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The Mountain Mires Of Southern New South Wales And The Australian Capital Territory: Their History And Future

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Abstract

The southern tablelands and alps of New South Wales support the most varied and extensive peatlands and mires of mainland Australia even though conditions today are marginal for mire growth. Mires huddle in valley bottoms particularly where there is run on and deep soil mantles to bring them water. Peat has accumulated with average depths of 1-3m although greater depths of up to 8m of sedge peat occur in a few cases. The mires are sensitive to trampling and drainage but are important for moderating runoff and maintaining summer flows in streams.

The peat-bearing mires are unusual in generally eroding mountain landscapes because they preserve their own history in the organic matter that accumulates in them. Many bogs formed as a result of post-glacial climate change about 12-8000 years ago when increasing rainfall offset the drying caused by rising temperatures. Drier conditions in the last 5000 years has seen some bogs cease to grow while for others there have been a major growth phase over the last 2-3000 years. Charcoal in the peat shows that the catchments have always experienced fire but an analysis of the last 9000 years in most sites shows that the largest change occurs with the arrival of European settlers, their grazing animals and weeds.

Bibliographic Note

Geoffrey Hope is Professor of Natural History in the Department of Archaeology and Natural History, Research School of Pacific and Asian Studies, Canberra. He studies peatlands in Australia, Southeast Asia and the Pacific as sources of records of environmental change and the history of human impact. In addition to his work in southeastern Australian mountains he has worked extensively in the above treeline communities of Papua and Papua New Guinea and visited mountain mires in several parts of the world.

Peatlands in Southeastern Australia

Australia is a temperate to tropical continent of high evaporation, unreliable rainfall and relatively subdued relief. Except in the coolest and wettest areas organic matter produced by vegetation will decay. The accumulation of peat or humus requires permanent inflows of water to maintain waterlogged conditions. Accordingly, almost all peat forming mires in Australia occupy low places in the landscape, and are termed *topogenous* mires (caused by topography). Other than estuarine infills, it is in wet, cool montane areas that low gradient valleys develop mires and peats may form. Near the alpine treeline these valley sites may extend onto gentle slopes to form *ombrogenous* (formed by cloud) blanket bog. There are almost no large raised bogs in Australia, in contrast to the cold wet areas of northern Europe, North

America, southern Chile and southern New Zealand where sedge or moss bogs may be many thousands of hectares in extent, and often over 8m in depth.. The average topogenous montane mire in southern New South Wales preserves 1-3 m of peat, emphasising the very marginal conditions for peat growth in Australia.

New South Wales is thus poor in peatlands, and the variety of types is not as great as in other countries. Nevertheless there is a rich mire flora and a wide range of vegetation communities, many growing in isolation from the nearest similar vegetation. The peatlands of Australia have been only briefly described (eg Campbell 1983, Kershaw et al 1993, Whinam et al 1989, in press) and merit further study. Although the total area covered by peatland is only small (<2% in the subalpine), the ecosystem is distinguished by preserving a record of the development of the site and surrounding vegetation in the organic remains. Peatlands are thus archives whose records are only beginning to be read.

Raw peat consists of up to 90% water, and peatlands are very efficient at trapping rainwater or surface flow. Dr A. Costin (pers. comm.) regards peat deposits as important in New South Wales and Australian Capital Territory catchments because they moderate runoff and, being thermally insulating, retain warmer groundwater than would otherwise be the case. For example Snowy Flat Bog is yielding 2.1 megalitres per day after 6 months of drought (A. Wade pers comm.). Water moves through peatlands as groundwater, in narrow deep channels or across the surface in wide shallow channels floored by depressions (Siegel 1992). The surface vegetation filters out mineral sediment and releases clear water, although it also uses up water in transpiration. The fibrous surface vegetation and top sediment layer are tough and resistant to erosion, which is often not very active on the flats and gentle slopes (Wimbush and Costin 1983).

Many terms exist to describe peaty wetlands, for example, bog, fen, mire, moor, marsh, swamp, morass. Of these, only bog, fen and moor have specialist definitions (Birks and Birks 1980, Bridle 1993):

Bog: characterised by complex vegetation with little free water surface: stagnant water; usually acidic and of low nutrition

Fen: simple vegetation with some open water: groundwater is moving and mineral matter often present, giving better nutrition.

