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The peat-forming mires of the Australian Capital Territory

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Abstract

The mountains of the Australian Capital Territory support substantial areas of peat-forming mires in interfluves and valley heads, as well as areas of riparian fen vegetation along streams. They include valley fill deposits with sedge fens at lower altitudes (800–1200 m), and shrubby subalpine bogs and restionaceous fens which sometimes include the hummock moss Sphagnum cristatum. There are several minor wetland vegetation types including aquatic communities, Leptospermum tall shrubland and Poa wet tussock grasslands but these are generally not peat-forming. While similar fens and bogs occur in the Snowy Mountains, the ACT represents a significant outlier of major biogeographic significance because the mires are near their climatic limits and hence sensitive to climate change.

Mapping of the ACT mires has been completed utilising air photography and satellite imagery supplemented by field checking to create an ARC INFO GIS that defines the boundaries of the mires and maps selected vegetation boundaries in the larger (>5 ha) swamps. The boundaries generally reflect the situation in February 2003 after a major fire when good colour air photography is available. This work is supplemented by data on the peat depths and history of the mires provided by a fifteen year program of coring that covers all types of organic deposit in the ACT. The report provides the first estimates of peatland extent, peat volume and carbon storage for the ACT.

Acknowledgments

This report reflects several decades of mire studies by palaeoecologists and ecologists from the Australian National University, CSIRO, NSW Parks and Wildlife Service and the Tasmanian Department of Primary Industry, Environment and Water. Mapping of the ACT bogs commenced in 2005 with external funding from ACT Parks, Conservation and Lands, Namadgi National Park and the NSW Department of Climate Change (DECC). The GIS mapping was developed by Rachel Nanson with additions by Iona Flett and Peter Jones and advice from Tony Sparks. We are grateful for assistance with field survey by Amanda Carey, Paul Cheesman, Ruth Crabb, Iona Flett, Roger Good, Simon Haberle, Justine Kemp, Virginia Logan, Dominique O'Dea, Ben Keaney, Colin de Paget, Matiu Prebble, John Rogers, Alan Wade, Bren Weatherstone, Jennie Whinam, Martin Worthy and a succession of classes from ANU. Permission to undertake the work was provided to GH by Parks Conservation and Lands, Territory and Municipal Services ACT and ACT Forests. We are indebted to Amanda Carey, Murray Evans, Trish MacDonald, Brett McNamara, Darren Rosso, Brian Terrill and Dave Whitfield for authorisations, advice and substantial field support.

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Introduction

The mountains of the Australian Capital Territory (ACT) are home to numerous small wetlands or mires that are unusual in forming peat and other organic-rich soils that are preserved due to waterlogging, acidity and cool temperatures. The peatlands have characteristic vegetation that sharply distinguishes them from the surrounding woodlands and grasslands and so can be seen as islands of habitat. Despite this, the peatlands support only a limited number of plant communities of shrubland, moss hummock and sedgeland. The communities are important within catchments through their role in the interception, filtration, storage and slow release of large volumes of water to streams and rivers. The peatlands provide significant environmental services crucial to both the natural environment and to the supply of water for lower altitude storages. They trap sediment, remove nutrient and store water, gradually releasing high quality flows to rivers. They are also important as animal habitat by providing green feed and water during dry periods to a range of grazers and invertebrates as well as supporting some wetland species such as freshwater crayfish, frogs and the broad-toothed rat (Lintermans and Osborne 2002). The montane peatlands and swamps of the South East Highlands and Australian Alps bioregions were listed in New South Wales (NSW) as an endangered ecological community in December 2004 on Schedule 1, Part 3 of the *Threatened Species Conservation Act 1995* (NSW). Additionally in 2008 the Alpine *Sphagnum* Bogs and Associated Fens ecological community was listed as Nationally Endangered under s. 266B of the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth).

Although the peatlands of the Australian Alps have been studied for a long time, most systematically by Alec Costin as part of his ground breaking survey of ecology and soils of the Monaro (Costin 1954), detailed mapping of mires is still incomplete. A study of treeless vegetation of the ACT by Helman and Gilmour (1985) contains the most comprehensive ecological study of the mires above 1000 m to date. Although it remains unpublished, its results have been included in a recent account of the treeless vegetation of the Australian Alps (MacDougall and Walsh 2007).

In a national survey of wetlands (Australian Nature Conservation Agency (ANCA) 1996) two Interim Biogeographic Regions were listed for the South East Highlands and Australian Alps of south-eastern Australia. These are equivalent to montane (>500 m) and subalpine (>1400 m) zones. The ANCA report extracted data from an earlier survey of montane peatlands in the ACT and southern NSW (Hope & Southern 1983). Since then more than 300 wetland sites in the ACT and southeastern NSW have been investigated, although many of these do not retain peat forming mires at present (Table 1).

Area (Bioregion)	This Report	ANCA 1996	Ramsar
ACT Alps (AA)	33	2	1
ACT highlands (SEH)	26	1	0
NSW Alps (AA)	8	3	1
NSW Southern Highlands (SEH)	14	8	0

Table 1: Significant peatlands noted in surveys and nominations.
AA =Australian Alps, SEH = South East Highlands

One mire in the ACT, Ginini Flats subalpine bog complex, has been described as an exceptional example of a subalpine *Sphagnum* bog and is on the Ramsar List of Wetlands of International Importance (Australian Ramsar site 45). Part of the listing reflects the importance of this site as breeding habitat for the highly endangered northern corroboree frog, *Pseudophryne pengillyi* (McElhinney and Osborne 1995).

Peatlands are scientifically valuable because they preserve their history in the accumulating peat. These archives provide evidence of the fire history and the past record of climate change. The peatlands themselves are sensitive indicators of environmental change. The ACT mires have been studied in the last few years to provide records of age of formation and long-term changes in catchment vegetation (Hope 2003, 2006; Hope and Clark 2008), the mire dynamics through time (Whinam and Chillcott 2002; Whinam et al. 2003), local fire histories (Banks 1989; Zylstra 2006) and a record of recent changes in vegetation and hydrology (Hope et al. 2005). Some of this work is in unpublished theses and reports (Clark 1980, 1983, 1986; Hope 1996, 1997, 1998; Hope and Southern 1983), but other material is still being prepared for publication (e.g. Whinam et al in press, Good et al in press).

Mapping of the significant peat-forming mires of the ACT has been completed and this report defines the criteria used to prepare a Geographical Information Systems (GIS) data base and map of the mires. The map shows the boundaries of the wetlands greater than ca 0.1 ha and provides simple vegetation boundaries for the larger (>2 ha) mires.

The Peatland Environment

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 and often acid 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.

Organic breakdown (humification) tends to produce similar material from diverse original sources. Typically, the proportion of fibrous peat decreases with depth in a deposit, and Clark (1986) argues that this reflects continuing breakdown in a deposit, so that older materials are more humic. However, more fibrous horizons may occur under humic ones, and these mark a period of rapid growth in a mire in the past. Ivanov (1981) distinguishes a shallow upper layer which has a fluctuating watertable, the acrotelm, from a lower, permanently waterlogged layer, the catotelm. Mire vegetation only survives in the upper layer and biological activity is greatly reduced in the lower. In this scheme, many topogenous mires in Australia have very deep acrotelm horizons, reflecting considerable drying out in droughts.

The vegetation forming the organic material varies according to availability and nutritional status of the water. 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. If increased nutrition, for example from groundwater, is available, shrubs, grasses and sedges will invade and co-exist with the moss, or exclude it. The growth of peat at the wettest places will block streamlines and form shallow ponds over time, retaining water in the mire. *Sphagnum* moss is particularly competent to do this, and can form a raised bog, well above the regional watertable. Sedges and restiads also act to create string bogs by creating peat dams. If the watertable occurs at the surface for a substantial time, many shrubs will not survive, and shallow rooted sedges, twig rushes and similar plants will form an open cover. 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. The dynamic growth of peatlands can thus result in the formation of a mosaic of communities. These processes are set back by disturbance or changes in water supply due to drought, fire or drainage and the peat can be humified or destroyed.

Peatland definitions in this report

We use the term '**peatlands**' to indicate terrestrial sediments in which organic matter exceeds 20% dry weight and with a depth generally greater than 30 cm. This is conservative by European measures (Whinam and Hope 2005) but even our definition would exclude some mires, such as Tasmanian buttongrass moorland. These may have shallower peats (15–25 cm), but must be included as peatland because they form extensive organic terrains. Many terms exist to describe peaty wetlands; for example, bog, fen, mire, moor, marsh, morass, swamp and swamp forest. Of these, only bog, fen and moor have specialist definitions (Charman 2002; Bridle 1994; Whinam and Hope 2005; Hope 2006):

Bog: Characterised by complex vegetation with little free water surface: stagnant water; usually acidic (pH 4–5) and of low nutrition as it generally depends on rainfall for minerals.

Fen: Simple vegetation often with some open water: fed by surface flow and groundwater and mineral matter often present, giving better nutrition and mildly acidic to neutral (pH 5–6).

Moor: Simple sedge, rush or open sedge-shrubland on slopes with shallow muck or fibrous peats, forming an organic soil. Nutrition from surface flow and mineral substrate; acidic to mildly acidic (pH 4.5–5.5).

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. This contrasts with some European authors who restrict the term 'bog' to communities that are fed by rain alone (also termed ombrogenous or cloudfed bog (Whinam and Hope 2005)). In southeastern Australia, 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 (Restionaceae, Juncaceae, Typhaceae). However, grass or sedge bogs are known, for example *Gymnoschoenus* (button grass) bog, in which densely packed graminoid hummocks provide a complex structure. All peatlands in the ACT are topogenous mires, meaning that they require slope runoff and groundwater to exist and hence occupy the base of slopes and valley floors. However, some areas on *Sphagnum*-dominated bogs have no overland flow and are raised above the surface flows, so may represent embryonic ombrogenous bogs.

