of the hummock/hollow partitioning of *Sphagnum* species in Australasia (MILLINGTON 1954, ASHTON & HARGREAVES 1983) than reported in the northern hemisphere.

In New Zealand, *S. australe* commonly forms small bogs and moss beds under beech (*Nothofagus menziesii* and *N. solandri* var. *cliffortioides*) forest canopies, yielding dominance to *S. cristatum* as light levels increase. *S. cristatum* covers extensive areas in wet heath and bog communities and may be regionally important, as in eastern Fiordland (DODSON 1977; MARK et al. 1979) and south Westland (DICKINSON & MARK 1994). In New Guinea *Sphagnum* occurs in wet hollows in montane forest, and along stream banks and lake edges above 3.000 m, in minerotrophic and some ombrotrophic situations. *Sphagnum* peatlands rarely occur anywhere in Malesia, New Guinea or the Pacific (HOPE 1980), although *Sphagnum* moss is present. In tropical and subtropical areas of the Pacific, small *Sphagnum* mossbeds occur in high mountainous areas on windward slopes in shrub-rich peatlands, as these locations experience high orographic rainfall (MUELLER-DOMBOIS & FOSBERG 1998).

Sphagnum peatlands are very restricted on subantarctic islands, becoming less frequent at higher latitudes. On subantarctic Macquarie Island *Sphagnum falcatulum* occurs in water-saturated conditions down to sea level, but covers a total area of less than 5 ha. These mossbeds most commonly occur on old coastal terraces where drainage is impeded, or in old elephant seal (*Mirounga leonina*) wallows or on the plateau in wet areas where skuas (*Catharacta lonnbergi*) add nutrients. Warmer temperatures over the past few years (KININMONTH 1992) have coincided with an increase in *Sphagnum* moss (WHINAM unpublished data). *Sphagnum* is abundant on subantarctic Campbell Island forming wet, deep, acid peats (MEURK et al. 1994b), but does not form extensive peatlands, and on the Auckland Islands *Sphagnum* is rare.


Fig. 10: A riparian *Sphagnum* peatland in central Tasmania. The shrubs lining the stream are *Leptospermum lanigerum*. *Richea pandaniifolia* is the emergent shrub, with ferns (*Gleichenia alpina*) on the moss surface. (Photo: Jennie WHINAM)

Threats to *Sphagnum* peatlands, both historically and currently include: draining for agriculture, grazing, frequent burning, peat mining (although to a lesser extent than in the northern hemisphere) and *Sphagnum* moss harvesting.


Fig. 11: Floating mats of *Sphagnum falcatulum* on the edges of a limestone sinkhole with euycalpts forming the overstorey in central Tasmania. (Photo: J. WHINAM)

Fig. 12: The Tasmanian endemic *Richea pandanifolia* (Proteaceae) emergent from carpets of *Sphagnum cristatum* in Cradle Mountain-Lake St Clair National Park, Tasmania. (Photo: J. WHINAM)

Fig. 13: Montane *Sphagnum* mire in the Victorian Alps. Snowgums (*Eucalyptus pauciflora* ssp. *niphophila*) form the overstorey with Epacridaceous shrubs (e.g. *Baeckea gunniana)* and *Richea continentis* (Proteaceae) form the shrub storey. (Photo: J. WHINAM)

Non-*Sphagnum* peatlands of New Zealand

B. CLARKSON & R. BUXTON

A classification system for New Zealand wetlands has recently been developed (JOHNSON & GERBEAUX 2004) and has been followed in this account. Wetland classes having peat substrates include bogs, fens, swamps, seepages, and pakihi/gumland. These classes are based on distinctive combinations of substrate, water regime, nutrient status and pH. Lower classification levels recognise wetland form (e.g., dome, blanket, cushion, string), vegetation structure and composition. Comprehensive descriptions and alternative classification systems for peatlands are provided by DAVOREN et al. (1978), DOBSON (1979), CAMPBELL (1983) and WARDLE (1991).

Bogs are rain-fed, nutrient poor, and markedly acid with a pH range about 3–4.8. They are the most important peatlands, with many containing substantial quantities of peat (DAVOREN et al. 1978). Bogs are widespread on level or gently sloping land throughout New Zealand (Fig. 14) and have wide-ranging vegetation types that include mosses, restiads (family Restionaceae), cushion plants, sedges, ferns, shrubs and trees.

Some of the largest bogs are the lowland restiad bogs (Fig. 15). These can form extensive domes covering several thousand hectares, with peat up to 13 m deep (CAMPBELL 1983). In northern North Island restiad bogs are co-dominated by *Sporadanthus ferrugineus* and *Empodisma minus*, whereas south of 38°S latitude only *E. minus* is present (where it is also common in mountain peatlands). E. *minus* is the main peat former, its dense mat of cluster roots at the bog surface having high water-holding capacity, and producing a fibrous peat (CAMPBELL 1983). The plant has adaptations to conserve water, allowing bogs to form in areas of high seasonal water deficit where they should not normally exist (CAMPBELL & WILLIAMSON 1997).

On Chatham Island, raised bogs are dominated by *Sporadanthus traversii* (CLARKSON et al. 2005). Heath shrubs are usually present, e.g., *Leptospermum scoparium*, *Epacris pauciflora* and *Dracophyllum* spp. on mainland New Zealand, and *D. scoparium* on Chatham Island (Fig. 16). *Sphagnum* mosses are also present, but do not thrive in the shade of the much taller restiads and/or drier conditions.

Blanket bogs are best developed in the very south of the South Island, Stewart Island, Chatham Island and the subantarctic islands. These areas are characterised by comparatively low relief, cool temperatures, frequent cloud cover, high relative humidity and exposure to strong oceanic winds (DOBSON 1979, McGLONE 2002). On Chatham Island 59% (totalling 53.000 ha) of the soils is peat WRIGHT (1959), mostly being blanket peat dominated, particularly in southern parts, by the small tree *Dracophyllum arboreum*.

Cushion bogs are well represented on the mountain plateaux in the South Island, descending to sea level in the far south (Fig. 17), as well as in the subantarctic islands. They are also important in Tasmania, with common species and genera being *Donatia novae-zelandiae*, *Phyllachne colossi*, *Oreobolus*, *Gaimardia*, and *Centrolepis*. The plants form hard, rounded 'cushions', up to 1 m or more in diameter, and their compact habit allows them to tolerate dry, sunny weather and the desiccating winds that limit *Sphagnum* and other species (GODLEY 1978).

String bogs have elongated ridges of peat that act as dams on slight slopes, creating a sequence of pools, their long axes aligned across the slope. The most extensive patterned systems have developed under cool, moist conditions in valley heads and on glacial benches in southern South Island (MARK et al. 1995). Important species include *Oreobolus pectinatus*, *Sphagnum* and other mosses, *Carex gaudichaudiana*, *C. echinata*, *Baumea tenax*, *Empodisma minus*, *Dracophyllum* spp., and *Leptospermum scoparium*.

Fens are characterised by having a mainly peat substrate, although usually shallower and with higher decomposition than in bogs. They are both rain and groundwater fed, and have low to moderate nutrient status and a pH of about 4 to 6. New Zealand does not have a high pH, rich fen equivalent of northern hemisphere wetlands because nutrient-rich limestone formations are very limited in extent. Fens frequently occur on slightly sloping land, around margins of bogs, or upslope of swamps. Dominant species include sedges (*Baumea teretifolia*, *B. rubiginosa*, *Schoenus brevifolius*, *S. pauciflorus*, *Carpha alpina*), ferns (*Gleichenia dicarpa*), tussock grasses (*Chionochloa rubra* – common in southern peatlands and at higher altitudes), and shrubs (*Leptospermum scoparium*).