Moor: simple sedge or open sedge-shrubland on slopes with shallow muck or fibrous peats: forming an organic soil.

In the absence of data on nutritional status, the terms are best used in relation to the structure of the major vegetation community on the site. Bogs may have cushion plants, including mosses, and often low shrubs or even trees. Fens have graminoid (grass-like) plants, especially sedges (Cyperaceae) or rushes (Juncaceae, Typhaceae, Restionaceae). However, grass or sedge bogs are known, for example *Gymnoschoenus* (button grass) bog, in which densely packed graminoid hummocks provide a complex structure.

Definitions of organic deposits are complex and highly variable internationally (Bridle 1992), because they can be viewed as sediments, soils and biological systems. Classifications of peatlands may include the physical peat typology, floristics, topographic setting, water inputs and chemistry (Moore 1984). Peat is one of several types of organic sediment which form from the dead remains of plants, both large and microscopic, almost always accumulating in permanently waterlogged conditions in which breakdown is hindered The presence of a high proportion of organic material creates reducing conditions which prevent microbial action, and the porous, relatively light matrix retains water readily. This moisture allows continued accumulation of organic matter. Peat is not just dead sediment but is also a component of a living ecosystem, the net production of which forms the substrate on which the living part depends. The surfaces of organic deposits provide specialised habitats for plants and animals tolerant of aquatic, or wet, reducing conditions. An organic deposit preserves some of the remains of plants and animals that have lived there through the period (or periods) over which the deposit forms. In this paper the term "peat" will be used for all organic sediments containing >40% dry weight of organic material. Moore and Bellamy (1974), define peat types more precisely. A peatland is an area in which at least 40 cm of peat has accumulated.

The vegetation forming the organic material varies according to availability and nutritional status of the water (Table 1). At one extreme, bogs dominated by slow growing mosses occur in very wet, cool climates in sites where groundwater is minimal, so that growth depends on nutrients brought in with rain water. Peat formed in these bogs is termed "terrestric". If increased nutrition, for example from groundwater, is available, shrubs and sedges will invade and co-exist with the moss, or exclude it. If the watertable occurs at the surface for a substantial time, many shrubs will not survive, and shallow rooted sedges, grasses, twig rushes etc. will form an open cover. Peat forming at the watertable is termed "telmatic". Finally, in deeper water, aquatic species such as cumbungi (bulrushes), reeds, sedges, water lilies, strap rushes and pond weeds will dominate, and the organic material will contain plant debris and organic muds (limnic or lake sediment).

Table 1: Characteristics of organic deposits in southern Australia.

Surface vegetation	**Moss cushions**	**Heath**	**Sedge fen**	**Open water**
Surface sediment	Fibrous moss	Wood peat	Fibrous sedge peat	Organic mud
Deep sediment	Humic peat	Humic peat	Humic peat (amorphic)	Organic mud (gyttya)
Water Table	Raised	Near surface	At surface	Above surface
Surface peat type	Terrestric	Terrestric	Telmatic	Limnic
Site type	Ombrogenous	Topogenous	Topogenous	Topogenous
Example	Blanket Bog	Valley Bog	Lake Edge	Tarn
Mineral Nutrition	Poor (Oligotrophic)	Medium (Mesotrophic)	Medium-good (Eutrophic)	Various
Source of minerals	Rainwater	Groundwater	Ground water and streams	Streams into lake

Growth of peat deposits

A mire will build up organic horizons if plant material build up exceeds losses due to decay and removal. Most Australian peat deposits represent a very slight positive balance, giving rise to long-term accumulation rates in the order of 0.01-1.0 mm per year (commonly expressed as 0.1- 10 cm/century). Production is increased by high temperatures, abundant water, light and nutrients and an absence of herbivores. However, the decay rate rises even more quickly with temperature and a good supply of mineral nutrients. This explains why peat deposits are rare in the subtropics. In cool, humid climates the rate of production is reduced, but a relative absence of decay by soil bacteria and fungi allows accumulation. Such peat bogs may be very slow to regenerate, once stripped of vegetation. Parts of a bog may collect litter at a fast rate, but this does not represent rapid growth of the peat because organic matter at the surface is uncompacted and less decayed than that at greater depth.