Peatland Vegetation

Keystone species

The plant communities of peat-forming mires in the ACT have simple floristics and share many species in a total flora of about 180 species* (Helman et al. 1988, Appendix). In the total flora of mire obligate or tolerant plants are a few keystone species which control the structure and function of a community, being always present and influencing some aspect of the community such as water-holding, pH or ability to exclude competition. Four species and two groups of related taxa influence mires in the ACT.

Sphagnum cristatum is a hummock or cushion-forming moss with a very open structure that can hold up to 20 times its own weight of water which it maintains at an acid pH and very low nutrient status, thus limiting competition. It is capable of blocking watercourses and building domes by wicking up moisture. In the ACT the living moss requires 30–70% shade but during a favourable season it can expand rapidly, adding several centimetres to the cushion. It spreads vegetatively along streams or by animal and bird dispersal as it only rarely spores in the ACT. It is fire sensitive, being completely killed by a light fire in accompanying vegetation. Whinam et al. (2003) note that the moss is near its climatic limits in the ACT, being unable to survive days of high temperature, low humidity and high radiation in summer except at high altitude and on shaded aspects with a good water supply. However, there are *Sphagnum cristatum* shrub bogs in the Barrington Tops and New England areas of northern NSW.

Empodisma minus (formerly *Calarophus minor*) (Restionaceae) is a grass-like twig rush that always accompanies *Sphagnum* in shrub bogs but also dominates fens on the margins of bogs. It is important structurally because it forms a tough cohesive root mat which readily resprouts after fire and which resists erosion. Like *Sphagnum* it can impede stream flow and create ponds. The resprouting root mat reduces the potential damage caused by fires and explains why peatlands persist on sites subject to repeated burning. It is often associated with a more robust restiad species, *Baloskion australe* (formerly *Restio australis*), and vegetation dominated by these plants is sometimes termed 'restiad bog'. However, structurally this community often occurs on slopes on shallow peat and more strictly should be termed moors. *Empodisma minus* extends from Queensland to Tasmania and is also important in New Zealand.

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* Plant species names follow Lepschi et al. (2008) which contains a Census of Vascular Plants in the ACT http://www.anbg.gov.au/cpbr/ACT-census/index.html

Carex gaudichaudiana is a grass-like sedge (Cyperaceae) which is scattered in bogs but dominates fens on seasonally inundated peat. Like *Empodisma* it readily resprouts after fire and stabilises burnt fens within a few weeks. Its dense sward can be 50 cm deep and it forms an effective filter, spreading water

Figure 1: Keystone species of ACT mires: a) *Sphagnum cristatum* sporing at Kosciuszko in 2007; b) The restiad *Empodisma minus;* c) Epacrid shrubs *Richea continentis* and *Epacris paludosa* with the restiad *Baloskion australe;* d) Myrtaceous shrubs *Baeckea gunniana;* e) *Carex gaudichaudiana;* f) *Carex curta* and willows g) *Myriophyllum pedunculatum* with fairy aprons, *Utricularia dichotoma*, h) *Poa costiniana* wet tussock

out across valley floors. It is an early pioneer of shallow ponds. *Carex* forms fens throughout montane Australia, New Zealand, the sub-Antarctic and also extends to subalpine New Guinea. Like many mire plants it may be dispersed by water birds.

Bog epacrids: *Epacris paludosa, E. brevifolia, E. microphylla* and *Richea continentis* are long-lived mire shrubs in the Ericaceae (heather) family (formerly Epacridaceae) which can tolerate low pH and colonise *Sphagnum* hummocks. They can grow to 120 cm and suppress *Sphagnum* when very dense. They are easily killed by fire and do not resprout, replacing themselves by seedlings. *E. paludosa* has wide altitudinal range but *R. continentis* is confined to the subalpine bogs.

Bog myrtaceous shrubs: *Baeckea gunni, B. utilis* and *Melaleuca pityoides* (formerly *Callistemon pityoides*) form a second group of low mire shrubs in the Myrtaceae but unlike the epacrids they readily resprout from the base after light fires. *Baeckea gunnii* occupies high altitude bogs and the very similar *B. utilis* is more common at lower altitudes. A taller ti-tree, *Leptospermum lanigerum* occupies mire margins. All species are readily inflammable and probably carry fire onto *Sphagnum* shrub bogs.

Poa costiniana is a medium sized tussock grass which is commonly found scattered in bogs and dominates sod tussock on the margins. It re-seeds profusely and can resprout if lightly burnt. It will invade mires if these are dried out and is an indicator of mires becoming degraded. Other *Poa* species, *P. clivicola* and *P. helmsii* often contribute with the larger tussock, *P. labillardierii* being common at lower altitudes on fen margins.

Vegetation communities in ACT mires

A review of the treeless communities of the Australian Alps (McDougall and Walsh 2007) provides a list of vegetation communities which includes the mires of the ACT mountains. They discern two types of *Sphagnum*-shrub wet heath, one alpine and the other subalpine distinguished mainly on structural grounds. The higher altitude community, *Richea continentis – Carpha nivicola – Sphagnum cristatum* wet heathland, contains low shrubs while the lower altitude community, *Baeckea gunniana – Callistemon pityoides – Sphagnum cristatum* wet heathland, has tall shrubs sometimes excluding *Sphagnum*. In the ACT the first community has been noted by Helman and Gilmour (1985) but it is only present in small areas and arguably merges with the second community. We subdivide the subalpine *Sphagnum* association into two distinct communities and recognise the following mire plant communities (Table 2).

Community name	**McDougall & Walsh 2007**	**ACT Alt range (m)**	**Substrate**
Sphagnum – Richea – Empodisma high altitude shrub bog	*Baeckea gunniana – Callistemon pityoides – Sphagnum cristatum* wet heathland	1400–1800	*Sphagnum* peat
Sphagnum – Epacris paludosa medium altitude shrub bog	*Baeckea gunniana – Callistemon pityoides – Sphagnum cristatum* wet heathland	980–1450	*Sphagnum* peat
Empodisma minus restiad fen (moorland)	Allocated between wet heathland and grassland depending on shrub cover	>1100	Humic peat and peaty silt
Carex gaudichaudiana fen	Fen	700–1750	Fibrous sedge peat
Phragmites – Typha tall sedgelands (fen)	Not in report	500–1000	Organic muds, clayey sedge peat
Poa sod tussock grassland (fen)	Subalpine valley grassland	700–1750	Humic silty clay
Lobelia surrepens – Ranunculus millanii herbfield	*Lobelia surrepens – Ranunculus millani* herbfield	1090–1770	Organic clay
Myriophyllum aquatic fen (herbfield)	Aquatic	1000–1750	Organic muds
Leptospermum lanigerum shrubland	Not in alps	1200–1600	Humic silty clays

Table 2: Vegetation communities in peatlands in the ACT

These generally conform with plant alliances and associations recognised by Costin (1954) for the Monaro and Snowy Mountains and Helman and Gilmour (1985) for the upper Cotter in the ACT. Of the nine communities, only the first five are peat-forming and have been included in the mapping, the *Phragmites – Typha* fen being included with *Carex* fen. The sixth, *Poa* sod tussock, generally grows on humic mineral soils on the margins of the peat-forming mires, commonly invading peatlands when these experience loss of organic content due to fire or drainage. The last three communities are common, but

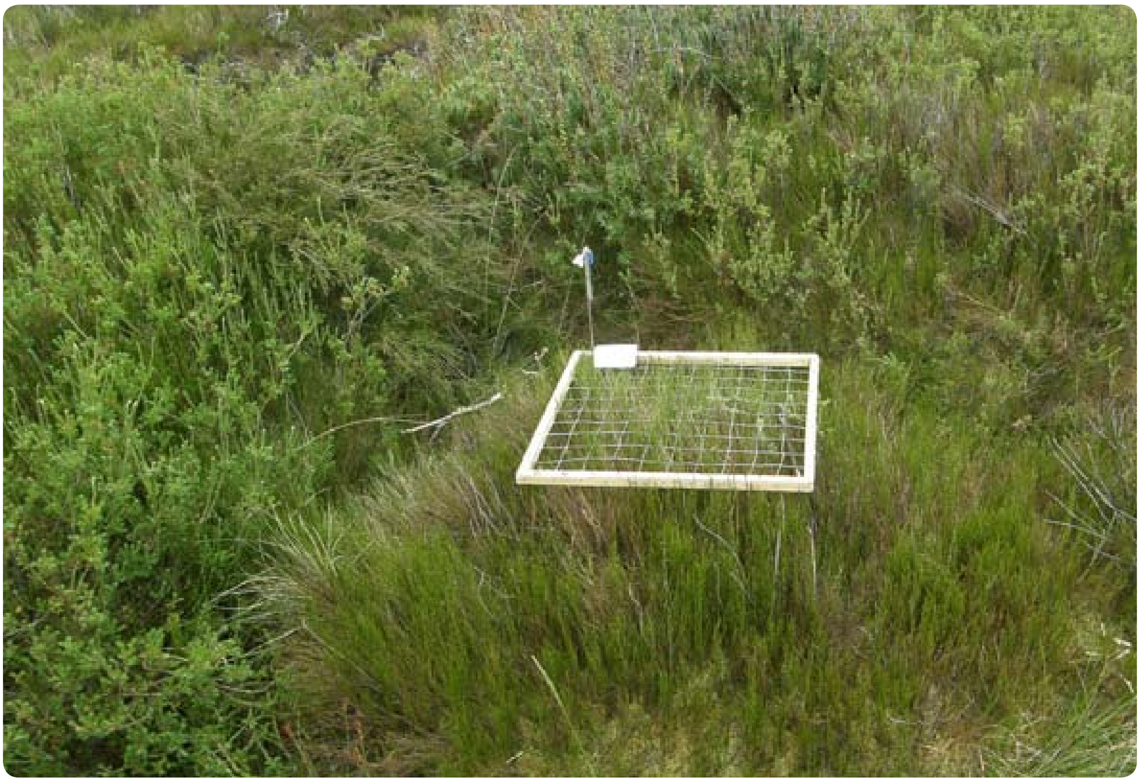


Figure 2 a) *Sphagnum* shrub bog Snowy Flat

Figure 2 b) medium altitude shrub bog, Tom Gregory not extensive, as they are restricted to ponds and riparian habitats. Other wetland vegetation has been defined, particularly wet heath, but this does not form peat.