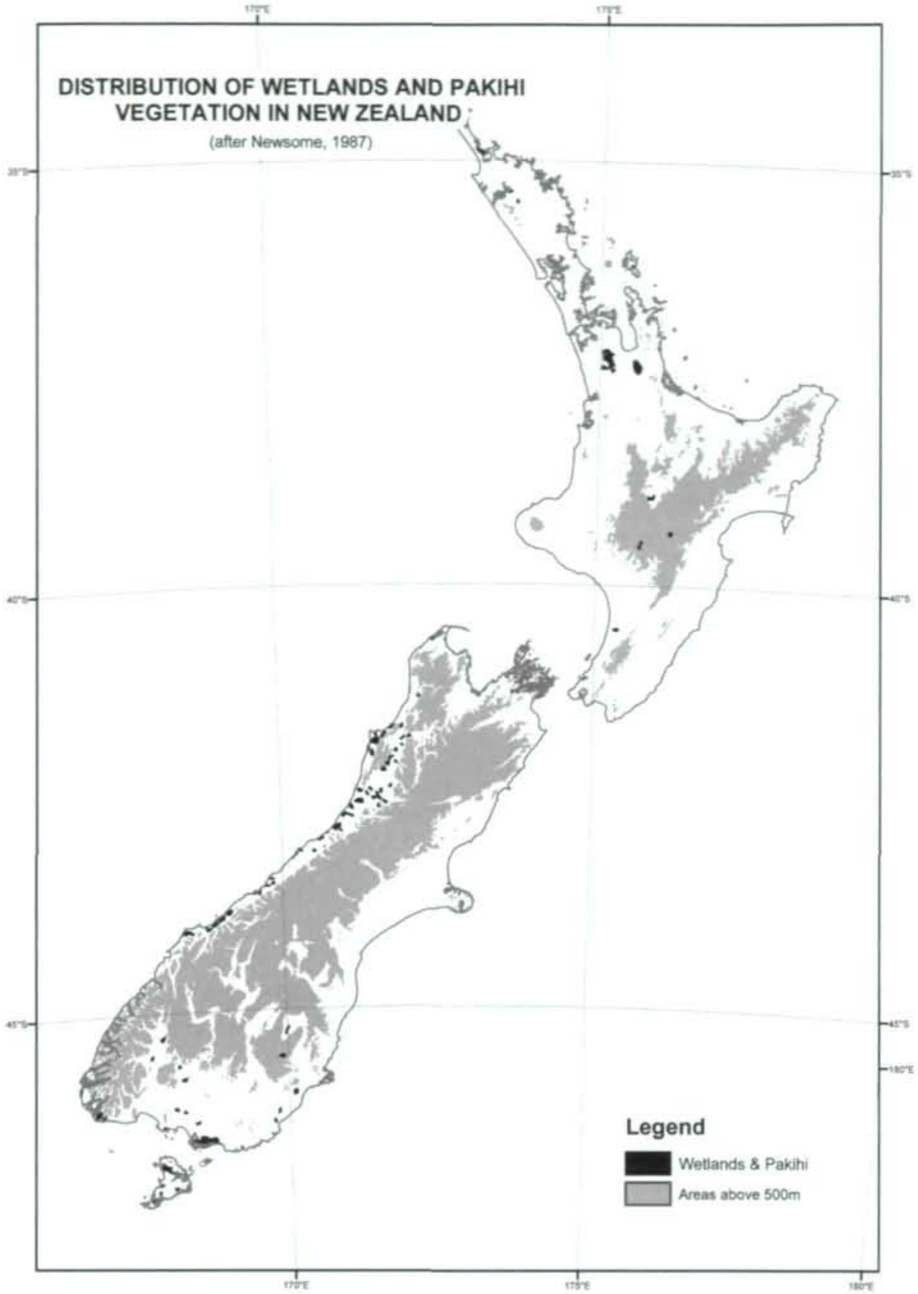

Fig. 14: Distribution of wetlands and pakihi vegetation in New Zealand (after NEWSOME 1987)

Fig. 15: Restiad bog at Moanatuatua, northern North Island, showing clumps of *Sporadanthus ferrugineus* overtopping *Empodisma minus*. (Photo: J. GREENWOOD)

Fig. 17: Cushions of *Donatia novae-zelandiae* near sea level at Awarua Bog, southern South Island. (Photo: Bev CLARKSON)

Fig. 16: Recently burnt blanket bog at Rakautahi, northern Chatham Island, with charred stems of *Dracophyllum scoparium* among clumps of *Gleichenia dicarpa*. (Photo: Bev CLARKSON)

Swamps are usually more recent formations or have had a long history of disturbance, e.g., continual river flooding. They have surface water and groundwater inputs, with peat and/or mineral substrate, moderate to high nutrients and pH range 4.8–6.3. Swamps develop on valley floors, plains and deltas throughout New Zealand and have a mixture of species including sedges (*Carex*), reeds (*Typha orientalis*), tall herbs (*Phormium tenax*), shrubs (*Coprosma*), and trees (*Dacrycarpus dacrydioides*, *Cordyline australis*).

Seepages typically occupy small sites on slopes, having flowing water with enhanced aeration and nutrient supply. They can occur as localised stand-alone wetlands or as features associated with other wetland classes. The vegetation is often dominated by sedges, e.g., *Carex* spp., *Schoenus pauciflorus* and *Carpha alpina*, as well as mosses, cushion plants, and occasionally, shrubs or trees.

The pakihi and gumland wetland class is characterised by ultra-infertile acidic soils (pH 4.1–5) of poor drainage because of an impervious horizon, being mainly rain fed and prone to temporary drought. The soils may be mineral, peat or mixtures of both; those with peat can be classified as bog or fen (JOHNSON & GERBEAUX 2004). Typical vegetation includes sedges (*Baumea*, *Schoenus*, *Gahnia*), ferns (*Gleichenia dicarpa*), restiads (*Empodisma minus*), and varying amounts of shrubs (*Leptospermum scoparium*, *Dracophyllum*). Extensive areas of peat-producing pakihi occur on flat land on the West Coast of the South Island where annual rainfall is usually >2.200 mm (MEW 1983). Gumland is confined to northern North Island on land formerly occupied by forests of kauri (*Agathis australis*), which were exploited for kauri gum. This ultra-infertile peatland type is similar to the buttongrass moorlands of Tasmania.

Many peatlands, especially lowland swamps, fens, and some bogs, have been drained and converted to pasture during settlement of land over the past 150 years. Drainage is the major threat to remaining peatlands, with fragmented systems also being affected by ongoing regional lowering of water tables. Wetlands of higher nutrient status – swamps, fens, and young bogs – are susceptible to invasion by introduced trees, particularly willow (*Salix cinerea*, *S. fragilis*), which can potentially overtop and displace native peat-forming species. Other threats include introduced browsing mammals, domestic livestock, nutrient inputs, fire, and peat mining. These need to be controlled or managed on a case-by-case basis to prevent further declines in peatland area and diversity.

The carbon budget of New Zealand peatlands

J. NIEVEEN & L. SCHIPPER

New Zealand wetlands are highly fragmented and threatened by drainage, burning, mining, agricultural and horticultural activities (TAYLOR et al. 1997; CLARKSON et al. 2005). The carbon budget provides knowledge on peat development, along with data and criteria useful for managing, restoring and monitoring peatland resources. Carbon budget studies from New Zealand peatlands have focussed on the northern North Island restiad bogs either still having original vegetation cover (SMITH 2003) or heavily drained and converted to pasture for dairying (NIEVEEN et al. 2003, 2005). Both long-term studies used the eddy-covariance technique to measure CO_2 exchange from the ecosystem to the atmosphere. The carbon budgets were determined from the difference between respiration losses (from both the peat and plants) and photosynthesis gains by plants.

Studies on a peat bog ecosystem were conducted at Moanatuatua peat reserve (a 114 ha remnant bog surrounded by farmland), 18 km southeast of Hamilton in the Waikato region. The main peat former is the restiad wire rush *Empodisma minus*. The annual carbon sequestration was 1.85 tC ha^{-1} yr^{-1} in 1999 and 2.10 tC ha^{-1} yr^{-1} in 2000 (SMITH 2003). This is greater than sequestration rates found for other wetlands around the world. The annual carbon budget differences were mainly caused by differences in the variation of peat temperature between the two years. Some of this carbon accumulation may have been from increased vegetation re-growth in recent years, and possibly caused by lower water tables and increased nutrients from fertiliser drift from the adjacent farmland (CLARKSON et al. 1999). The carbon budget for the pasture system on drained peats showed a very different picture. SCHIPPER & MCLEOD (2002) measured average subsidence rates of 3.4 cm yr^{-1} during the first 40 years of dairy farming in the Waikato and attributed 37% of the subsidence to respiration, the rest to shrinkage of peat. This rate of peat subsidence has been confirmed for other parts of the Waikato region although the proportion attributable to mineralisation was not established (MCLEOD M. unpublished data). Using the eddy covariance technique, NIEVEEN et al. (2003, 2005) developed a carbon budget for pasture on peat of –45 kg C ha^{-1} yr^{-1}, i.e. a loss of carbon. After including other carbon sinks/sources (e.g., methane emissions from cows and production of milk), the net annual carbon loss was 0.99 tC ha^{-1} yr^{-1}.

Much like other parts of the world with peat, land use changes of natural peatlands in New Zealand have led to large losses of carbon to the atmosphere, estimated at 30–370 Mt C yr^{-1} globally (ARMENTANO 1980). This has caused a significant shift in the world's carbon balance (see e.g. OECHEL et al. 1993). Land use change also threatens biodiversity. Fortunately in New Zealand large remaining peat bogs such as Koupoutai and Whangamarino along with other smaller bogs have received statutory protection. Restoration approaches are being also applied to peat mining areas (SCHIPPER et al. 2002) to reinstate their unique habitat and biodiversity.

Fig. 18: Bega Swamp is a topogenic mire in New South wales at 1040m altitude. It supports a mosaic of epacrid shrubs, graminoids and *Sphagnum*. It is the site of the most detailed pollen and isotopic studies carried out in Australia. (Photo: Geoff HOPE)

Montane Swamps of eastern Australia

G. HOPE & P. KERSHAW

In addition to the *Sphagnum* dominated shrub bogs of the subalpine and montane region that have previously been mentioned, topogenic fens and swamp shrublands are widespread (KERSHAW et al. 1993, HOPE 2003). Fens dominated by *Carex gaudichaudiana* and other sedge and restionaceous species such as *Lepyrodia anarthria* and *Baloskian australe* form large peatlands up to 300 ha in extent, such as at Wingeecarribee Swamp in southern New South Wales. Peat growth may be rapid in these mires with 6m being formed in the last 3.000 years. Others have slower net growth or have had periods of oxidation and erosion that may be associated with stream incision. Nursery Swamp, a 28 ha *Carex* fen at 1.090m in the Australian Capital Territory, has layers of humic peat or peaty clay between horizons of fibrous peat, the total depth being about 3m. Typically fine charcoal occurs in all samples in these mires indicating that fires during drought periods on the fen and the immediate catchment are very common. Such fires may maintain the sedgeland that might otherwise trend towards shrub bog.

The peatlands grade downvalley into organic-rich silty-clay alluvium that often also underlies the peat. These sediments are liable to erosion and once a single channel has started to incise they will often erode completely. Several phases of channel incision and refilling have been found in some valleys and it is likely that peatlands have eroded in a similar manner. A range of initiation dates are known from eastern Australia (KERSHAW & STRICKLAND 1989) that indicate that mid and late Holocene destruction events have been common, as sites such as Wingeecarribee and Ginini Bog date from 2.000 - 3.000 years ago, or have only restricted areas of older peats (MACPHAIL & HOPE 1985). The oldest bogs, such as Bega Swamp, are about 12,500 years old and on the wettest sites at mid-altitude (Fig. 18). A *Carex* fen, Mulloon Bog, New South Wales, at 790m, has basal ages of ca 4.000 years ago on fallen trees beneath three metres of peat.