Clark (1983) has reviewed growth rates for *Sphagnum* bogs and made observations on Ginini Bog (ACT) over several seasons. She found that while the moss surface might increase by 30 cm in a good growing season, all this height can be lost in a single winter due to compression by snow or animal trampling, and that the current net growth in the bog is almost nil or perhaps negative. The long-term growth rates for moss bogs in good conditions rarely exceed 5 cm century; for Ginini Bog the long-term growth rate is 3.5 cm century. Sedge fens in extremely good conditions may reach 10cm/century. For example the upper 25 cm of peat at Nursery Swamp, (ACT) has accumulated in less than 250 years. Again decay and compression result in a long-term accumulation rate of less than 4.0 cm/century of fibrous sedge peat.

Major hindrances to growth are caused by erosion, gullying or fire. Increases in the rate of loss or of decay may prevent further growth by drying out the entire surface, which may then become hydrophobic. Some peat bog taxa are intolerant of too much or too little nutrition, so that pollution or changes in water supply may affect accumulation rates. Growth may not be continuous because the establishment of a species may lead to change in hydrology, for example moss hummocks may block the drainage.

Continued accumulation at any spot leads to a hummocky microtopography. The vegetation tends to be a mosaic which is not static but changes with the microhabitats of the site. The most detailed study of this process in Australia has been carried out in a subalpine bog in Victoria by Ashton and Hargreaves (1983). They found that moss hummocks several times replaced shrublands over 4,000 years. Fire was important in causing changes to surface topography. Also zinc was shown to be a limiting micronutrient and fires resulted in net losses of stored nutrients which probably impeded shrub re-invasion. Drainage-impeding growth gradually raises the local watertable and maintains wet conditions and further growth. In this sense peatlands represent a renewable resource, but the growth is too slow to allow Australian peat to be "harvested" on any commercial timescale.

Stability

Peat bogs in Australia are delicately balanced, and relatively minor changes may have large responses. Change can take place in the following ways (Table 2).

Table 2: Peatland Instability

Change	Possible Cause	Effect
Increased production	Cool moist conditions	Growth on drainage lines, local flooding and fen development
Decreased production	Hot dry conditions, increasing drainage	Growth ceases, dry-land plants invade
Increased nutrition	Catchment erosion spreading on to the peatland; animal manuring	Death of oligotrophic taxa, eg. *Sphagnum*, weed growth
Increased drainage	Gullying or drains; growth of trees	Growth ceases, top layers dry out, become water repellent, liable to fire
Clearance in catchment	Agriculture or forestry	Higher peak discharges, incision by streams increases drainage. Mineral matter covers swamp.
Stream incision	Clearance, compaction	Bank collapse by groundwater under-mining. Peat bursts
Surface compaction	Grazing or traffic	Infiltration reduced, increased surface runoff and erosion, elimination of taxa
Loss of surface peats	(1) Fire following lowered watertable	Peat fires slow but hot, totally kill all surface plants, erosion follows
	(2) Oxidation	Peat decays to ash, and becomes compact by loss of moisture. Erosion follows
Collapse and slumping	Heavy runon, reduced strength due to ditching and mining	Bogs may catastrophically slump, the fibrous layers shearing above weaker layers.
Flooding, water diversion	Water supply dams, catchment clearance	Death of plant cover, erosion

Fires can totally remove peat deposits and are very difficult to stop once established. Several peatlands in Australia have been destroyed by fire, for example blanket bog in the Central Plateau of Tasmania smouldered for five months in 1961 and over 20,000 ha were reduced to mineral soil. This quickly eroded into creeks and rivers, and plant regrowth in the area has been extremely slow (Jackson 1973). At Wyrie Swamp, a peat mine in South Austra1ia, attempts by bulldozing and pumping water failed to control a fire. It was only extinguished by totally flooding the site by blocking the outfall drains (Dodson 1977). The extent of peatlands destroyed by fire following drainage in Australia is unknown, but is probably very great.

The reason for the persistance of under surface fires in peat derives from the changes in properties in peats once they dry out. The infiltration capacity may become low, and the large void space allows combustion to proceed slowly. Hosing down the area will not extinguish the fire because peat is an excellent insulator and this protects the fire from chilling as well as smothering. Water reaching these fires will react with the burning peat to produce carbon monoxide and hydrogen which can eventually burn. From time to time the surface peat will collapse into the firehole and a normal fire can result, with a risk of spreading fire into adjacent vegetation. Raised bogs are at greater risk from fire than valley bogs.