Sphagnum – Richea – Empodisma high altitude shrub bog is a variable community with *Sphagnum* cover varying from nil to 90% with variable shrub and restiad cover. The *Sphagnum* has a hummock form with hummocks generally 40–70 cm in height under under emergent mytaceous and ericaceous

Figure 2 c) *Empodisma* fen and *Myriophyllum* aquatic pool, Cotter Source Bog

Figure 2 d) *Carex* fen with *Typha* and *Phragmites australis*, Orroral Valley shrubs. *Epacris* species are always present with spiky *Richea continentis* prominent on unburnt bog. Small moss-edged ponds are common, often fringed by a larger restiad, *Baloskion australe*. *Empodisma* and *Carex* are always present and may form fen areas within the bog complex. *Sphagnum*-shrub bog is best developed at the break in slope where groundwater is abundant. It may be patchy on valley floors or localised to seepage sources.

Sphagnum – Epacris paludosa medium altitude shrub bog is less diverse than high altitude shrub bog because several species such as *Richea* and *Epacris brevifolia* are restricted to high altitudes. It has similar structure to the higher altitude community but occupies wet gullies and spring lines, often under woodlands.

Empodisma minus restiad fen can form a sward of *Empodisma* with scattered shrubs and herbs present. It is capable of occupying wet slopes (where it is essentially a moor) and often marks the boundary between wetland and dryland vegetation. *Baloskion* and *Euphrasia* are usually present.

Poa sod tussock grassland invades dried out peat and can withstand waterlogging. In general it is found on dark grey humic silts (gleyed soil) but has been recorded on peat. The grassland is dense, with tussocks interleaved and scattered Asteraceae (daisies) and other herbs. *Empodisma minus* is often present.

Carex gaudichaudiana fen includes the largest mires in the ACT, generally at medium altitudes, where a stand of grass-like *Carex* is the main structural cover and other plants such as *Carex appressa*, *Elaeocharis acuta*, *Phragmites australis* and *Lythrum salicaria* occur along shallow drainage lines. *Carex gaudichaudiana* fen is ubiquitous in all wet situations, often forming small patches in wet tussock, *Sphagnum* shrub bogs or a ribbon of fen along stream banks. *Carex* fens are widespread in south-eastern Australia, New Zealand and the mountains of New Guinea.

Several areas on saddles in the ACT mountains are intermittently flooded and form small ephemeral shallow lakes such as Scabby Lake between Mt Kelly and Mt Scabby. These have aquatic vegetation of *Myriophyllum*, sedges and patterned tussock grassland with occasional water lilies. Those examined have very shallow sandy soils and may be formed by periods of deflation by wind.

Figure 2 e) Scabby Lake with marginal *Carex* and wet tussock fen. Photo taken in October, 2004

Methods

The ACT peatland map

The mapping product consists of an ESRI ArcGIS database in the 'AGD 1966 AMG Zone 55' coordinate system ('transverse mercator' projection), consistent with the ACT mapping series. Metadata within the mapped shapefiles includes details of the scale at which each shapefile was mapped, the name of the operator who undertook the interpretation and mapping, the level of ground truthing (and participants), and details of the imagery from which the boundary interpretations were made. A version of the GIS database has been provided to Research and Planning, Parks Conservation and Lands, Territory and Municipal Services, ACT Government. The database is maintained at the Department of Archaeology and Natural History, Australian National University, and will undergo further additions and corrections as an ongoing project.

Mapping techniques

Mapping of the mires was developed in three stages using orthorectified aerial photography and satellite imagery. Orthorectified images, acquired during February and March 2003 following severe January 2003 bushfires, were used to map peatlands in the Cotter River catchment. Pre-fire images were used to map regions of the Naas–Gudgenby catchment that were not surveyed as part of the 2003 post-fire image capture and these were further supplemented with LANDSAT imagery (30 m pixels) where no photographic images were available. The advantage of the post-fire cover was that burnt *Sphagnum* shrub bog showed up clearly and the lack of tree canopy revealed several bog areas. Pre-fire vegetation and extent of peatlands were roughly indicated by the NSW Land and Property Information 1:25 000 contour and photomosaic mapping and the earlier 1:10 000 ACT Planning series maps.

Mapping Level 1

No data currently exist for the comprehensive identification of both the location and number of mires in the ACT and neighbouring regions. Point location is a first step in quantifying the extent of these features for both threatened species habitat and for budgeting catchment hydrology. The first level of mapping has therefore identified mires as **points** based on:

a) The identification of bog sites by **visual scanning** of the orthorectified images at varying scales, depending on the quality of the aerial photography at 1:20 000, or zoomed to 1:3000 scale where imagery was blurred (a result of the orthorectification process).

b) The use of **existing point datasets** including the corroboree frog point dataset (Dave Hunter), the montane peatland database (based on Hope and Southern (1983) and subsequent work) and an existing dataset for the upper Cotter catchment (kindly donated by Dr Alan Wade).

A total of 179 mires have been identified at this level in the ACT region and 166 of these are within the boundaries of the ACT.

Mapping Level 2

Determining the lateral extent of peatlands in the ACT enables changes in such extents to be monitored and the total volume of peat and other organic sediments in the mires to be used to estimate their total water holding and carbon storage capacity. The second level of bog mapping entailed **digitising mire boundaries** at 1:3000 scale. Mapping was undertaken in *streaming mode* with vertices placed every 2 m. All significant mires (generally larger than 0.5 ha) in the ACT have been mapped using this method, totalling 62 individual peatlands (either *Sphagnum* bogs or *Carex* fens).

Mapping Level 3

The mapping of selected larger mires included the digitising of simplified vegetation unit mire and marginal tussock grasslands boundaries.

Vegetation Mapping Units identified included:

1. Live *Sphagnum* shrub bogs including both high altitude and mid-altitude communities.
2. Burnt *Sphagnum* shrub bogs.
3. Sod tussock *Poa* grasslands on wet sites with minor components of *Empodisma* or *Carex* fens.
4. *Poa – Danthonia* grasslands where these lie within the mire area, for example, as 'islands' of dry habitat.
5. Restiad fens dominated by *Empodisma minus*, *Baloskion australe* and occasional grasses, shrubs and *Sphagnum* moss.
6. *Carex gaudichaudiana* fens.

Shrublands of *Epacris paludosa* and tall shrublands of *Leptospermum lanigerum* are too small to map. These occur along streamlines or on the edges of fens.

Mire areas are determined by the sum of all mapped areas, minus the *Poa – Danthonia* grasslands. Mean peat depths are assessed from transects of coring and can be used to estimate volumes. The analysis of peat and sediment samples of cores can provide values for water and carbon content which can be used to estimate total carbon.

Field validation/checking

Most significant mire areas in the ACT have been visited by foot or helicopter and boundaries checked against the mapping using handheld and differential GPS. Peat type and depth has been checked by probing and coring with a D section corer. Boundaries have also been amended and additional sites added with advice from ACT Parks, Conservation and Lands staff. Some of the survey work has been associated with the program for assessing fire damage and repairing the hydrology of burnt mires from 2003 to 2009 (Carey et al. 2003; Good 2006). In addition a post-fire monitoring program (Hope et al. 2005; Whinam et al. in press) has resulted in repeated visits since 2003 to assess mire condition and remeasure permanent plots at Ginini Flats (west), Snowy Flats, Rotten Swamp, Top Flat and Cotter Source Bog. Mire assessment has also been included in a continuing study to investigate the history of the peatlands. Stratigraphic coring has been carried out by the authors, assisted by staff and students from the ANU, at Blundells Flat, Bogong Creek Swamp, Tom Gregory Bog, Coronet Creek, Nursery Swamp, Boboyan Swamp, Sheep Station Creek, Rotten Swamp, Ginini Flat, Snowy Flat, Top Flat, and Cotter Source Bog.

Results of Mapping

Distribution of bogs and fens in the ACT

The *Sphagnum – Richea – Empodisma* high altitude shrub bogs of the ACT occupy basins above 1450 m along the Brindabella and Scabby ranges. The largest stands occur on benches near the crest of the range, such as Ginini West (1599 m, 14.3 ha) and Snowy Flat (1616 m, 20.5 ha). *Sphagnum – Epacris paludosa* medium altitude shrub bog occurs in small areas in the upper Cotter valley such as Tom Gregory (1029 m, 2.3 ha) and the headwaters of Gibraltar Creek, Nursery Creek and the Orroral River. *Sphagnum* shrub bog at Rotten Swamp (1446 m, 18.5 ha) is transitional between the two types as it lacks *Richea continentis* but has two species of *Epacris* and a more diverse flora than the lower altitude sites. The *Sphagnum* shrub bogs are usually in a mosaic with *Empodisma* fen which extends onto the drier margins and has invaded some bogs after fire. *Empodisma* fen is the dominant mire type in several peatlands where *Sphagnum* shrub bog has retreated after fire, for example at Cotter Source Bog (1718 m, 5 ha), Rotten Swamp, Ginini Flat (East) (1584 m, 22.6 ha) and Murrays Gap (1530 m, 8.1 ha). There are also some significant areas such as Big Creamy Flat that have limited *Empodisma* fen with very restricted patches of *Sphagnum* shrub bog set in large areas of sod tussock grassland. It is not known if peat-forming communities were formerly more widespread at these sites.