Peatlands dominated by shrubs are widespread in the mountains, although peat accumulation is not normally great. Common Myrtaceous taxa are *Leptospermum juniperinum*, *L. lanigerum*, *Callistemon sieberii*, *Baeckia gunnii*, *Eucalyptus ovata* and *Calythrix tetragona*. Epacridaceous heaths include *Sprengelia incarnata*, *Epacris paludosa*, *E. breviflora* and *Richea continentis*. *Leptospermum lanigerum* can reach 8 m in height and form a low forest if protected from fire for a long time.

Aquatic communities also build up peat, the main agents being *Phragmites australis* and *Typha angustifolia* with help from robust sedges such as *Eleocharis sphacelata*, *Isolepis aucklandicus* and *Juncus* spp. These peats are coarsely fibrous and very moist.

A restricted mire type that occurs on the highest ranges above 1.800 m is blanket bog, dominated by *Empodisma minus* with contributions from the lily *Astelia alpina*, various sedges such as *Oreobolus pumilio* and *Carex* spp, and herbs such as *Chionogentiana* spp. and composites such as *Celmisia* and *Brachycome* spp. Blanket bogs form quite extensive deposits near snow patches and have been shown to have grown in several episodes in some sections (COSTIN 1972), perhaps reflecting moist equable periods disturbed by cold and dryness. In alpine regions of mainland Australia restricted areas of *Carpha alpina* fen occupy hollows in feldmark. In Tasmania, montane peatlands can be dominated by the fern *Gleichenia alpina*, although they are generally shallow, low organic-content peats.

The montane peatlands are finely balanced and are sensitive to catchment change and alteration in local vegetation cover. Many have been eroded since European settlement due to cattle grazing and ditching.

Temperate coastal peatlands in Australia

P. ADAM & P. HORWITZ

The coast line and coastal lowlands of temperate Australia provide the setting for a diverse range of peatlands. There is marked variation in climatic conditions around the coast: summer rainfall dominance, but with appreciable rain throughout the year, in southern Queensland and northern New South Wales, winter maxima in southern New South Wales, Victoria and Tasmania and a very strongly winter rain dominated Mediterranean climatic regime in south west Western Australia. An extensive stretch of the southern coastline and hinterland in South Australia and Western Australia is arid and lacks peatlands.

Intertidal saltmarshes and mangroves are found fringing many estuaries and coastal lagoons; and although mostly on inorganic sediment, layers of peat may be found at some sites (WOODROFFE 2003). Much of the coast is fringed by sand dunes, which support a diversity of wetlands. Interdune swales may contain extensive wet heaths and woodlands, sedge swamps and lakes. Lakes may be window lakes, exposing the freshwater lens found in most dune systems, or perched lakes, where water is held up above the regional water table by an impervious organic layer. In western Tasmania open ponds 4.000 years ago are invaded by *Melaleuca ericifolia* shrublands (HOPE 1999). Some of the best examples of perched dune lakes in the world occur on Fraser Island and the Cooloola sand mass in southern Queensland (SINCLAIR 1997). The peat deposits in these dune systems are mainly shallow, and derived largely from Cyperaceae and Restionaceae, although locally *Sphagnum* may be abundant (Fig. 19). Variation in structure and composition of the vegetation in swales normally follows a simple pattern related to depth to watertable, but there are more complex patterned systems, as for example the fens on Fraser Island, where the main peat former is the restiad *Empodisma minus*.

Fig. 19: Hind dune swale near Smiths Lake, NSW. The tall sedge is *Gahnia sieberiana*, the isolated small trees are *Melaleuca quinquenervia* and *Eucalyptus robusta*. This swamp is one of the large number of sedge swamps and wet heaths in the Eurunderee sand mass. (Photo Paul ADAM)

The landform and vegetation of a number of coastal dune systems in northern NSW and southern Queensland was destroyed during mining for mineral sands (rutile, zircon). Public pressure in the 1970s led to conservation of many of the dune systems and phasing out of mining. Although dunes were reformed and revegetated following mining, it will be many years before peat deposits lost during mining and replaced by natural processes.

The coastal plains in Western Australia have much more subdued relief than the east coast dune systems. Although the rainfall is strongly seasonal, there are large numbers of permanent wetlands, some with considerable peat deposits, but most with at least shallow development of organic profiles. Some of the more pronounced of these may be seen on the Swan Coastal Plain where unconfined aquifers in the deep sandy soils keep depressions regularly, if not permanently, saturated. TEAKLE & SOUTHERN (1937) suggested that 5% or more of coastal sandhill zones of the Swan Coastal Plain, a bioregion of approximately 400 km x 50 km wide could be classed as peats and related soils. The long term build up of organic profiles is derived from sedgeland vegetation (predominantly Cyperaceae and Restiona-

Fig. 20: The Trennery Reserve, Coogee (DODSON et al. 1995). The small peatland basin supports wet heath vegetation, which now includes a number of invasive weed species. (Photo: A. ROBBIE)

ceae). Another feature of note for some of the wetlands in the region is the occurrence of diatomaceous soils, occasionally as organic rich diatomite (see for instance ALLEN 1979).

Since sea level reached its current level estuaries have continued to infill, the rate of development varying considerably between systems. Many of the east coast barrier estuaries have reached a late stage of evolution and are substantially infilled (ROY 1984), with extensive alluvial floodplains. At the time of European settlement there were extensive swamp forests and other wetlands on these floodplains but there has been widespread clearing for urban and agricultural development. Most of the wetlands were on alluvial soils, but locally shallow peat deposits had formed. The swamp forests were dominated by paperbarks (*Melaleuca* spp.) or *Eucalyptus*. In southern Queensland and northern New South Wales the major *Melaleuca* species is M. *quinquenervia* which is a tall tree. Further south a number of lower growing species, including M. *ericifolia* and M. *squarrosa*, form dense thickets. Community dominant eucalypts include *Eucalyptus robusta* and *E. ovata*. At least seasonally the watertable in paperbark and eucalypt swamp woodlands is above ground; *Casuarina* dominated stands occupy the drier fringes of the swamp forests and are rarely flooded.

The coastal plain reaches of rivers in southwest Western Australia also support sedgelands and *Melaleuca* thickets over peat (see, for example, HODGKIN 1978, HODGKIN & CLARK 1988), although unlike the east coast there has been less clearing and draining.

Peat deposits have also formed on areas of impeded drainage on and above seacliffs. The small peat basin in the Trenerry Reserve (Fig. 20), in the Sydney suburb of Coogee, has provided a palynological record documenting the impact of European settlement (DODSON et al. 1995). The peat deposit formed in a small basin in the Hawkesbury Sandstone, fed by seepage from a small shale lens and by overland flow from the surrounding catchment. The vegetation is a wet heath, dominated by the sedge *Baumea juncea* with shrubs such as *Baeckea imbricata*, *Hakea teretifolia* and *Westringia fruticosa*. The exposed peat face supports a number of small herbs and graminoids, including *Centrolepis strigosa*, *Drosera* spp. *Eriocaulon scariosum*, *Isolepis cernua* and *Triglochin* spp. Although very small, this site is important as habitat for locally uncommon species and for the historic record it provides. Similar basins occur elsewhere along Sydney's sea cliff line where topography and drainage permit and others have been lost to development.

Similar coastal springs and seepages can result in build-up of organic rich soils in far south-western Australia, particularly where contact zones between impervious gneiss or granites and more porous limestones are exposed by coastal erosion.

Changes to peatland systems in coastal south-western Australia may be symptomatic of changes occurring elsewhere in Australia. The extensive urban development on the Swan Coastal Plain (including the city of Perth) has led to many of these wetlands being subject to cultivation for horticulture, peat extraction, drainage, and in-filling, often in that order (see TEAKLE & SOUTHERN 1937, GIBLETT 1996, HILL et al. 1996). Those that remain are subject to declining water tables, the result of over-extraction of groundwater (for irrigation or domestic consumption), a series of drier years, and land use changes. The increased likelihood of drying of organic rich soils can have severe consequences - where drying occurs in areas of potential acid sulphate soils, subsequent rewetting will produce an acidification response (see SOMMER & HORWITZ 1999). Drying will also exacerbate the risk of exposure to fire, and peat fires have become more common in recent times (see HORWITZ et al. 2003).

Peatlands of the coastal wallum of northeast NSW & southeast Queensland

Sediments from five peatland sites within the coastal wallum (sand heath) communities in northeast New South Wales and southeast Queensland provide evidence of long-term vegetation histories, via pollen analyses, of the coastal wallum (sand dune and plain) environments of the central east coast of Australia. The sites are: Eighteen Mile Swamp, on the seaward side of North Stradbroke Island, Queensland; Ningi Swamp, in Deception Bay, northern Moreton Bay, Queensland; Bungawalbin Creek, northern New South Wales, Bundjalung National Park, northern New South Wales; and Emu Swamp, northern Sunshine Coast, Queensland. The sedimentary records at these sites span the last 2.500, 6.000, 6.500, 9.000 and 20.000 years respectively, and indicate local and regional change in floral regimes.