Increased drainage also allows peat to oxidise and become compressed or decay to organic loams However fibrous peat is quite resistant to streamflow erosion. Ditches cut in Mulloon Swamp still retain the scoop marks after 12 years, although the ditches have precipitated headward erosion at the the downstream end. Catastrophic peat losses are known to occur when undercutting of the trenches by upwelling water is followed by slumping. Once disturbed, breakdown and erosion may be rapid and complete. Topogenous mires such as valley bogs with substantial catchments are particularly at risk. Remnant stacks of peat occur for 3 km down stream of Jackson's Bog, N.S.W., and indicate that up to 20 ha of peat have been eroded completely by a stream now flowing on bedrock (Kershaw et al. 1993). The cause of incision by the stream is unknown, but stock damage to watercourses and possibly fire may have been important. The largest montane mire in southeastern Australia, Wingeecarribee Swamp, lost about 1,600,000 cu m of peat on 9 August 1998 after very heavy rains (Whinam et al in press).Rain swelled the peat, possibly allowing hydrostatic pressure in the underlying gravels to lift the upper layers of the mire, which then slumped into the cut mine ponds starting a catastrophic failure that reached to the head of the bog. A stream now flows through the former peatland. Dewatering of the peat reduced it from 6m to ca 2m blocks.

Peatland in the Australian mountains

A national survey of wetlands has been completed (Australian Nature Conservation Agency 1996). The ANCA report lists two Interim Biogeographic Regions for the montane area, Australian Alps and South Eastern Highlands of NSW. These are equivalent to montane (>500m) and subalpine (>1400m) zones. The ANCA report extracted data from an earlier survey of montane peatlands (Hope and Southern 1983), and further research on mires has taken place since then, with about 165 sites being investigated, the majority of which do not retain peat forming mires at present.

Table 3. Peatlands noted in surveys and nominations

Area (Bioregion)	This Report	ANCA 1996	RAMSAR
ACT Alps (AA)	4	2	1
ACT highlands (SEH)	2	1	0
NSW Alps (AA)	5	3	0
NSW Southern Highlands (SEH)	15	8	?1

Peatlands in montane southern New South Wales show a striking distribution pattem. Most obvious is the lack of peatbearing deposits in the central plains between the ranges presumably because this area is within a general rainshadow. Most sites occur on the western, eastern and southern ranges of the region, notably at altitudes of about 1000 m above sea level.

There are 12 large peatlands (with greater than 1,000,000 cubic metres of peat) and a further 45 minor peatlands. (Figure 1).