The large *Carex gaudichaudiana* fens of the ACT occur in elongated valleys on the eastern flank of the mountains at Orroral (9v40 m, 31.3 ha), Nursery Swamp (1108 m, 23.9 ha), Bogong Creek Swamp (995 m, 41.9 ha) and Boboyan Swamp (1166 m, 39.6 ha) in the upper Naas and Gudgenby catchments. These, together with neighbouring large fens in NSW at Bradleys Creek and Yaouk Swamp, form a remarkable cluster of peatlands of regional significance. However, small stands of *Carex* fen occur at all altitudes and may be locally important as on the valley floor at Rotten Swamp.

Table 3 and Figure 3 summarise the distribution and aggregate area of mires in Namadgi National Park, outside the park, and in NSW, but within about 10 km of the southern and western border of the ACT. The mire types are also divided into *Carex* fen, all *Sphagnum* dominated bogs, and *Empodisma* fen, and shown in Figure 5 for the ACT only.

Area	Number of mires	Total Bog Area (ha)	*Carex* Fen	*Sphagnum* shrub Bog	*Empodisma* fen
Namadgi > 1400 m	25	226.7	12.6	148.5	65.7
Namadgi 600–1400 m	33	346.6	275.9	18.1	52.6
Namadgi (whole park)	58	573.3	288.5	166.6	118.2
ACT ex-Namadgi	1	9.3	9.3	0	0
Scabby Range Nature Reserve	5	104.8	69.3	13.5	21.9
Kosciuszko National Park North	12	43.7	2.1	9.2	32.3
Bimberi Nature Reserve	3	10.8	0	6.8	4.1
NSW outside reserves	2	199.9	199.9	0	0
ACT region mires total	81	941.8	569.1	196.1	176.6

Table 3: A summary of mapping progress in the ACT and surrounds

When mire area is plotted against altitude (Figures 4 and 5) it is clear that the bulk of mires are small (<20 ha) and that they are almost all above 850 m. Two groups exist, one from 900–1250 m and the

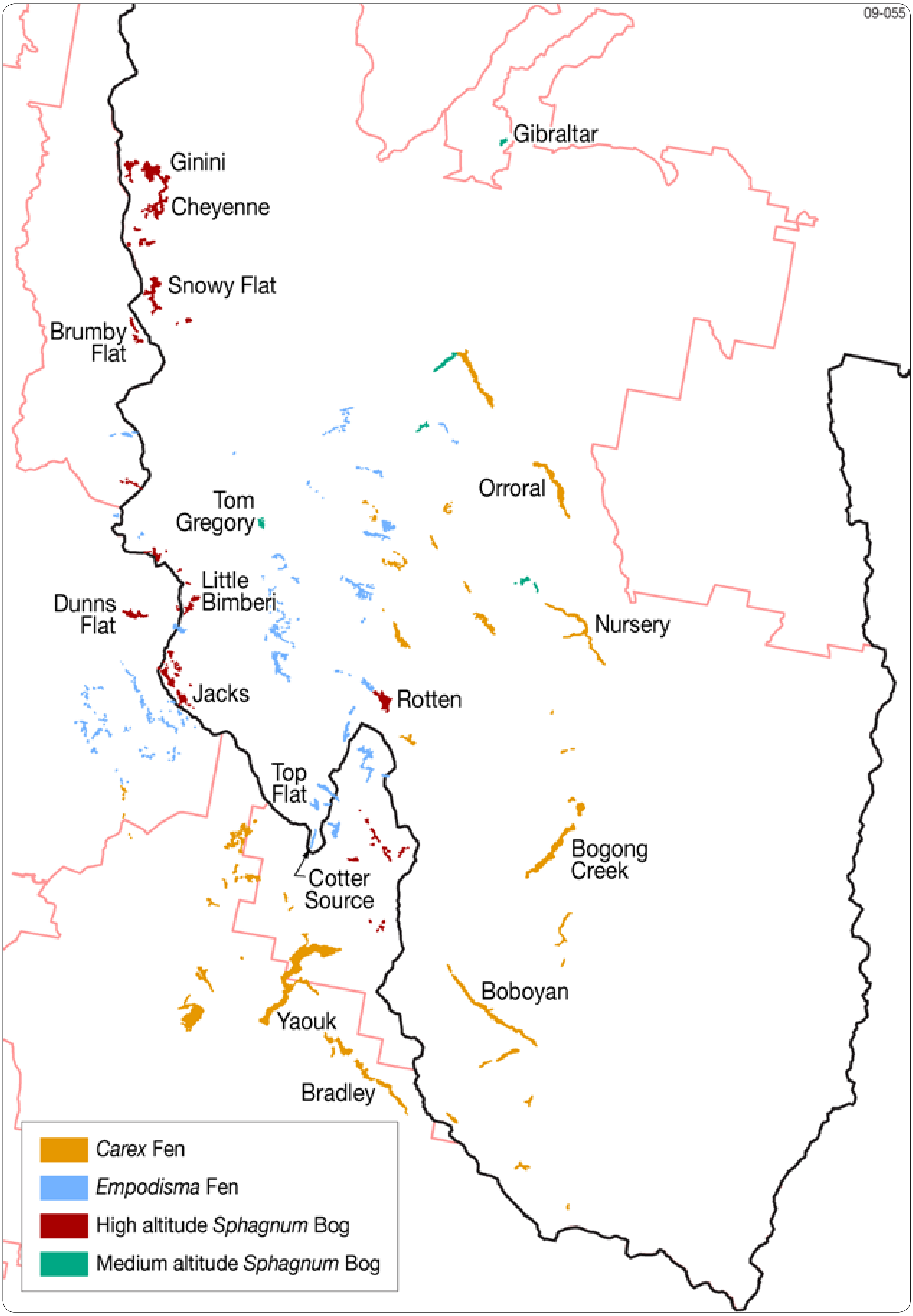


Figure 3: Map of ACT mires. Blundells Flat is not shown

other from 1350–1750 m. This may reflect valley bottom and summit plateau settings, with steep slopes preventing mire formation at intermediate altitudes.

The lower altitude group includes all the large *Carex* fens and some medium altitude *Sphagnum* – *Epacris* shrub bog. The higher altitude group are mosaics of *Sphagnum* shrub bog and *Empodisma* fen. The values in Table 3 are not precise because the whole areas of individual mires have been allocated to the dominant vegetation type, concealing the contributions of other mire types. Additionally small mire patches have not been included and these may add a significant area to the total. Small patches also add greatly to connectivity between the larger mire areas. Taking these unmapped mires into account, the ACT has nearly 6 km^2 of peat forming mires or about 0.25% of the total area of the ACT and 0.47% of the area of Namadgi National Park. This estimate omits small patches of mire and riparian habitat which are widespread through the ranges.

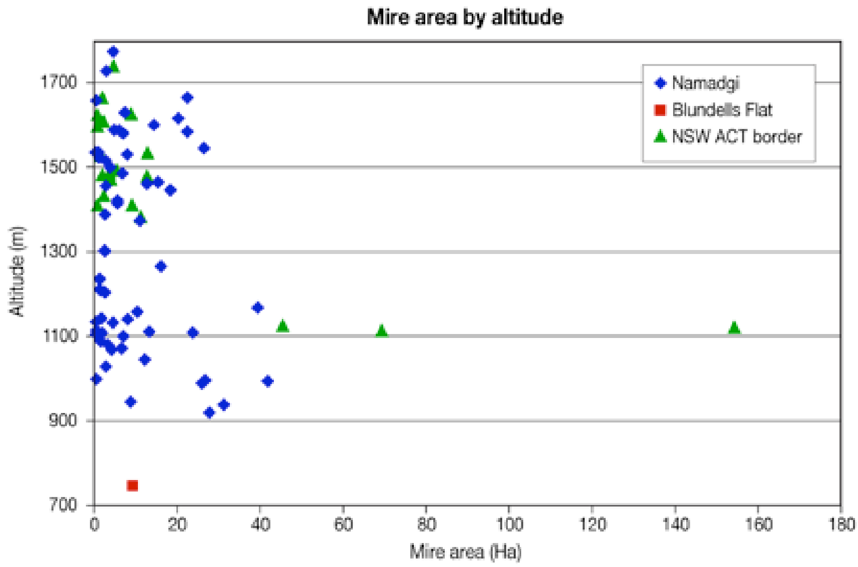


Figure 4: Distribution of ACT and neighbouring NSW mires by area and altitude

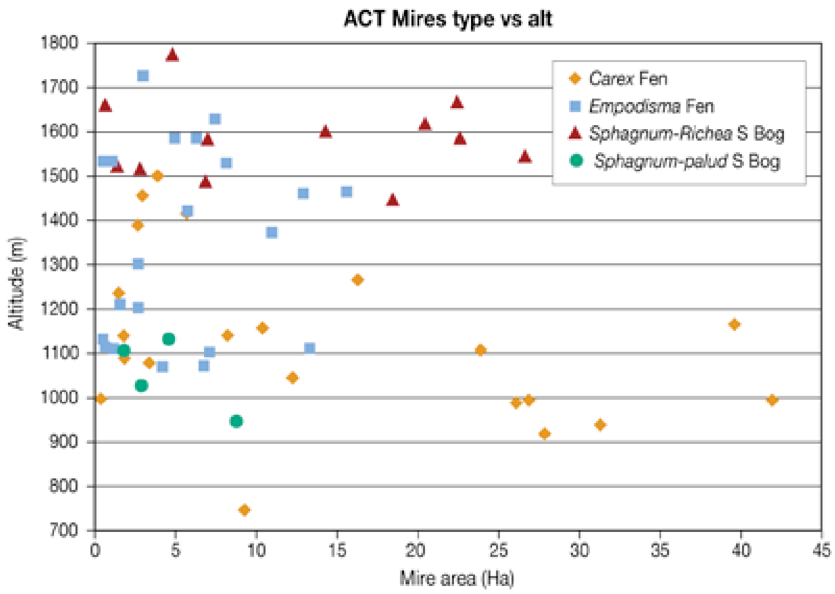
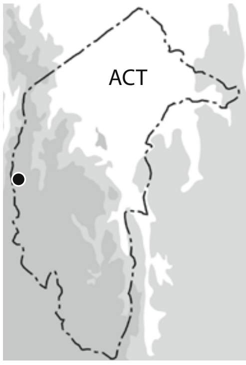


Figure 5: Distribution of ACT mires by mire type, area and altitude

Descriptions of Four Characteristic Mires

Four characteristic ACT mires are described below, representing two high altitude bog types, an intermediate mire mosaic and the largest montane *Carex* fen. All have supported various scientific investigations and have been mapped in detail. Climatic data is estimated from available stations using BIOCLIM (Houlder et al 2000).