The individual studies illustrate several important points regarding the history of the vegetation of the coastal wallum of northeast New South Wales and southeast Queensland, reflecting both the peatlands contained within these coastal environments and their related aquatic and terrestrial systems. As is expected in such studies, the natural vegetation has rarely remained static over time, and that in all the cases examined, over time scales of hundreds and thousands of years the dominant composition and the structure of the vegetation at every locality has changed. Whereas some of the evidence reflects the effects of changing water table hydrology on especially the composition of coastal wetlands, the nature of the dryland vegetation in the vicinity of the study sites has also been shown to change. These latter changes in large part reflect climatic changes that, while not necessarily being of great magnitude, were probably sufficiently influential to cause changes in dominance. Secondary changes also affected the vegetation, especially the effects of changes in water availability and fire regime. The second major environmental contributor to vegetation change in this region is sea-level change. Sea levels have been fluctuating at a global scale throughout geological time. With the rise of sea level in post-glacial times, shorelines have moved landwards across what is now the offshore continental shelf. With this shoreline migration, not only has the terrestrial hydrology been affected, but entire ecosystems have had to shift from being predominantly inland systems to being coastal systems. Some of the compositional changes at these sites represent this important change. Finally, it should be noted that neither natural climate change nor natural sea-level change has ceased. While human activity may be having an effect on, for example, global warming and sea-level rise, the effects - climatic, physical and biological - of these may not be distinguishable from the natural changes in these coastal environments. Many of the changes witnessed in the modern environment may indeed be those expected under natural conditions of climatic and sea-level change.

Inland spring mounds

B. BOYD & J. LULY

The Great Artesian Basin is the world's largest artesian basin, with inflow mainly at its eastern Queensland margin, and outflows along its southern and western margins at mound springs formed by the build-up of precipitates and aeolian sediments (BOYD 1990a). The water flowing from these point sources of permanent fresh water in a largely waterless environment generally evaporates or soaks into the soil within tens or hundreds of metres. Occasionally, there is sufficient water to form permanent swamps, some with growing peat. Spectacular examples are the active swamps at Dalhousie Springs in the Witjira National Park (26°25' S 135°30' E, 100-125 m a.s.l.), c. 50 km west of the Simpson Desert, in a region of c. 100 mm annual rainfall. The springs are surrounded by stone-covered clay plains with sparse low chenopod saltbush. Regionally, small lime-

Fig. 21: One of the springs in the Elizabeth Springs mound spring complex near Boulia, another of the Great Artesian Basin artesian spring systems. Soft sediments in these relatively intact springs are peaty marls. The majority of the arid zone mound springs are dominated by inorganic sediments derived by precipitation of calcium carbonate and trapping of aeolian dust. (Photo J. Luly)

stone pavement areas support sparse herbaceous vegetation, saline flats support samphire vegetation, and floodplains support a richer flora of perennial shrubs, some trees (*Acacia* spp. and *Eucalyptus* spp.) and herbs.

There are several active and buried peat swamps at Dalhousie Springs, the largest being *c.* 6 km long and to 1 km wide, aligned *c.* N-S, and fed from the south. Its surface lies 0.5-1 m below the surrounding land surface, and comprises over 3 m of swamp sediments. Peat is currently growing closest to the spring, whereas further away the swamp plants grow directly on sand. Swamp vegetation grows profusely, generally to 100% cover, as a mosaic of four types dominated variously by *Phragmites australis*, *Cyperus gymnocaulos*, *Juncus kraussi* and *Typha domingensis*; upstream, the swamp is dominated by *Phragmites* growing over 4m high, with *Juncus* at the downstream end surrounded by a terminal fringe of *Melaleuca glomerata* swamp.

Two pollen sequences have been examined from this swamp, providing local history of the last two millennia or so (Boyd, 1990b, 1994). Swamp growth probably fluctuated, expanding downstream at *c.* 210 m per century for at least a thousand years, and during the last 700 years at *c.* 75 m per century. This is probably less in response to spring water flow changes than to the geomorphologic characteristics of the land surface upon which the swamp sits. The fossil pollen all represents current vegetation elements, and inferred vegetation changes relate to the establishment of the spring and fluctuations in the spring water flow and swamp growth. Such changes are temporal variants of the present spatial patterns on the swamp, and mainly represent natural succession. Although the springs were focal points for prehistoric aboriginal occupation, there is no evidence for human impact on the swamps. Swamp growth that pre-dates European presence caused neighbouring salt flat expansion, with the rising water table inducing soil salinisation.

The majority of the arid zone mound springs are dominated by inorganic sediments derived by precipitation of calcium carbonate and trapping of aeolian dust. Hergott Springs is an example of a degraded arid one mound spring from the western margin of the Great Artesian Basin near Marree, South Australia. Sediments are primarily inorganic – any peat once present has been lost through reduced water levels and intensive trampling by stock. In the Elizabeth Springs mound spring complex near Boulia (Fig. 21), soft sediments in the springs are dominated by organic rich marls. The springs are relatively intact and have recently been fenced to regulate stock access. Survival of the springs is still threatened by decreased groundwater pressures in the Great Artesian Basin.

Mound springs are also part of the tropical landscape, forming in localities fed by artesian waters (Fig. 22) or where overflow of aquifer intake areas occurs. The majority of peat-dominated tropical mound springs have been destroyed by drainage to provide water supplies and by trampling by feral pigs and livestock (Fensham et al. 2004). Two peat-dominated tropical mound spring systems have been investigated (Luly et al, in prep. a, b). Both systems began life as lakes or ponds and became mounds relatively late in their histories. Wombe Spring is one of three mound springs making up the Flying Fox Springs complex in Keep River National Park in the Northern Territory. It stands approximately 3 metres above the surrounding floodplain of Flying Fox Creek and is covered by a dense monsoon vine thicket. Peat formation began in a shallow lake or swamp at or before 35.000 BP (Luly et al. in prep. b) and persisted through the dry climates prevalent at the height of the last glacial maximum. The older peat is strongly humified, fine grained material derived from sedges or other monocotyledonous taxa. By 10.000 BP, lacustrine deposition was replaced by formation of a peat mound comprising fibrous material derived from trees and shrubs. Peat accumulation in the mounded, vine thicket phase, of swamp history was remarkably rapid with the three metres of mounded peat accumulating within the space of about 9.000 years. The modern vine thicket vegetation occupying the mound is significantly younger than 1.000 BP.

Like Wombe Spring, the Pelham Springs are localised mounds of peat standing proud of surrounding flat floodplain country. The Pelham Springs are supported by artesian waters from the Great Artesian Basin. Two peat dominated mounds survive in the complex. Tuckett's Spring is a small, much degraded mound surmounted by *Melaleuca* and *Pandanus* dominated swamp forest. Reduced groundwater flow to the mound as a result of diversion of water to stock tanks and reduced pressures in the Great Artesian Basin overall has allowed invasion of the mound by dry-land species. The edges of the peat mound are subject to erosion by pig and stock activity, as well as sapping of excavated faces by internal groundwater pressure. Lake peat began to accumulate at the site some 5.000 BP, to be replaced by a peat mound from 3.500 BP.

At nearby Black's Spring, the same pattern of sedimentary history can be discerned but at wildly differing timescales. Organic lake sediments began to accumulate at about 16.500 BP and the mound of fibrous peat characteristic of the swamp forest dominated mound dates from 16.000 BP (LULY & SMITHERS unpublished data).

The timing of peat formation in tropical mound springs differs widely, occurring in sympathy with the dynamics of groundwater systems rather than the more immediate effects of climate. For example, Dragon Tree soak, in north Western Australia, formed ca 6.500 years ago and has had phases of bullrush peat accumulation (PEDERSON 1983).

Fig. 22: Flying Fox Springs in the Keep River National Park, Northern Territory. This spring is approximately 30 m in diameter and rises approximately 3 m above the level of the surrounding savanna. (Photo: Bev JOHNSON)

Tropical Peatlands Of Northern Australia

J. G. LULY
& J. F. GRINDROD

The tropics of northern Australia, that is, areas north of the Tropic of Capricorn, are a climatically complex region dominated by summer rain deriving from monsoon related synoptic systems. Despite what might be expected, most of the area is arid; a substantial proportion is strongly seasonal (wet – dry) and only a small portion, principally those places geographically disposed to intercepting orographic rains brought by the southeast trades, can be considered perennially wet. Temperatures in most areas are high but outside the wet tropics, productivity of plant communities is restricted by seasonal drought and low nutrient soils, with high organic decomposition rates. Tropical Australia is, therefore, hardly an ideal setting for the development of peat dominated landscapes. Nonetheless, where conditions are right, peat accumulates and provides locally important windows into palaeoenvironments of the region. Many tropical peatlands in Australia are threatened by drainage works, reductions in groundwater pressure consequent on over-exploitation of artesian water supplies, increased rates of soil erosion and the exploitation of peat for commercial purposes. Their long term future in a "greenhouse" world is uncertain at best.

Fig. 23: A lagoon at South Beach on Orpheus Island. True mangrove peat occurs below the fresh water sediments impounded by the rainforest covered boulder dominated beach ridge in the background. (Photo J. LULY)

Coastal swamps and wetlands

Coastal peatlands in northern Australia occupy a variety of settings in which impeded drainage and high rainfall allow preservation of organic materials. Coastal settings most conducive to peat accumulation include mangrove swamps, inter-dune swales, perched dune lakes and on broad floodplains of major wet tropical rivers.

Mangrove shorelines

Mangroves produce distinctive coastal sediments often referred to in the literature as mangrove "peat" though for the most part, the materials are fine-grained mud or clays shot through with coarse woody or root-derived debris. This sediment type dominates present mangrove shorelines, and is widely preserved in continental shelf sequence stratigraphies (GRINDROD et al. 2002). True mangrove peat - material in which loss on ignition values exceed 35% (WUST et al. 2003) - is relatively rare in northern Australia. It is found in sheltered locations where restricted water circulation prevents flushing of accumulating organic matter into the open ocean and where persistent anoxia inhibits bioturbation and consumption by crabs or other mangrove residents. Though mangrove peat is most often found in wet tropical settings, peat beds outcrop on eroding beaches in the dry tropics near Bowen and Townsville and probably reflect local equivalents of the "mid-Holocene big swamp" phase described elsewhere (WOODROFFE et al. 1985). The processes leading to development of peat rather than the more typical mangrove sediments in these areas remain to be investigated.