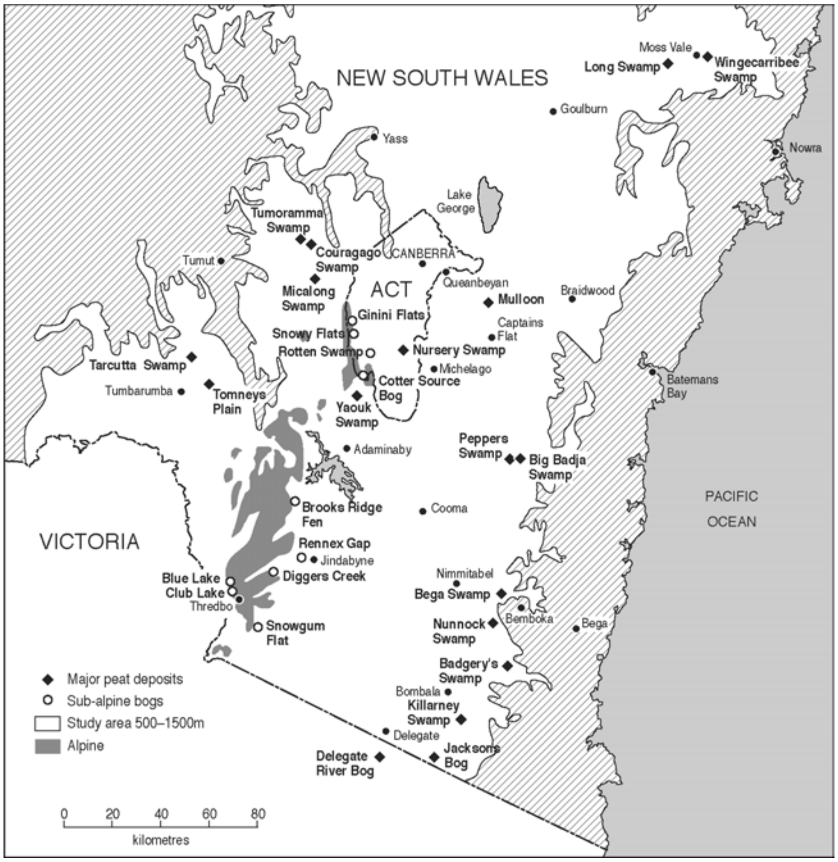

Figure 1 Location of major peatlands in southern montane New South Wales. Where available an ANCA reference number is provided (ANCA 1996).

One or two clusters of sites do emerge, specifically in the southeast (Jackson's Bog, Craigie Bog, Killarney, Badgery's and Bega Swamps) and the western ranges (Tomney's Plain, Spencers Bog, Tarcutta, Micalong, Couragago, Tumorrama and Yaouk Swamps). According to Costin's (1954) map of soils for the Monaro Tablelands there is also a dense cluster of small peat deposits around the Badja Swamps, including Pepper's Swamp to the west.

Fens (those where the watertable is at the surface for much of the year) in southern montane New South Wales are largely dominated by sedges (Cyperaceae), especially *Carex gaudichaudiana.* Costin (1954) distinguishes rich and poor fen peat with *Carex* dominating the formation of both. The difference between these peats lies within the acidity of the sediments: rich fen peat being slightly acid to alkaline and poor fen peat being moderately to strongly acid. Costin also notes an altitudinal separation of these peats with the latter mainly in the alpine and subalpine areas. Average pH values for fen peat are 5.6 - 5.8. Good examples of deep fen peat were found at Wingecarribee, Killarney and Nursery Swamps, Jacksons Bog, Micalong, Tarcutta and Yaouk Swamps. Restionaceae (*Anarthria, Baliskion, Empodisma*) may contribute to some swamps.

The best development of such sites is seen in areas with granite as basement parent material, as these produce coarse sands that underly the peat and act as aquifers. The major exception to this rule is Wingecarribee Swamp which has developed to a remarkable degree upon a sandstone and shale base. A gently sloping landscape helps to explain its presence but the singularity of this site in terms of size, volume and distance from other major peatlands suggests a geological explanation connected with aquifer discharge into gravels from beneath the basalt flows on the eastern margin. Long Swamp, west of Moss Vale, is also unusual, being a *Carex gaudichaudiana* fen peatland infilling a sandstone cliffed valley.

The development of shrub-*Sphagnum* bogs is best in small catchments with only minor streams since it thrives in conditions of deprived nutrient intake while having sufficient moisture to maintain growth.

Below altitudes of about 1100 m the development of such peats is relatively uncommon (Whinam and Chilcott in press) although *Sphagnum* is found almost to sea level. Shading and local groundwater may limit the lower altitude bogs to the base of valley slopes where it is shaded. *Sphagnum* grows only where sheltered by valley sides and forest at Nursery Swamp and Tom Gregory Bog. Small *Sphagnum* bogs occur along subalpine creek lines with increasing frequency above 1100 m altitude. A rough estimate is that collectively these bogs may make up about 1% of the area above 1300 m. Shrub richness increases with altitude, lower altitude bogs having *Leptospermum* and *Epacris* species. Above 1400m *Richea continentis* is often dominant with *Baeckia gunniana*. Peat depth is not so great as for fens, being generally 1-2m and they are more acid, pH < 4.5. *Sphagnum* moss often develops into hummocks which can attain heights of up to a metre as at Snowy Flat. The moisture balance within the hummocks is maintained by the capillary action of *Sphagnum*. During summer the surface of the hummocks may show severe drying but the subsurface moss is moist and green. Destruction of the living *Sphagnum* quickly results in the decomposition of underlying peats since the mechanism which maintains the moisture level in the hummocks is lost. Once exposed to the dry aerobic conditions the peats rapidly decompose and lose their characteristic structure.