Ginini Flats (West)



Location	35°31'S 148°46'E
Type	*Sphagnum – Richea – Empodism*a high altitude shrub bog
Altitude	1590 m
Area of deposit	12.5 ha
Area of catchment	1790 ha
Max. altitude of catchment	1762 m
Estimated Precipitation	1038 mm
Mean Annual Temp	6.7°C.

Ginini Flats (West) lies at the head of Ginini Creek near the crest of the Brindabella Range on the north-eastern summit slopes of Mt Ginini, about 800 m east of the ACT–NSW border. It is a valley floor and edge bog about 12.5 ha in extent with peaty riparian mire extending south-west along the tributary stream lines. The area of catchment is 1790 ha and a permanent stream flows through the mire from Mt Ginini.

Mt Ginini is formed from contact metamorphic hornfels rocks underlain by the Gingera granodiorite batholith (MacPherson 1998). Granodiorite outcrops on the southern and eastern sides of the bog and corestones are scattered through it. The climate is sub-alpine but McPherson (1998) has identified active periglacial activity at the summit of Mt Ginini, in areas he believes may have been exposed by intense fire. The bog occupies a broad gently sloping flat between moderate slopes. Ginini Bog (West) is the northern section of a complex of shrub bog, *Empodisma* fen and wet grassland in mires such as Ginini Flats (East), Cheyenne Flats and Snowy Flats which occur on other streams on the eastern slopes, assisted by a broadening of the range at this point to form a relictual plateau about 2 km^2 in extent. This area receives snow in winter and has distinctly denser vegetation than the steep exposed western slopes of the range.

Ginini Flats (Figure 6) is dominated by low shrublands of *Richea continentis, Epacris paludosa* and *Baeckia gunniana* over extensive *Sphagnum cristatum* hummocks, intergrown by the restiads *Empodisma minus* and *Baloskion australe*. This surface is slightly raised away from the valley sides and individual hummocks are ~50 cm above hollows. Wet areas support tiny stands of *Carex gaudichaudiana* fen with *Gonocarpus micranthus* and *Myriophyllum pedunculatum* in shallow sandy ponds. The bog grades up to steeper slopes with an *Empodisma* fen that includes *Poa* spp., snow daisies, alpine gentians and shrubs such as *Comesperma retusum* and *Hakea microcarpa*. Shrubs and small trees of *Leptospermum lanigerum* grow on the bog margin and up wet gullies. Above the peatland, *Poa* grasslands surround the site with snow gum, *Eucalyptus pauciflora*, forming woodlands on the slopes, with an understory of *Tasmania xerophila* and leguminous shrubs.

Species	A	B
**Acetosella vulgaris*	1	
Acaena novae – zelandiae	1	
Aciphylla simplicifolia	1	1
**Anthoxanthum odoratum*	1	
Arthropodium milleflorum	2	1
Asperula gunnii	1	
Baeckea gunniana		5
Baloskion australe	2	4
Brachyscome scapigera	1	
Carex gaudichaudiana	1	3
Celmisia paludosa	1	1
Celmisia tomentella	1	
Chionogentiana cunninghamii	2	
Comesperma retusum		2
Cotula alpina	1	1
Craspedia glauca	2	1
Austrodanthonia alpicola	1	
Deyeuxia gunniana		2
Empodisma minus	6	3
Epacris breviflora	1	4
Epacris paludosa	2	1
Epilobium billardierianum subsp. cinereum		1
Euchiton traversii	1	2
Euphrasia caudata	1	
Galium nigrans		1
Geranium neglectum	1	
Gonocarpus micrantha	1	
Hakea microcarpa		2
**Hypochaeris radicata*	2	
Isolepis crassiuscula		1
Isolepis fluitans		2
Juncus brevibracteus		2
Lagenophora montana	1	
Lobelia gibbosa	1	
Luzula australasica	2	1
Lycopodium fastigiatum	2	1
Melaleuca pityoides		2
Myriophyllum pedunculatum		2
Olearia algida	2	1
Oreobolus distichus	3	1
Oreobolus oxycarpus		1
Oreomyrrhis ciliata	2	
Plantago antarctica	1	
Poa clivicola	1	
Poa costiniana	1	
Poa sieberiana var. *cyanophylla*	1	
Pratia pedunculata		1
Ranunculus graniticola		2
Richea continentis		5
Sphagnum cristatum	3	4
Stellaria pungens	2	1
Stylidium graminifolium	2	
Thelymitra cyanea		1
Utricularia dichotoma		1
Viola sp		1
Wahlenbergia ceracea	1	1

Table 4: Taxa noted in the Mire complex
A = Mire margin, B = *Sphagnum*-shrub bog and ponds
* = Introduced weed

Domin Scale	Abundance	Cover
1	rare	<1
2	scarce	1
3	scattered	2–5
4	common	6–10
5	common	11–20
6	any number	21–33
7	any number	34–50
8	any number	51–75
9	any number	76–95
10	any number	100

Floristic cover-abundance was assessed subjectively using a modified Domin scale 1–10 (Bannister 1966)

Ginini Flats (West) has been nominated as an outstanding example of a subalpine *Sphagnum*-shrub bog because it has extensive well-preserved fibrous moss peat, and is included as part of the only Ramsar wetland in the ACT, the Ginini Flats mire complex. It is also one of two nominated wetlands for the Australian Alps bioregion (IBRA), the other being the alpine Blue Lake on Mt Twynham. This mire is described by Costin (1972) as one of the largest and best preserved *Sphagnum* bogs in Australia, and it is noteable for the extensive stands of *Richea continentis*. Faunal studies are continuing on this mire as it is a northerly habitat for the corroboree frog and access is now discouraged to protect the fauna. New techniques of carbon particle analysis and tree fire scar recording have been researched at this site to provide a history of fire from about 1820 (Banks 1982; Clark 1983; Zylstra 2006). Clark (1983) studied the growth of *Sphagnum* hummocks, concluding that fast apparent growth took place, but could be reversed after heavy snow compressed the hummocks.

Some removal of surface *Sphagnum* (for filler in acetylene tanks and bandages) occurred in 1940, and an 80 m long trench was dug to 1.5 m in 1938 on the northern slope (Environment ACT 2001). This drained the bog near the trench which lost *Sphagnum* and became fen and shrubland. Serious fires have been common in the catchment, and burning possibly limits the distribution of the *Sphagnum* community to the wettest areas. Former bog may have been converted to sod tussock grassland on the western side by earlier fires. The fires of 14–18 January 2003 (Figure 24) burnt about 50% of the vegetation on the bog, killing areas of *Sphagnum* and the epacridaceous shrubs which have been transformed to *Empodisma* fen (Figure 7). Peat fires also occurred on dried surfaces along the trench and nearby formerly harvested hollow, removing 10–30 cm of peat and leaving orange ash. A program of using hay bales and coir logs to impede water flow has been trialled, together with shade cloth to assist with *Sphagnum* recovery, as *Sphagnum* requires a minimum of 30% shade. The fire-sterilised peats have not regenerated, other than a few scattered *Poa* tussocks, as they have remained dry with water passing under the peat. As such they remain vulnerable to future fire. Six *Sphagnum* transplants were placed in the trench and most have successfully expanded except where water flow removed them (Figure 23).

Floristic cover-abundance was assessed subjectively using a modified Domin scale 1–10 (Bannister 1966).

Stratigraphy and dating

The mire slopes quite steeply from the northwest and becomes shallower to the east on granite, with tors emerging through the surface. The depth of peat varies considerably with an average of 75 cm under moss hummocks up to 80 cm in height. Grey pebbly clay underlies the peat. The peat is formed from *Sphagnum* throughout and is considerably humified near the base with some *Sphagnum* remains and possible *Richea* wood. The base of the peat section through the trench has been dated to about 3200 yr BP (Costin 1972, Table 5). This has been confirmed by a new date on the fine organic fraction in peaty clays at the base (114–115 cm).

The section from which Costin obtained his dates was sampled at approximately 10 cm intervals in 2002 and the samples analysed for pollen and charcoal (Hope unpublished). A second site on the western edge of the bog was cored in 2006, recovering 80 cm of moss peat overlying 50 cm of more humic peat. This was underlain by 60 cm of orange-white sandy clay. Dating (Table 6) indicates regular accumulation over the past 3200 years.

Sample	Depth (cm)	Age yrs BP	Lab No	Cal yr BP	Pretreatment
GIN72-2	ca 100	3050 ± 80	GRN 2492	3130–3344	Wood
GIN72-1	ca 110	3280 ± 70	GRN 2491	3442–3600	Bulk peat
GIN02-3	114–115	3170 ± 70	ANU 12021	3322–3467	<220µm fraction NaOH insoluble

Table 5: C^{14} dates Ginini Flat (West) Trench Section

Sample	Depth (cm)	Age yrs BP	Lab No	Cal yr BP	Pretreatment
GIN06-1	70–75	1730 ± 35	Wk18653	1592–1691	<220µm fraction after NaOH leach.
GIN06-2	125–130	3082 ± 45	Wk18654	3251–3354	<250µm fraction after NaOH leach

Table 6: C^{14} dates Ginini West Edge core

These dates, the moss peat sections and pollen data all indicate that at Ginini the peat has accumulated within the last 3500 years and that it has been a *Sphagnum* bog throughout its history. Charcoal is present throughout the profile showing that the bog has experienced numerous fires. The dated sections are the deepest found and the average peat depth is 50–75 cm. The long-term accumulation rate is about 0.3 mm/year showing that the mire is finely balanced between accumulation and loss.