Mangrove peats occur in sites where water circulation is restricted by topography and where rainfall is sufficient to support a complex mangrove community. On Orpheus Island north of Townsville, mangrove peat has accumulated behind boulder beach ridges at Cattle Bay and South Beach (Fig. 23). Both localities are now freshwater systems dominated by terrigenous sedimentation as a result of sealing of connections to the sea by re-organisation of the boulder ridge barrier. Peat in these sites dates to the time of sea level stabilisation (around 6.000 BP) and correspond in age to the "big swamp" phase of mangrove expansion recognised from Hinchinbrook Island (GRINDROD & RHODES 1984) and the Northern Territory (WOODROFFE et al. 1985) though in these areas, mangrove facies deposition was dominated by inorganic mud and clay. Mangrove peat also outcrops on beaches on the seaward side Cape Bowling Green and on beaches adjoining the mouth of the Don River near Bowen (SMITHERS pers. comm.). These deposits suggest that they formed when both wetter climate and substantial change in the sand barriers which must have been present to protect them from direct attack from the sea. The peat deposits in both localities are being rapidly eroded as a consequence of rapid coastal retreat. Mangrove peat exposed on the seaward side of beaches of Cape Bowling Green near Townsville, north Queensland. These peat deposits, comprising humified wood, leaf fragments and fibrous root mat, are atypical of mangrove sediments in northern Australia.

Inter-dune swales

Peat formation post-dates stabilisation of modern sea level at or slightly before 6.000 BP. The peat tends to be quite fibrous and is comprised of material derived from swamp forest species such as *Melaleuca leucadendron* and *Pandanus* sp., as well as sedges such as robust-growing *Gahnia* species. Excellent examples can be found on Whitsunday Island and in the dunes behind Cowley Beach and Kurrimine Beach.

Perched lakes are found on extensive coastal dune systems, principally on Cape York, where the Cape Flattery and Olive River dune fields are spectacular examples. The lakes are closed basins formed by deflation or intersection of dune slopes and are fed by rainfall and seepage from local dune water tables. In most cases, the water is conspicuously tannin stained. Organic materials are generally fine "gyttja" like materials, especially in the centre of the lake but around the margins, more fibrous peats derived from swamp forests, sedges, water lilies and water ferns. The ages of organic matter in such sites can be impressive. LONGMORE & HEIJNIS (1999) report perched lake sediments on Fraser Island exceed 100.000 BP while LEES & SAENGER (1989) have radiocarbon ages in excess of 30.000 BP from comparable materials in the Cape Flattery dunefield. Younger lake peats are also known (LULY et al. in prep.a), and the cycle of lake formation and in-fill continues in the region.

Floodplains

Major river systems in the wet tropics region develop broad flood plains laced with palaeochannels produced by channel migration and avulsion. The typical vegetation is a tall forest of *Melaeuca argentea*. The lagoonal environments which develop along palaeochannels can be readily seen on aerial photographs and are especially prominent on the Russell – Mulgrave, Moresby, Murray and Tully River systems of Queensland. While many of the palaeochannels are filling with terrigenous over-bank sediments, lagoons further from the main channels accumulate more organic materials derived from local gallery forests. These deposits are thin with high inorganic content and are likely to be occasionally flushed from the system by high flow events associated with tropical cyclones. Much larger swamps such as Babinda Swamp and Eubenangee Swamp owe their origins to ponding of water between the Malbon-Thompson Range and associated alluvial fans. The swamps are extensive and contain peat dating to about 13.000 BP (CROWLEY & GAGAN 1995) though for the most part, ages for the onset of peat formation reflect the timing of mid-Holocene sea level stabilisation.

Mountain swamps and lakes

The cool wet tropical uplands of the Atherton Tableland provide the best known examples of Australian tropical peatlands. Unlike the coast, peat accumulation sites on the Tablelands differ widely in age; Holocene deposits are common, but so too are organic deposits dating to beyond 50.000 BP (TURNEY et al. 2001) and probably beyond 200.000 BP. The majority of peat accumulation sites on the Atherton Tableland owe their origin to explosive maars. The steep-sided depressions formed by phreatic eruptions rapidly fill with water and begin to accumulate organically derived sediments. Maars such as Lake Barrine, Lake Eacham and Lake Euramoo remain primarily lacustrine; others such as Lynch's Crater and Bromfield Swamp have filled with organic sediments and their modern surfaces are maintained at a level determined by the relative height of outlet channels. The age of maar activity on the Atherton Tablelands is not well known but chronologies from Lynch's Crater suggest organic sediments have been accumulating for at least 200.000 years in such sites.

In addition to peats accumulating in lakes formed by volcanic action, the Atherton Tablelands also have a less conspicuous and substantially younger collection of swamps formed by blockage of drainage lines by basalt flows or mass movement processes. The best example is Upper Barron Swamp, a valley-bounded swamp impounded to form a diatomite dominated lake at about 7.000 BP but which changes to be peat dominated with a swamp forest cover at about 4.000 BP. The fibrous peats deposited in the latter phase of swamp history are being mined for horticultural products and the swamp will soon disappear.

Fig. 24: *View of the infilled floodplain of the Sepik River near Timbunke, Papua New Guinea. A complex of oxbow lakes, swamp forest, sago palm and tall graminoid dominated swamps contain up to several metres of peat.* (Photo: Geoff HOPE)

Pacific Mires

G. HOPE

The western Pacific islands are tropical to equatorial and hence can have very high rainfall throughout the year, particularly on slopes exposed to the Trade winds. Peat forming mires are common and fall into four main groups, namely coastal infill swamps, topogenic mires such as valley fill deposits or successional mires in closed basins formed by tectonic, volcanic or glacial processes. In addition the highest areas of New Guinea have extensive blanket bog formed by sedges, grasses and cushion plants. The widespread mires underline the wetness of the New Guinea region, where rainfalls exceeding 10.000 mm per annum are common and seasonality not marked.

Coastal infill swamps

These have been studied in several locations in Fiji, Vanuatu and New Guinea as well as northern Australia. Typically basins are flooded by post-glacial transgression about 7.000 years ago and contain short estuarine sequences of coral sand, shell and mangrove mud. Dense mangroves then form woody peat and this may be several metres in depth, and display a succession to freshwater swamp forests dominated by *Pandanus*, sedges, palms and saline tolerant trees such as *Exocoeria anagallocha*. The most striking examples are the infilled estuaries of some of the large rivers of New Guinea such as the Sepik and lower Mamberamo, where buried estuarine sediments are found 250 km from the modern mouth of the river (SWADLING & HOPE 1992) and a complex of oxbow and levee dammed lakes have peat forests and sedgelands around their margins (Fig. 24). However even small islands may have infilled embayments with peat built up behind beach ridges. On Norfolk Island peat outcrops on two beaches, and about 2 m of peat is buried below builders' rubble placed by convicts to fill in the swamp (MacPHAIL et al. 2001).

With a good water supply the sedgeland-grassland-fern component may increase, as at Bonatoa Bog, Fiji (SOUTHERN 1986). Human burning and increased slope erosion has sealed many bogs with layers of clay above which sedge-grass peats occasionally build up, as at Yacata island, Fiji (CLARK & HOPE 2001). Other bogs may reach an equilibrium with the sea level and cease to accumulate peat in the last 2.000 years or so. Buried peats are common on the drier side of Viti Levu, Fiji and Aneityum Island, Vanuatu. This may mark a mid-Holocene fall in sea level in the Central Pacific, but it also reflects limits to peat formation once the water table is reached. The unusual sedge mire of Teraina (Washington) atoll in Kiribas however is only ca 2.000 years old and it infills a former lagoon that became exposed due to the sea level fall. The peatland is dominated by *Scirpus littoralis* that has formed 2-3 m of sedge peat. (WESTER et al. 1992).

Topogenic mires.

River floodplains and other areas with high water tables support bogs in the tropics. These are typically tall graminoid fens with a simple flora of grasses such as *Miscanthus* sp. *Phragmites* sp., sedges and ferns together with herbs and shrubs such as *Polygonum* spp., and *Melastoma*. A mire complex of about 600 ha containing 2-3 m of peat is known from Vanua Levu, Fiji at around 400 m altitude. Nadrau Swamp, at 700 m in central Viti Levu, has about 5 m of sedge-grass peat built up in the last 2.000 years. As pointed out by HOPE et al. (1999), in many cases peat formation has followed forest clearance which may raise water tables locally. This has not been the case at Kosipe Swamp at 1996 m in New Guinea. Here a stream levee formed a wetland about 40.000 years ago and this peatland expanded with younger initiation date of 18.000 yr BP 4 km up valley from the initiation point (HOPE unpublished).

Successional peats in closed basins.

Much of the Pacific and especially New Guinea is tectonically active and also has active vulcanism. Fault dammed valleys, subsidence basins and lava-dammed valleys are relatively common. Active peat growth takes place as vegetation infills lakes in these basins. At a late stage in the succession floating peat mats are common and these may infill a lake leaving a lens of water below the peat layer. A small example occurs at the landslip basin of Nurank Swamp, at 2.200 m in the central ranges of Papua New Guinea. Here *Sphagnum* and sedge peat form a 1m mat over water above 8 m of lake sediment representing 4.000 years of accumulation. A 300 year old tephra is repeated in both the floating mat and the upper layers of lake sediment, showing that the final infill is quite recent (GILLIESON et al. 1990). Other examples include lava-dammed basin near Tari (HABERLE 1998) that contains a ca 100.000 year sequence of peat and a volcanic lahar dammed valley near Tambul, PNG that preserves 40 m of peat dating to around 50.000 years ago. Lake Tagamaucia, at 780 m on Taveuni Island, Fiji is a subsided volcanic basin, and has an extensive floating sedge mat that drifts about the lake (SOUTHERN 1986).