The alpine region above the treeline has extensions of shrub bogs and *Carex* fens which resemble those of the montane southern group, though usually these communities are shorter, and lacking several subalpine species such as *Hakea microcarpa*. *Carex gaudichaudiana* fens are widespread, but shrub bog tends to be riparian. Unlike the montane area, wet habitats extend out onto slopes and below long lasting snow patches, so that the alpine mires include the moist areas of sod tussock grassland and alpine herbfield. These are highly related to topography but the low evaporation and high precipitation give rise to areas of poorly developed blanket bog, dominated by *Empodisma minus*, tussock grasses and snow daisies.

Mire Histories

Peatland initiation

Current research based on carbon dating, fossil pollen and spores, and microscopic charcoal suggests that the majority of peatlands in the region post-date the last period of glaciation which occurred from 26-16,000 years ago (Barrows et al 2001) and owe their origin to the post-glacial amelioration of climatic conditions. At the end of the Pleistocene most montane streams lay above the treeline and their channels were choked infilled by sands and gravels. Increasing temperature and precipitation allowed grasslands to stabilise the catchments permitting the establishment of many swamp plants on the river flats. The plants blocked streams and the wet conditions created of anaerobic conditions and peat accumulation followed.

Some valley wetlands may formerly have held peat bogs which were lost through erosion, fire or drying. Wood in black clays below sands at Wingecarribee Swamp provides an age of 37,000 BP for a probable early swamp building phase. One remarkable Victorian site, Caledonia Fen has preserved a deep deposit with repeated phases of bog formation (M. MacKenzie personal communication).

There is no clear correlation between the onset of peat formation and mire altitude. Early sites at 14-15000 BP occur at all altitudes and must reflect topographically favourable locations (Table 4). By 10,000 BP peat formation was extremely widespread; thus we can conclude that slopes had become increasingly stabilised between 15,000 and 10,000 years ago. The pollen analyses at montane sites (eg Delegate River Crystal Bog Jacksons Bog Rennex Gap) show that forest vegetation developed in the region after 11,000 BP while in alpine sites (Blue Lake, Mt Twynham, Raine 1974), original fjeldmark was replaced by alpine herbfields or heaths by about 9000 BP.

There is thus good reason for presuming that climatic conditions and well developed vegetation generally resembled present day environments by 9000-10,000 BP. This broad conclusion needs a great deal of further research on a geographical range of sites to obtain detail on the processes of environmental change. The reasons for the variation in ages for the initiation of peat are not yet understood. Possibly the early sites are those in the most humid regions and increasing rainfall probably played a part.