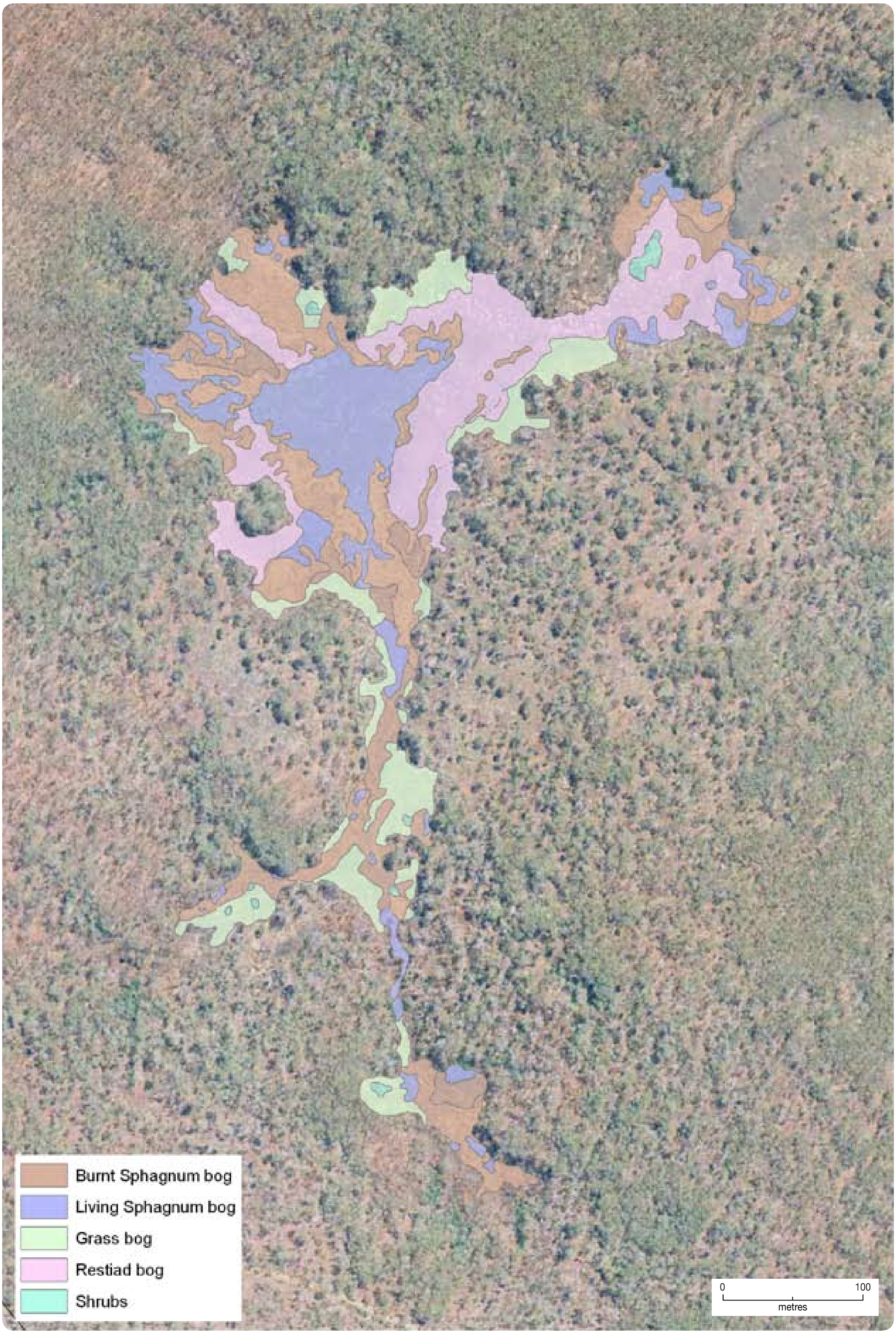
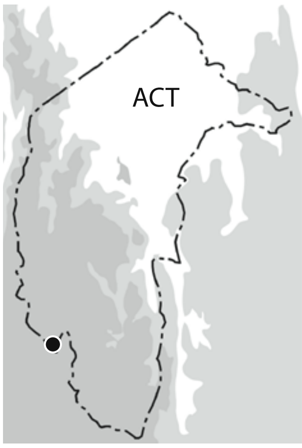


Figure 6: Mapping of Ginini Flat (West)

Figure 7: Photograph of Ginini Bog after the 2003 fires showing burnt *Sphagnum* and transformation of areas to *Empodisma* fen

Cotter Source Bog



Location	35°45.3'S 148°51.45'E
Type	*Empodisma* fen with ponds and *Sphagnum – Richea – Empodisma* high altitude shrub bog
Altitude	1718 m
Area of deposit	5 ha
Area of catchment	25 ha
Max. altitude of catchment	1801 m
Estimated Precipitation	1327 mm
Mean Annual Temp	5.7°C

This subalpine *Empodisma* fen with scattered *Sphagnum – Epacris* shrub bog occupies a north facing valley near the summit of Mount Scabby on the southern border of the ACT and NSW and fills distinct steps in the floor of the valley formed by boulder lines (Hope and Clark 2008). It is about 300 m long and 100 m wide in the main basin, but steps on the slope above also support restiad fen (Figure 8). It has the best developed pool complex in the ACT, with numerous ponds and hollows which hold water after rain (Figure 9). A small stream meanders through the fen, incised about 40 cm into it with *Sphagnum* shrub bog along the banks. The creek flows northwards across granite slabs to form the Cotter River. The peatland has occupied areas infilled by slope debris and covers old slope deposits that may relate to periglacial weathering during the coldest times in the Pleistocene. The rocksteps may be blockstreams which have brought granite boulders into the valley. The area was formerly used for summer grazing but now lies within a zoned wilderness area. The climate is cold, with snow falling in winter and remaining for lengthy periods.

Species	A	B
Acaena novae – zelandiae	1	
**Acetosella vulgaris*	1	
Aciphylla simplicifolia	1	
**Anthoxanthum odoratum*	1	
Asperula gunnii	1	2
Asplenium flabellifolium		1
Baeckea gunniana		5
Baloskion australe	2	4
Brachyscome scapigera	1	
Brachyscome spathulata	1	
Carex breviculmis	1	1
Carex capillacea		1
Carex gaudichaudiana	1	3
Celmisia paludosa	1	1
Celmisia tomentella	1	
**Centaurium erythraea*	2	
Comesperma retusum		2
Cotula alpina	1	1
Craspedia glauca	2	1
Austrodanthonia alpicola	1	
Austrodanthonia monticola		1
Deyeuxia gunniana		2
Drosera peltata	1	
Empodisma minus	5	3
Epacris breviflora	1	4
Epacris paludosa	2	1
Epilobium billardierianum subsp. cinereum		1
Epilobium billardierianum subsp. hydrophilum		1
Euphrasia caudata	1	
Galium gaudichaudii		1
Galium nigrans		1
Geranium neglectum		1
Euchiton limosus	2	
Gonocarpus micranthus	1	
Hakea microcarpa		2
Hierochloe redolens		2
Hydrocotyle laxiflora	1	1
**Hypochaeris radicata*	2	
Isolepis crassiuscula		2
Juncus brevibracteus		2
Juncus phaeanthus		1
Lagenophora montana	1	
Leptospermum lanigerum	1	
Lobelia gibbosa		1
Luzula sp.	2	1
Lycopodium fastigiatum	2	1
Melaleuca pityoides		2
Myriophyllum pedunculatum		3
Oreobolus distichus	3	1
Oreomyrrhis ciliata	2	
Plantago antarctica	1	
Poa costiniana	1	
Poa sieberiana var. cyanophylla	1	
Pratia pedunculata		1
Ranunculus graniticola		2
Ranunculus lappaceus	1	1
Ranunculus millanii		1
Scleranthus fasciculatus	1	
Sphagnum cristatum	3	4
Stylidium graminifolium	2	
Uncinia flaccida		1
Utricularia dichotoma		2
Wahlenbergia ceracea	1	1
Wahlenbergia communis	1	

Table 7: Taxa noted in the Mire complex
A = *Poa* sod tussock,
B = Restiad fen and shrub bog
* = Introduced weed

Depth (cm)	Sediment
	30 cm of living and compressed *Sphagnum*
0–10	Rootmat and litter (CSBA96 core)
10–115	Humic black peat with little fibrous material
115–135	Peaty clay
125–130	Soft black organic mud
130–140	Yellow grey sandy clayey gravels with scattered rootlets

Table 8: Stratigraphy from the centre of Cotter Source Bog in *Sphagnum* shrub bog

The site lies close to a probable altitudinal treeline with an open low woodland of *Eucalyptus pauciflora* on slopes above the mire but absent from the highest ridge crests which have a tall heath of *Acacia alpina, Kunzea ericoides* and *Hovea montana*. There is a *Poa seiberiana – P. costiniana – Craspedia* sp. tussock grassland zone around the mire, extending under the surrounding snowgum woodland which lies 2 m above the level of the swamp. This zone may be a frost hollow. Scattered bushes of *Olearia algida* and *Asterolasia trymalioides* are restricted to this community.