The largest tectonic peatland in the region is the upper Mamberamo basin, the Lake Plain, in northern New Guinea. This 25.000 km^2 basin floods to a depth of 3 m each wet season and is mostly covered with swamp forest (LAM 1945). Peat depth is unknown, but away from the main rivers it may be very considerable. Two other types of closed basins are known. Glaciation affected ca 2.000 km^2 of New Guinea above 3.600 m and has left widespread tarns and mires infilling moraine dammed valleys (HOPE 1980). Solution basins are also widespread in both limestone and ultramafic rocks, and many of these are infilled with lake sediments and peats. An example is the 4 m of Pleistocene peats of Lake Suprin, in an ultramafic basin in New Caledonia (HOPE & PASK 1998).

Fig. 25: Hard cushion bog at 3.200m near Lake Habbema, , central Papua, Indonesia with the cushion shrub *Rhododendron saxifragoides*. Grasses, sedges and a *Myrmecodia brassii* are present as invaders in the hard cushion bog of *Oreobolus pumilio, Centrolepis philippinensis* and *Potentilla forsteriana*. (Photo Geoff HOPE)

Blanket and Cushion Bogs

The high wet mountains of New Guinea support large areas (perhaps 10.000 km^2) of blanket bogs in a mosaic with fens of *Carex gaudichaudiana* and *Carpha alpina*. The bogs are also dominated by grasses, restiads and sedges such as *Poa crassiusculus*, *Centrolepis philippinensis* and *Oreobolus ambiguus* and a variety of herbs such as *Potentilla foesteriana* and *Eriocaulon* spp. Shrubs may contribute including *Trochocarpa decockii* and *Rhododendron saxifragoides*, the latter forming hummocks up to 2 m in length (Fig. 25). In places a hard cushion bog exists with abundant mosses and hepatics. A cushion forming herb, *Astelia papuana*, is sometimes dominant in hard cushion bog (HOPE 1980, GIBSON & HOPE 1986). Fern bog dominated by *Gleichenia vulcanica* is widespread on only a few mountains. More widespread is grass bog dominated by *Deschampsia klossii* and *Poa* spp., as this follows stream lines and occupies wet slopes.

The tropical peatlands are subject to drainage and burning where they occur in agricultural areas. Even at high altitudes human caused fires have cleared forest and allowed peatlands to expand.

Peatland Management

Reservation and Conservation Status

J. WHINAM & G. HOPE

There is considerable variation in the current condition, the level and type of threats affecting their long-term conservation and the reservation status of the different types of peatlands throughout the regions of Australasia. The legislative framework of peatland protection includes: the international World Heritage Area Convention (applies to subantarctic Heard and Macquarie Islands, and the Western Tasmanian Wilderness), National Park status (Australia, New Zealand, New Guinea and New Caledonia), Flora, Scenic or Conservation Reserves (all States of Australia, most Pacific countries), threatened species legislation (at both a national and state level) in Australia and New Zealand. Peatlands are also included in a more general attempt to protect wetlands for ecological functions and particularly bird habitat conservation. The montane peatlands of Australia, New Zealand and western New Guinea (Indonesia) are partly protected in large National Parks (eg Kosciuszko NP, Cradle Mountain-Lake St Clair NP, Lorentz Taman Nasional). Some very large coastal parks are also protecting estuarine and riverine wetlands noteably Kakadu NP, and the Wet Tropics World Heritage Area in the tropics, and Fiordland NP, Wilsons Promontory NP and the Tasmanian Wilderness World Heritage Area in the temperate region.

Peatland management in Australasia is not unified but is mainly driven by the need to protect/reserve representative examples of the full range of natural biodiversity. For example, less than 10% of the original area of wetlands now remain throughout New Zealand (NEWSOME 1987), making conservation of all remaining wetlands significant. In New Zealand, peatlands have an additional conservation value in that they have revealed, and still contain, many significant cultural artefacts from early Maori settlement. Wyrie Swamp, in South Australia is also now a protected site because wooden artefacts, including the world's oldest boomerang, were found there (LUEBBERS 1975). Ironically this peatland was badly affected by an accidental peat fire in a peat extraction area prior to reservation.

The current condition of peatlands covers the full range from natural and undisturbed (e.g. the subantarctic peatlands, the *Sphagnum* peatlands of alpine and sub-alpine New Zealand and Tasmania), through to disturbed sites where either historical or current land use patterns threaten the integrity of the peatlands (e.g. grazing in the montane swamps of eastern Australia, the impacts of land subdivision on the temperate coastal peatlands), and including highly modified sites that are often mere remnants of once large peatlands (e.g. deforestation of tropical rainforests, peat mining at Wingecarribee Swamp). Added to these historic and current threats is the likely catastrophic impacts that climate change will have on the relatively small, but distinctive and ecologically important, peatlands of Australasia. Some of the identified threats to peatland conservation in Australasia are addressed below.

The Potential Impact of Climate Change on Australian Peatlands

K. BRIDLE

Australian climate change projections estimate that average annual temperature will increase by 0.4-2.0 ºC by 2030, and by 1.0-6.0 ºC by 2070 (HOWDEN 2003). Increases in temperature are anticipated across the whole continent with the least increase in south-eastern Australia (CSIRO 2001). Rainfall predictions show a trend for increased rainfall during summer and autumn for much of the continent, but for a wetter winter and a drier spring, summer and autumn for southeastern Australia (CSIRO 2001).

Many of the climatically-constrained peatlands (blanket mires, alpine fens and *Sphagnum* mires) are found in south-eastern Australia. Therefore, these ecosystems are likely to experience increased temperatures over all seasons and less rainfall during the warmer months. If we accept that the extensive and biologically important cyperaceous blanket mires of western Tasmania (see section on Tasmanian buttongrass moorlands) are already at their climatic limit (DAMMAN in JARMAN et al. 1988), then the future of these peatlands is uncertain. Existing meteorological data from the region illustrate that precipitation is less than evaporation during the summer months, (BRIDLE 1994, BRIDLE et al. 2003). Extended dry periods and resulting low water-table levels have been reported during the summer months for Australian blanket mires (BRIDLE et al. 2003), *Sphagnum* mires (WHINAM et al. 2003) and peatlands on sub-antarctic islands (BERGSTROM 2003) since 1999. Research elsewhere has shown that an increase in temperature and a lowering of the water-table may result in increased CO_2 emissions from peat, though the response may depend on peatland morphology (MOORE et al. 1988 in CHARMAN 2002) and dominant vegetation type (BUBIER et al. 2003). It is not yet known whether existing Australian peatlands are still accumulating carbon (sinks) or are now in a state of decay (carbon sources).

Fires

G. HOPE

Climate change is also likely to affect fire regimes on peatlands. Peat fires are likely to increase under a warmer, drier climate due to a combination of increases in the frequency of lightning strikes and drier soil profiles. However fire has been a major influence on most Australian peatlands throughout the Holocene, as shown by virtually continuous charcoal particles in most core sections. Such fires mostly represent burning of the surface vegetation from which the peatland recovers eventually. These fires probably hinder the development of bogs and favour sedgelands. Long term accumulation rates (as little as 50 - 100 cm in 10.000 years) are also slowed by repeated burning. With European settlement, policies of fire suppression may have led to less frequent but potentially more damaging fires during drought periods. In 2003 about 85% of all mires were burnt in a wide area of Victoria, New South Wales and the Australian Capital Territory, killing *Sphagnum* bogs and shifting the balance towards sedge and tussock grasslands. Only minor peat destruction resulted however, mainly along lines of drainage such as stream margins and artificial drains. Rehabilitation trials are currently being undertaken on several *Sphagnum* peatlands in the Victorian Alps (PAPST pers. comm.), Kosciuszko National Park and the Australian Capital Territory (HOPE & WHINAM unpubl. data).

In recent years, extensive peat fires have occurred in acid sulphate soils in north-eastern New South Wales (2002-2003) and in a paper-bark swamp forest on King Island, Tasmania (2000). Both of these fires burnt underground for more than 3 months, removing an estimated 1.5 million m^3 of fibric peat from the King Island fire alone. There are approximately 3 billion m^3 of moorland peat in Tasmania, of which it is estimated that 10% has been removed by fire and subsequent erosion (HANNAN et al. 1993). The indirect impact of fire on peat profiles is relatively unknown. Frequently burnt peat has lower levels of organic carbon than unburnt peat, even when the soil itself is not burnt (GARNETT et al. 2000). Australian land management agencies undertake fuel reduction and/or ecological fire management practices on sedge dominated peatlands. Whether these burns will advance or mitigate the demise of Australian peatlands under a warmer climate is not known.

In New Guinea extensive fires were associated with the 1997-8 El Niño event. These burnt into peatlands such as Kosipe and Lake Kopiago, and destroyed thousands of hectares of subalpine forest and blanket bog. Even more extensive fires occurred in the Kalimantan and Sumatran peatlands where 10.000 km^2 were burnt.

Agriculture

G. HOPE

The greatest loss of peat over the past 200 years in Australia, New Zealand and Fiji has been due to direct attempts to drain swamps for agriculture and settlement. Swamps potentially provided rich land with good water supply and nutrients, mainly for pasture. Particularly notable were the peatlands of coastal western Victoria and south-eastern South Australia where interdune swale peats and riverine peats covered about

2 million hectares to a depth of several metres (WILLIAMS 1974). These have been almost entirely trenched and the peat has collapsed and been destroyed by oxidation and fire (TAFFS 2001). Schemes for soldier settlement opened up many coastal peatlands as authorities organised large scale drainage, as at King Island. Many swamps have been drained and filled for urban expansion as well. An example is a settlement south of Suva, Fiji, where housing has been constructed on a thin clay layer placed over a 6 m *Phragmites* peatland. This development took place because the swamp was of "no use" and hence not subject to traditional land tenure controls.