Table 4. Dates for the Initiation of Peat Formation in Montane Sites

Site Name	Locality	Altitude	Date (years BP)	Lab Number	Peat (cm)	Material	Source
Bega Swamp	30 km E of Nimmitabel	1080	13,400±280	ANU-1216	268	Humic peat	Polach and Singh (1980)
Big Badja Swamp	35 km E of Cooma	1030	9760±170	GRN-3523	218	Humic peat	Martin, unpubl.
Black Swamp	Barrington Tops	1550	8,865±120	SUA-1414	180	Humic peat	Dodson, (1987)
Bogong Swamp	Mt. Kosciuszko	1590	2,750±970	SUA-1623	220	Core peat	Martin, unpubl.
Brooks Ridge Fen	Happy Jacks Plain	1450	3730±300	β-81387	47	Fibrous peat	Mooney et al 1997
Bunyip Bog	Mt Buffalo, Vic	1330	10,250±220	GX-3981	300	Sphagnum peat	Binder (1978)
Caledonia Fen	Mt Buller, Vic	1280	>80,000	OSL	1900	Organic clay	MacKenzie unpubl.
Club Lake	Mt Kosciuszko	1955	9,770±140	SUA-1259	265	Peaty silts	Martin 1986
Cotter Source A	Mt Scabby, ACT	1720	9040± 80	ANU 10194	115	Peaty sand	Hope unpubl.
Crystal Bog	Mt Buffalo, Vic	1350	14,190±170	GX-5234	285	Organic clay	Williams(1980)
Delegate River	12 km S Bendoc, Vic	1000	12,160±310	GaK-5846	298	Organic sands	Ladd (1979)
Diggers Creek	Mt Kosciuszko	1755	10,170±100	GaK-3929	132	Sandy peat	Martin (1999)
Echo Flat	13 km E Lake Mt Vic	1370	5,380±160	GaK	160	Sphagnum peat	Ashton andHargreaves (1993)
Ginini Bog	Mt Ginini, ACT	1590	3,280±70	GRN 249l	120	Sphagnum	Costin unpubl
Ginini Bog	35 km SW Canberra ACT	1590	3,280±70	GRN-249l	220	Sphagnum peat	Costin (1972)
Horse Swamp	Barrington Tops	1260	10,725±130	SUA-1415A	150	Organic clay	Dodson (1987)
Jacksons Bog	30 km SW Bombala	780	11,725±460	GX -7301	320	Organic sands	Southern (1982)
Micalong Swamp	35 km E Tumut	1100	12,330±250	ANU-3342	390	Sedge peat	Kemp (1993)
Mulloon Swamp	25km west of Braidwood	799	3440 ± 90	ANU 10753	345	Peaty clay	Hope, unpubl
Nursery Swamp	40 km SW Canberra, ACT	1100	8,200±250	ANU-3357A	298	*Carex* peat	Hope unpubl.
Rennex Gap	Mt Kosciuszko	1575	10,600±135	ANU-2177	150	Humic peat	Hope unpub.
Rotten Swamp	Northeast of Mt Kelly, ACT	1445	5,500±90	ANU 9484	60	Peaty sand	Clark 1986
Snowy Flat	Mt Gingera, ACT	1618	7,130 ± 70	ANU 11464	205	Muck peat	Macphail, unpubl
Tarcutta Swamp	South of Batlow	780	9420 ± 110	ANU 4384	525	Peaty clay	Williams, unpubl
Upper Snowy River	Mt Kosciuszko	1830	15,000±350	NZ- 399	ca50	Sedge peat	Costin (1972)
Wilsons Valley	Mt Kosciuszko	1460	1,600±80	GaK-3923	53	Sphagnum peat	Martin, unpubl.
Wingecarribee	20 km E Moss Vale	670	2,520±180	ANU-1452	605	Sedge peat	Singh, unpubl.
Wingecarribee B	20 km E Moss Vale	670	14,900±1200	ANU-1257	995	Humic peat	Singh, unpubl.
Yaouk Swamp	Scabby nature reserve	1100	9250 ± 40	ANU 11439H	195	Peaty clay	Keany, unpubl

Holocene histories

Some subalpine mires , for example Ginini Flats and Rotten Swamp, have not preserved their earlier Holocene fill. Both peatlands rest on gravelly slope deposits of probable late Pleistocene age. A lower altitude *Carex* fen, Nursery Swamp, preserves humic clays from the early Holocene, period, but the bulk of the sediment there is fibrous peats formed within the last 3000 years. Wingeecarribee has old organic clays, but the upper 6m of the peatland also seems to have formed within the last 3000 years (Kodela 1997). At about this time there is a probable development or expansion of *Sphagnum* moss bogs. Bunyip and Crystal Bogs have an expansion event dated at 2050 and 2650 years ago respectively (Binder 1978; Williams 1980). At Jackson's Bog the presence of *Sphagnum* is first detected 2800 years ago (Southern 1982). Costin (1972) gives a basal date of 3280 years BP for the *Sphagnum* peats at Ginini Bog. Similarly the Lake Mountain bog commenced growth about 3500 BP. There is a possibility that these changes represent inherent instability or fire events. The preliminary data hints that peat growth was a regional event and hence probably related directly or indirectly to climate (Macphail and Hope 1985).

Yaouk Swamp, and possibly Snowy Flat, have peaty sediments that are early Holocene. A suggestion is that since wet sclerophyll forest expanded in the mid-Holocene to altitudes beyond present limits, wetter conditions than present may have occurred from 9000 to about 4000 years BP. This may have been a time of consistent peat formation and the late Holocene growth phase did not occur at these sites. A few swamps, such as Bega Swamp, Rennex Gap Bog and possibly Cotter Source Bog provide full records of the Holocene.