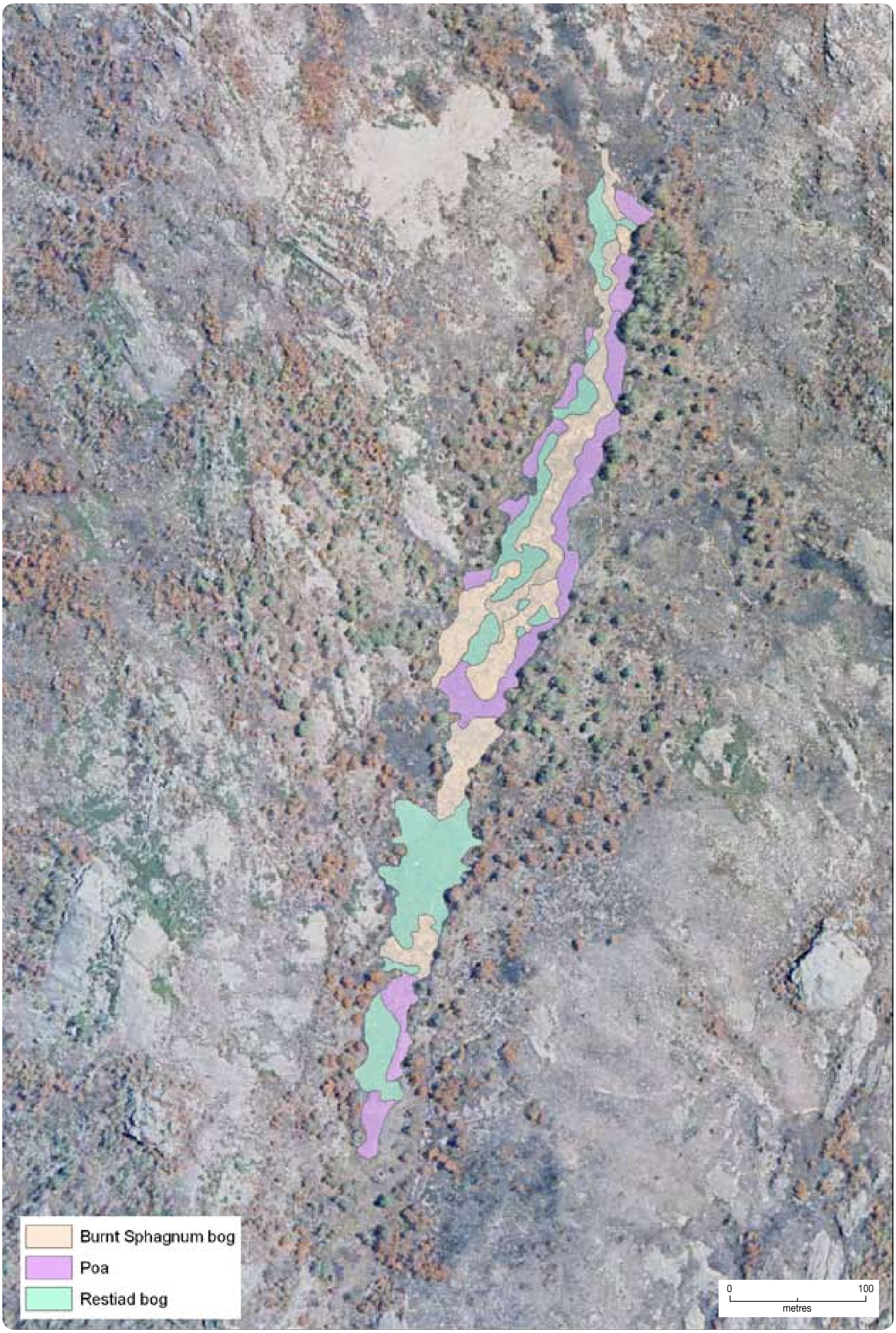


Figure 8: Cotter Source Bog vegetation boundaries

Figure 9: Photograph of Cotter Source Bog showing pool complex. *Poa* tussock is colonising a peat fire area in foreground

The mire is a mosaic of open shrubland over *Empodisma* fen, *Carex* fen, ponds and sod tussock. The shrubland is formed by *Epacris brevifolia, E. paludosa, Melaleuca pityoides, Comesperma retusum,* and *Baeckea gunniana* but there are small areas of *Sphagnum cristatum* hummocks with *Richea continentis*. The more inundated parts of the bog are dominated by the restiad *Empodisma minus* with *Baloskion australe, Oreobolus distichus* and *Juncus* sp. and scattered shrubs. Ponds, 1–4 m across, support a reddish mat of *Gonocarpus micrantha*, with *Ranunculus lappaceus* and *R. graniticola* present, often fringed by *Baloskion australe*. The site lacks the alpine indicator species *Astelia alpina* found elsewhere at this altitude.

Depth (cm)	Age yrs BP	Lab No.	Cal yrs BP	Pretreatment
0–10	100.8 ± 2.6 (Modern)	ANU 10815		Fine fraction peat NaOH insol.
10	40	–	30–50	Pine pollen.
42–48	2600 ± 110	ANU 10816	2505–2810	Fine fraction peat NaOH insol.
61–69	3220 ± 140	ANU 10193	3280–3620	Fine fraction peat NaOH insol.
121–131	9040 ± 80	ANU 10194	10 025–10 270	Fine fraction sandy muds NaOH insol.

Table 9: C^{14} dates from the centre of Cotter Source Bog in *Sphagnum* shrub bog

Depth (cm)	Sediment
0–13	Brown fibrous peat with occasional sand grains.
13–29.5	Black peat with coarse sand.
29.5–44	Black humic peat.
44–47	Sandy gravelly peat.
47–53	Black humic peat.
53–57	Grey peaty clay with abundant fine gravel.
57–65	Yellow mottled grey clayey sand with scattered gravel

Table 10: Stratigraphy of the Cotter Source Bog Margin, core CSBM96

The bog and surrounding slopes showed signs of past fire, with burnt shrubs and trees with fire scars. Some hollows along the creek were eroded, possibly by past stock or wild horse populations, which have now been eradicated. The site was partly burnt in 1983 and 80% burnt in 2003 with small areas of peat fire on dry peat.

Stratigraphy and dating

A transect of cores across the bog at its widest point showed great variability in depth, presumably reflecting an uneven boulder field below (Hope and Clark 2008). Peat was generally shallower on the eastern side, where it overlay a scree slope from Mt Scabby. Coring in 1996 and 1997 sampled a 35 cm layer of fresh *Sphagnum* overlying 115 cm of the humic peat above peaty sandy clays with a base of gravel (Tables 8 and 9). Most of the area has 50 cm of *Empodisma* peat.

These dates show that there may be a relatively complete Holocene sequence preserved in the Cotter Source Bog, with stabilisation to a fen by 10 000 years ago and subsequent development of a localised *Sphagnum* shrub bog.

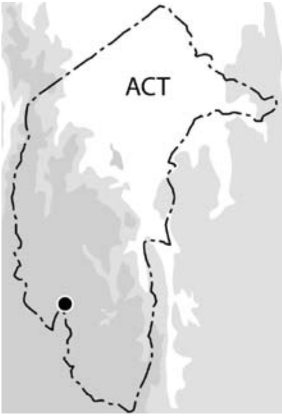
A second section (CSBM96, Table 10) was obtained from a pit dug 8 m from the western margin of the mire under *Empodisma* fen (Hope and Clark 2008). The site was chosen to see if erosion had been sending slope materials onto the bog, as an occupation site had been reported about 30 m up from the swamp.

Pollen diagrams from both sections suggest relatively stable vegetation on the bog over the Holocene. It is possible that the bog has gradually changed from restionaceous-grass bog to a more shrub-rich bog in which *Sphagnum* may have replaced *Empodisma*. The general trend has been towards wetter conditions, indicated by increased *Myriophyllum* and other herbs. *Carex* fen was never dominant, nor did myrtaceous thickets invade. On the surrounding slopes eucalypts are less frequent at the base but a woodland has been present from the start of the record about 9500 years ago. Trees increase in the last 2000 years although the persistence of a composite grassland understorey seems likely. Charcoal is reasonably common throughout but shows apparent fluctuations with a generally reduced influx over the last 2500 years. European disturbance is indicated by pine pollen within the upper *Sphagnum* or *Empodisma* peat. Charcoal influx increases in the surface sample, but the only associated change is an increase in sedges, possibly reflecting trampling in the bog.

A significant inversion in the carbon dates was found in the marginal section suggesting erosional episodes that brought older sediments over younger ones, presumably as a result of fires. Pollen spectra indicate that the bog type also changes, with increased Apiaceae and *Epacris* and reduced *Myriophyllum*. This reflects a drier, more marginal bog type. Above 13 cm the bog has increasing levels of Cyperaceae and shrubs, which are maintained to the present. Within European times charcoal influx increases markedly and grass, which is at surprisingly low levels up to this point, increases also. *Podocarpus* appears in the last few centuries, as it does in the central core, suggesting that both its arrival and subsequent loss are recent phenomena.

During a fire in 1983 bulldozers were brought in from the east to form a track on the eastern side, but otherwise the area has little recent disturbance. In the early 20th century there were feral horses in the Cotter catchment that impacted on stream bank stability. Horses were removed in 1986 allowing ponds to stabilise. There is an active pig control program in the park to reduce impacts of feral pigs. The 2003 fires placed the pond structure at risk from stream incision and a major effort at maintaining the water table and flooding the fen was instituted. This has been successful despite dry succeeding years and the surface is largely revegetated.

Rotten Swamp



Location	35°42'S 148°53'E
Type	*Sphagnum – Epacris* shrub bog with *Empodisma* fen and *Carex* fen
Altitude	1445 m
Area of deposit	28 ha
Area of catchment	240 ha
Max. altitude of catchment	1828 m
Estimated Precipitation	1038 mm
Mean Annual Temp	6.7°C

Rotten Swamp is a subalpine shrub bog which lies at the headwaters of Licking Hole Creek, one km northeast of Mt Kelly in the central-south of Namadgi National Park. It is one of a cluster of *Sphagnum*-shrub bog and restiad and sedge fens along the eastern boundary of the upper Cotter River catchment in the Australian Capital Territory. These saddle and headwater bogs reflect groundwater from surrounding peaks and they experience cold air drainage. Rotten Swamp is surrounded by high granodiorite peaks and has a subalpine climate. Occasional snow and intense frosts are experienced in winter, with parts of the swamp freezing to a depth of 30 cm for up to 3 months.