Generally speaking there has been little or no control over wetland destruction on privately owned land in the region. Swamps are still widely perceived as "waste land", and peat swamps as dangerous to stock. Mulloon Swamp, New South Wales, has 3-4 m of fibrous sedge peat and is a privately owned grazing area. To make the bog into firmer pasture, this mire was ditched by the landowner in 1988. It has subsequently eroded by wall collapse for a distance of about 120 m, sending blocks of fibrous peat down channel. Although the bog has been invaded by grasses and introduced weeds, and the peat has become compressed, the remaining peat is still fibrous (HOPE unpublished data). Belated attempts to control this erosion by blocking the drains are currently in progress, paid for by public Landcare funds. This case underlines the problem that there is very little familiarity with peatland processes and management options in Australia, due to the rarity of peatlands.

The montane mires have mainly suffered through their use as summer or drought grazing, many being ditched and burnt to encourage pasture grasses and reduce their bogginess. The alpine bogs were similarly grazed but cattle were generally excluded from areas above 1350m around 1960 to protect catchment values. Bogs have made a slow recovery except in parts of alpine Victoria where grazing is still permitted in National Parks, against strong ecological advice.

The losses of peat in the tropics due to fires associated with illegal logging and clearance for oil palm and sugar plantations have been large. In Fiji the sugar industry has reclaimed many swamps while in Indonesia several million ha of peat swamp have been converted from swamp forest to grassland, cropland and oil palm, particularly in Kalimantan and Sumatra. However sago swamp is still very important, particularly in New Guinea, as a source of starch from the palm *Metroxylon sagu*. This palm will not grow on deep peat however and is mainly found on inundated alluvial plains in shallow muck peat. Locally, efforts are made to maintain water tables in these areas to encourage the swamp regeneration.

Sphagnum moss harvesting

J. WHINAM

Sphagnum moss is harvested primarily for use in the horticultural industry (see WHINAM & BUXTON 1997). Its waterholding capacity makes it a useful potting medium, favoured by orchid growers and often used to wrap rose and fruit tree rootstock for transportation. Harvesting is commonly done by hand, with the covering vegetation, usually rushes, cleared with a scrub cutter and rake. At some sites drains have been constructed around the edge of the peatland to allow easier extraction, but this practice appears to have longterm detrimental effects on recovery (VASANDER 1987).

Over the last three decades the *Sphagnum* moss harvesting industry has expanded dramatically, with exports levelling off in the early 1990s at about 1.000 tonnes of dry moss in New Zealand and roughly 15 tonnes in Tasmania. A small amount of *Sphagnum* moss is harvested in Victoria. In Australia, virtually all alpine and subalpine habitat is reserved in National Parks. Consequently there has been considerable pressure on unreserved peatlands. In New Zealand it is estimated that 20-30% of *Sphagnum* moss-producing land is in private ownership, the remainder being administered by government agencies. Large parts of subalpine New Guinea are still remote and not accessible to harvesters, with a small amount of moss collected for traditional use.

The sustainability of *Sphagnum* moss harvesting is influenced by growth rates, which in turn are influenced by altitude, shade, watertable level and amount of reseeding. Growth rates decline with both increasing altitude and latitude. Occasional summer moisture deficits limit growth. *Sphagnum* growth in montane situations in New Zealand and Australia is slow, ranging from 0.9 to 7.3 cm/year (WHINAM & BUXTON 1997).

Sphagnum regeneration on the bare peat surface left after complete moss harvesting in Australia and New Zealand is slow, or sometimes absent, leading to dominance by other species, notably Restionaceous and Cyperaceous graminoids. Prescriptions for sustainable *Sphagnum* moss harvesting have been developed (WHINAM & BUXTON 1997).

Peat mining: the collapse of Wingecarribee Swamp

P. ADAM

Australia's peatland resources are limited and the scale of peat mining is small when compared to northern hemisphere operations. Australia is a net peat importer, with historically most supplies coming from Canada, New Zealand, Germany and Ireland although in recent years increasing amounts from the Baltic States and the Ukraine have been available in garden centres. Mushroom farming is the largest single user of peat, with horticulture and landscaping also being major users. A particularly absurd case has been the attempt to develop an export market for sedge peat from Western Australia for golf courses in Japan. Smaller amounts are used as absorbants in industry and pollution control and for specialist uses such as whisky distilling in Tasmania.

Peat extraction currently occurs in a number of states (MORRISH & HOFSTEDE 2000, WHINAM et al. 2003), with in most cases an absence of requirements to regenerate or rehabilitate sites post mining. There is a significant New Zealand industry for moss peats, but virtually no utilisation by Pacific countries.

Wingecarribee Swamp, in the Southern Highlands of New South Wales was the largest upland restionaceous peat deposit in mainland Australia, originally covering 650 ha in with 4-9 m of fibrous peat. In 1974 the western half of the swamp was submerged under a reservoir, and small scale peat extraction commenced in the remaining eastern swamp. Mining was subsequently expanded with a unique wet extraction process, in which a lake was excavated in the swamp and peat pumped as a slurry to an onshore processing plant. By the mid 1990s production was about 30.000 m^3 yr^{-1}, the mining pond was 20 ha in extent and several metres deep with a steep exposed peat face at the upslope end. The risk to the peatland was pointed out at a licence renewal enquiry but the decision to keep mining was made in 1997 (BOULTON & BROCK 1999).

During the night of 8-9 August 1998 the swamp upstream of the mine pond collapsed. An estimated 6.000 megalitres of peat and sediment, and 6.500 megalitres of runoff water, was swept into Wingecarribee Reservoir (ARACHCHI & LAMBKIN 1999). After the collapse about 70% of the remaining swamp dewatered and sank by 3 to 4 m, becoming fragmented by a network of deep fissures extending down to the basal clays (WHITE 2000, see Fig. 26). These stranded blocks continued to dry, oxidise and shrinkage is still occurring. The dry peat is vulnerable to fire and the whole swamp has suffered weed invasion by willows and blackberries. The ecosystem services of the peatland, which filtered and purified an important water source, have been completely lost as a stream now runs straight down valley to the reservoir. The collapse of the swamp highlights the need for conservation and management of what are, in the Australian context, rare and sensitive ecosystems.

Peatland education

G. HOPE

Peatlands have not been a focus of education and interpretation programs in Australasia. This may reflect the relatively small proportion of the landscape that they occupy in the arid continent of Australia and also their lack of competitive appeal to the general public when compared with the charismatic ecosystems of the tropical rainforests of Indonesia, the tall eucalypt forests of Tasmania or the alpine meadows of New Zealand. However, when educational material is prepared, it can be informative and at-

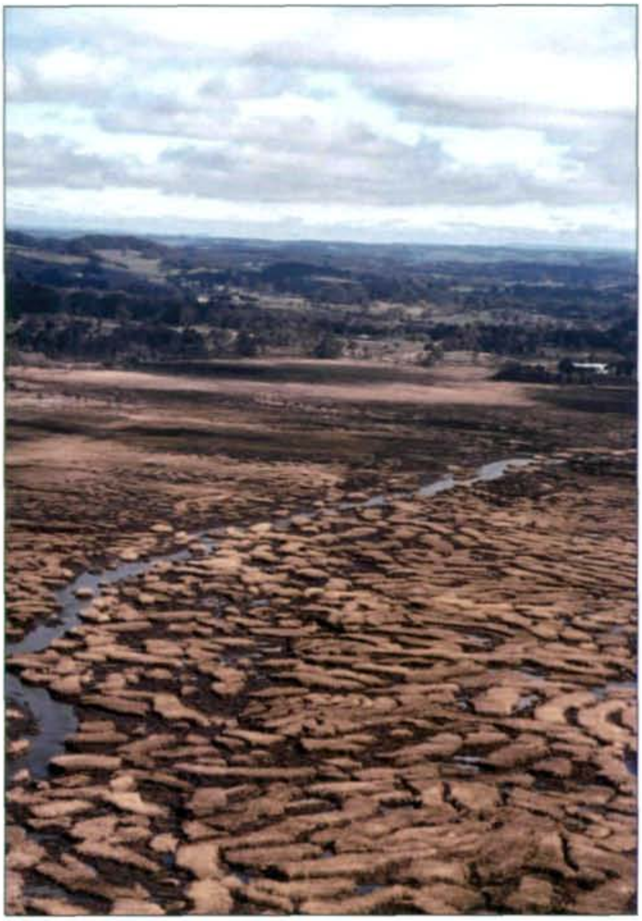

Fig. 26: Peat collapse and channels that have formed at Wingecarribee Swamp associated with peat mining activities. (Photo: Paul ADAM)

tractive (Fig. 27). School field sites and boardwalks in peatlands are being planned in South Australia and some other states of Australia. It should be possible to link peatlands to other wetlands as these are acknowledged as important through the RAMSAR convention (ANCA 1996). Several wetland study centres, for example the Shortland wetland centre in Newcastle and the mangrove boardwalk in Cairns, are supported by education departments or tourism authorities. There is a wetland education group within the Australian Association for Environmental Education.

Conclusion

If we are to ensure the long-term conservation of peatland ecosystems in the Australasian region, then it is imperative that politicians and land managers at all levels of government be informed and convinced of the ecological importance of these ecosystems and the increasing threats they face. Currently, there is little funding for research into the various types of peatlands throughout the region or to address mitigation measures for some of the identifiable threats. The situation is even more stark outside of Australia and New Zealand where development is likely to overide conservation considerations. However the importance of wetlands as biodiversity and carbon reservoirs is becoming better understood and local communities are coming to value their peatlands. Although not extensive, peatlands act as refugia and stepping stones and their isolation provides a range of novel habitats and ecological diversity. They are thus vital to the ecological health of the regions.