European land management

The impact of European pastoralism can be discernedin virtually every record that has been examined, and that impact is the greatest alteration to the enviroment that can be seen in the Holocene. Several records have been completed at high resolution, including Bega Swamp (Hope unpublished), Cotter Source Bog (Hope unpublished), Brooks Ridge Fen (Mooney et al 1997) and Club Lake (Dodson et al 1994). Pine pollen forms a useful marker as it occurs in all sites within the last 100 years. Usually introduced daisies such as *Hypochoeris* increase before the appearance of pine, and in some sites (but not Brooks Ridge) charcoal reaches a peak soon after this. Sites in reserves, such as Rennex Gap and Cotter Source Bog, show a decline in charcoal to low levels after pine is well established, probably around 1935. This indicates that Europeans were responsible for a considerable shift in fire regimes throughout the mountains and elsewhere (Dodson and Mooney 2002). Figure 2 shows a pine and charcoal curve from Top Flat, just below Cotter Source Bog in the ACT, which has these features. There is a rise in charcoal near the top of the section which may be a result of the 1983 fire that burnt across the bog. Post fire stream incision started to dry out the shrub bog so planks were placed across the channels to block the drainage. This was partially successful and bog regeneration has occurred in some sections.

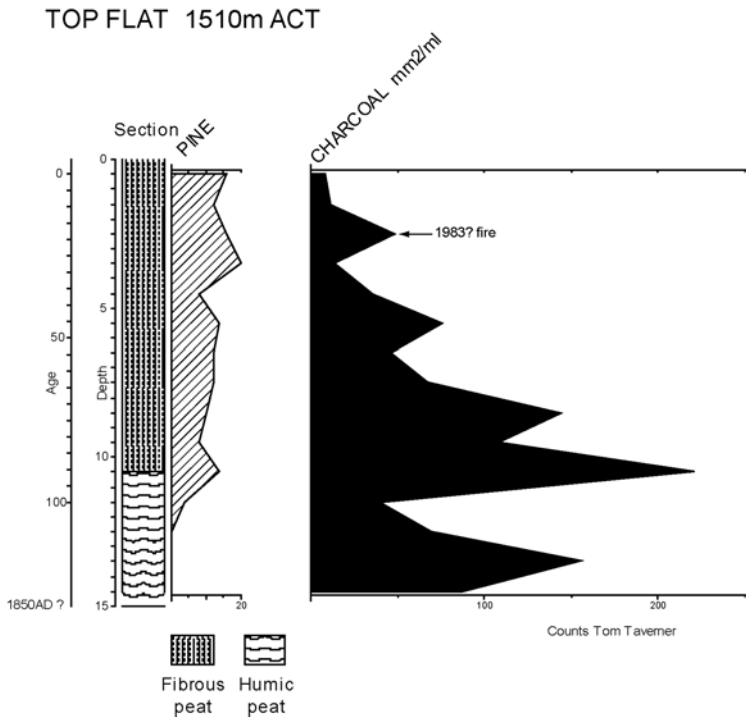

Figure 2. Charcoal concentration change at Top Flat mire, Cotter River, ACT.

Management considerations

Southern montane New South Wales has the largest biologically distinctive montane peatlands on the mainland. This relative richness compared to the rest of inland Australia creates a good case for optimising the catchment conservation and scientific values of the peatlands as a whole. The agricultural use of these bogs is not compatible with high conservation values and extractive mining demonstrably is a considerable risk to them. Although considerably altered from pre-disturbance state, regeneration is possible, as the communities are adapted to change and colonisation. Causes of disturbance must first be removed, by fencing the perimeter if necessary. The main aim is to return the watertable and flow regime can be returned to pre-drainage conditions. Above the nick points on artificial drains or incising channels this can be achieved by blocking the drains at intervals determined by the natural fall of the bog. The effect of these barriers would be to direct flow out onto the bog surface where it would disperse amongst the vegetation. *Carex* and other sedges would thrive and the peats will expand as water re-enters the dry sediment. Barriers should be extended above the present upstream limit of peat formation so that sediment load can be caught before it enters the mire.

Below the nickpoints the aim is to raise the watertable and reduce the hydraulic gradient which is causing wall slumping. In some cases an earth wall with a down stream dissipative slope would create a pond. Alternatively grading an even slope from the bog to the downstream channel would allow the generalised flow to wet the entire area, propagating the bog downstream. Shrubs such as *Leptospermum lanigerum* might be used there to create a stable vegetation tolerant of intermittent flooding. Re-wetting the bog will solve most weed problems.

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