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Zusammenfassung

Moore von Australasien – Die australasische Region erstreckt sich von den ozeanisch geprägten sub-antarktischen Inseln bis hin zu temperaten und tropischen Tiefländern und Gebirgen. Entsprechend groß ist auch die Vielfalt der Moore dieser Region. Das umfasst bedeutende Deckenmoorgebiete auf den subantarktischen Inseln, im südwestlichen Neuseeland und in den Hochlagen Neuguineas ebenso, wie die Heiden des maritimen Tasmanien mit nur geringen Totfmächtigkeiten. Weiter verbreitet als die vorher genannten Moortypen sind topogene Niedermoore und Küstenmoore, die von Sträuchern dominiert werden und in den tropischen Regionen Nordaustraliens und im gesamten pazifischen Bereich tropische Wälder tragen. Beispiele für ausgedehnte Gebirgs- und Beckenmoore findet man in Neuseeland und Neu Guinea, wo auch kleine montane bis subalpine Niedermoore auftreten.

Obwohl einige der Moortypen mit de-

nen der Nordhemisphäre durchaus vergleichbar sind, z.B. torfmoosdominierte Hochmoore, seggendominierte Niedermoore und von Schilf und Rohrkolben dominierte Moore im Überflutungsbereich der Flüsse, gibt es doch eine Reihe von Moortypen, die auf die australasische Region beschränkt zu sein scheinen. Beispiele sind die von *Gymnoschoenus sphaerocephalus* gebildeten „Knopfgrasmoore" Tasmaniens, die Restionaceen-Seggenmoore Neuseelands, die *Melaleuca*-Waldmoore in Nordaustralien und die „Hartkissenmoore" auf Neu Guinea. Manche Moortypen, wie z.B. die inneraustralischen, aufgewölbten Quellmoore und die *Melaleuca*-Waldmoore auf King Island (Tasmanien) sind auch an außergewöhnliche hydrologische Bedingungen gebunden. Wie bei allen Mooren gibt es eine enge Beziehung zwischen vorhandenen Arten, dem Auftreten von Torf, den hydrologischen Verhältnissen und den Auswirkungen der Evapotranspiration auf die Humifizierungsprozesse. Generell ist festzustellen, dass die australasischen Moore eher von monocotylen Arten dominiert werden und weniger von den in der Nordhemisphäre viel wichtigeren Torf- und Braunmoosen.

Die Torfprofile der australasischen Moore erstrecken zumeist über das Holozän, oft nur über jüngere Phasen, es gibt aber auch Beispiele, die einen gesamten Eiszeitzyklus umfassen. Das alter der Moore kann sehr verschieden sein und ist abhängig von den Feuchteverhältnissen und dem Einfluss von Feuer in der Vergangenheit. Das Torfwachstum kann sehr schnell erfolgen, es gibt Beispiele wo sechs Meter Torf in lediglich 3.000 Jahren gebildet wurden, aber viele Torfprofile sind nicht länger als 1-2 m und zeigen deutliche Spuren von Oxidation. Die weit in die Vergangenheit reichenden Profile stammen aus Seggenmooren (Cyperaceen und Restionaceen) und den tropischen Waldmooren. Auch Abfolgen von Mudde und Torf sind weit verbreitet, z.B. in Westaustralien, wo man insbesondere kieselalgenreiche Sedimente finden kann.

Die gegenwärtigen Umweltbedingungen für die Moore reichen von natürlich und ungestört bei den subantarktischen Mooren und den *Sphagnum*-Mooren der subalpinen und alpinen Lagen Tasmaniens und Neuseelands bis hin zu stark gestört in Bereichen, wo die historische oder gegenwärtige Landnutzung ihren Einfluss auf die Moore ausgeübt hat. Beispiele dafür sind die als Viehweiden genutzten montanen Niedermoore Ostaustraliens oder die durch die Landteilung und Entwässerung beeinträchtigten temperaten und tropischen Küstenmoore, die, einstmals großflächig ausgebildet, heute auf kleine Restbereiche reduziert wurden. Auch durch Feuermanagement, Landwirtschaft und Torfabbau werden die australasischen Moore stark beeinträchtigt, wahrscheinlich mit Auswirkungen auf den Klimawandel aber unbemerkt, wegen ihrer geringen Bedeutung. Das Wissen um die Funktionen und den Wert der Moore für den Menschen ist in der gesamten Region nur sehr gering, obwohl sie im Bereich des Naturschutzes eine durchaus wichtige Rolle spielen. Jedenfalls muss diese Situation deutlich verbessert werde, um einen langfristigen Fortbestand der Moore zu gewährleisten.

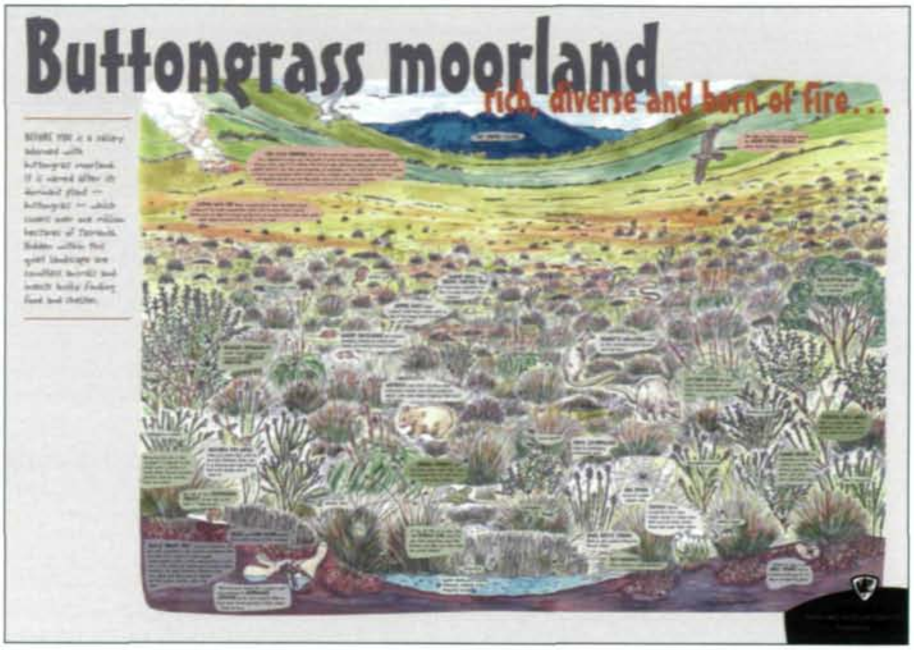

Fig. 27: Educational poster highlighting the different values of Tasmanian buttongrass moorlands (Courtesy of Parks & Wildlife Service, Tasmania ©). (Artwork: Samantha HIGNETT)

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Address of the authors:

Paul ADAM
School of Biological, Earth
& Environmental Sciences
University of NSW
E-Mail: p.adam@unsw.edu.au

J. BALMER
Nature Conservation Branch, Department
of Primary Industries,
Water and Environment
E-Mail: Jayne.Balmer@dpiwe.tas.gov.au

Kerry BRIDLE
School of Geography and
Environmental Sciences
University of Tasmania
E-Mail: Kerry.Bridle@utas.edu.au

Bill BOYD
Environmental Science and Management
Southern Cross University
E-Mail: bboyd@pophost.scu.edu.au

Rowan BUXTON
Manaaki Whenua – Landcare Research
PO Box 69 Lincoln, New Zealand
E-Mail: BuxtonR@landcareresearch.co.nz

Bev CLARKSON
Manaaki Whenua – Landcare Research,
Private Bag 3127, Hamilton, New Zealand
E-Mail: Bev@landcareresearch.co.nz

M. DRIESSEN
Nature Conservation Branch,
Department of Primary Industries,
Water and Environment
E-Mail: Michael.Driessen@dpiwe.tas.gov.au

J.F. GRINDROD
School of Geography and
Environmental Science
Monash University, Clayton
E-Mail: John.Grindrod@arts.monash.edu.au

Geoff HOPE
Australian National University
Canberra ACT, Australia
E-Mail: Geoffrey.Hope@anu.edu.au

Pierre HORWITZ
Edith Cowan University
100 Jondalup Drive
Joondalup, Western Australia, Australia
E-Mail: p.horwitz@ecu.edu.au

Peter KERSHAW
Monash University
Clayton Vic, Australia
E-Mail: peter.kershaw@arts.monash.edu.au

John LULY
School of Tropical Environment
Studies and Geography
James Cook University, Townsville
E-Mail: jonathan.luly@jcu.edu.au

M.S. MCGLONE
Landcare Research,
PO Box 69, Lincoln, 8152, New Zealand
E-Mail: mcglonem@landcareresearch.co.nz

Joost NIEVEEN
Manaaki Whenua – Landcare Research,
Private Bag 3127, Hamilton, New Zealand
E-Mail: nieveenj@landcareresearch.co.nz

M. PEMBERTON
Nature Conservation Branch,
Department of Primary Industries,
Water and Environment
E-Mail: Mike.Pemberton@dpiwe.tas.gov.au

A. RICHARDSON
School of Zoology, University of Tasmania
E-Mail: Alastair.Richardson@utas.edu.au

Louis SCHIPPER
Manaaki Whenua – Landcare Research,
Private Bag 3127, Hamilton, New Zealand

J.M. SELKIRK-BELL
Graduate School of the Environment,
Macquarie University,
NSW 2109, Australia
E-Mail: jbell@mrt.tas.gov.au

Jennie WHINAM
Nature Conservation Branch,
Department of Primary Industries,
Water and Environment,
Hobart Tasmania, Australia
E-Mail: Jennie.Whinam@dpiwe.tas.gov.au

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