The swamp is broken into two areas, an upper flat about 28 ha in extent at the headwaters of Licking Hole Creek and a further area of about 7 ha, one km downstream. Both east and west swamp areas are formed on gently sloping colluvial fans which are incised by Licking Hole Creek. Shrub bog development currently occurs on mid-slope positions where groundwater emerges and there are areas of tussock grassland and snowgums on drier areas with bedrock within the flat. *Sphagnum* is scattered but extensive, following streamlines and creek banks (Figures 10 and 11). The valley floor is partly covered by a *Carex gaudichaudiana* fen while *Empodisma* fen is extensive and extends on the northern and eastern slopes beyond the shrub bog areas. The flora is similar to Cotter Source Bog but includes abundant gentians and lilies *(Chionogentiana cunninghamii* and *Arthropodium milleflorum)*.

Rotten Swamp was probably named by pastoralists from the Naas Valley seeking to use it for summer grazing and it may have been partially fenced and drained at some stage. There are no historical records of fires on the swamp before 1983, but it is likely that early settlers burned the area frequently to promote new growth of grass for stock moved into the mountains for summer grazing. Later, fires may have been set by rangers stationed at Cotter Hut (J. Banks, pers. comm.). As well, small lightning fires may have burned the swamp without being noticed or recorded. Low numbers of wild cattle and horses were in the catchment until the 1960s. Rotten Swamp is one of several sub-alpine bogs in the southern part of the ACT partially burned by the Gudgenby fire in January 1983 and again in the more widespread fires of January 2003 (Hope et al. 2005). The bogs were exceptionally dry as the fires followed long droughts. On Rotten Swamp, the 1983 fire was of sufficient intensity to burn into the margins of *Sphagnum* hummocks and, in some cases, to be carried down shrubs and burn out the centres of hummocks. In 2003 the area was completely burnt but the fire was rapid and regeneration of the grassland took place quickly. Some former areas of *Sphagnum* shrub bog are known to have been completely replaced by *Carex* and *Empodisma* fens since these fires, and the presence of *Sphagnum* peat on the floor of the valley under *Carex* fen demonstrates that similar replacement happened at an earlier time. Although the 2003 fire killed almost all areas of surviving *Sphagnum,* limited recovery has occurred. Regeneration trials using shade cloth to encourage *Sphagnum* regeneration were commenced in October 2003 (Hope et al. 2005).

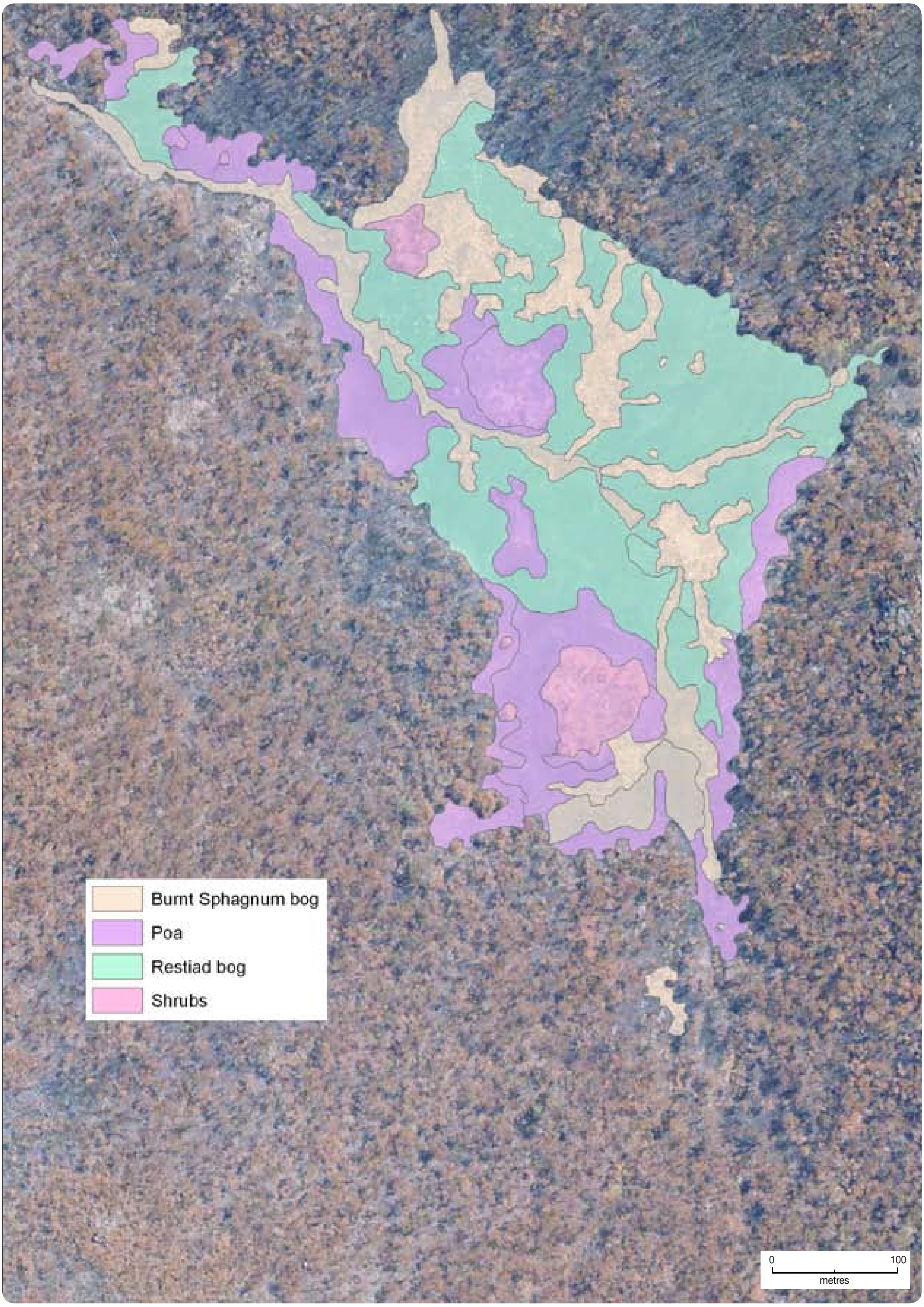


Figure 10: Rotten Swamp vegetation boundaries

Figure 11: Rotten Swamp showing shade cloth on burnt *Sphagnum* areas in 2006

Stratigraphy and dating

A transect of cores taken in 1984 from the northern slope to the Licking Hole Creek revealed the maximum depth of moss and peat to be 150 cm about midway along the transect so a core was collected near this point (Clark 1986; Hope and Clark 2008). The hummock above the peat consisted of 66 cm of *Sphagnum*, grading from scorched fresh material at the top to partly humified at the base. Below were 100 cm of *Sphagnum* peat, increasingly humified with depth, overlying 32.5 cm of sandy gravel, cemented in the lower 13.5 cm. A supplementary basal core was taken 12 m away and found to contain 43 cm of sand and gravel containing two clay layers, the upper of 3.5 cm and the lower of 13 cm. The base consisted of clean gravel. Gravel layers within the peat would have been deposited by streams, such as those that flow between *Sphagnum* hummocks today, but the clay must have settled out in still water. It is likely that water in this area was ponded behind a rock barrier, now covered with peat or organic soil.

The most recent chronology can be inferred from the appearance of weed and exotic pine pollen in the core, marking European impact and the spread of pine in southeastern Australia. The first appearance of pine pollen at 10 cm is probably about 60 years, the top of the peat about 35 years and the top of the hummock about one year. The greater number of large charcoal fragments above 23 cm and the 'fresh', unweathered state of these fragments are probably the result of burning by European stockmen

Depth (cm)	Age C14 yr BP	Lab no	Cal yrs BP	Material
10 (Pine)	40		40 (1910 AD)	Pine appears
20–22	620 ± 110	ANU 9483	545–675	Fine fraction peat NaOH insol
83–88	4570 ± 110	ANU 4227	5065–5425	Bulk peat
99–102	5500 ± 90	ANU 9484	6210–6390	Fine fraction peat NaOH insol
102–130	166.7 ± 4.9%	ANU 9485B	Modern	Sandy clay: Fine fraction NaOH insol.

Table 11: Dating at Rotten Swamp

after about 1850. Three radiocarbon dates show that this section is about 6350 years old (Table 11). An attempt to date the basal gravels, thought by Clark (1983) to probably be older than 10 000 years, failed due to the presence of modern plant materials in the aquifer gravels.

In the fresh peat samples taken for charcoal analyses, *Sphagnum* fragments were found in every sample down to 27 cm and intermittently from there to the base of the peat showing that *Sphagnum* has been growing at the core site throughout the 6250 year period of peat accumulation. *Sphagnum* spores are also present which is of interest because sporing events are uncommon and may reflect a post-fire response in some cases.

Bogong Creek Swamp

Location	35° 45 8'S, 148° 57.4'E
Type	*Carex gaudichaudiana* fen
Altitude	1001 m
Area of deposit	35 ha
Area of catchment	1000 ha
Max. altitude of catchment	1500m
Estimated Precipitation	830 mm
Mean Annual Temp	10.2°C

Species	A	B
**Acetosella vulgaris*		2
Baeckea utilis		1
Blechnum minus		2
Brachyscome scapigera		1
Carex breviculmis		2
Carex apressa	2	3
Carex gaudichaudiana	10	3
**Centaurium erythraea*	1	2
Austrodanthonia eriantha		3
Drosera peltata		1
Eleocharis acuta	2	
Epacris paludosa		1
Epilobium billardierianum subsp. hydrophilum	1	2
Galium gaudichaudii		1
Geranium neglectum		2
Gonocarpus micrantha	2	
Hakea microcarpa		2

Species	A	B
**Holcus lanatus*	1	4
Hydrocotyle laxiflora	1	
Juncus falcatus		2
Leptospermum lanigerum		1
Luzula australasica	1	3
Lythrum salicaria		2
Myriophyllum pedunculatum	2	
Phragmites australis	2	1
Poa costiniana		4
Poa labillardierii		2
Ranunculus fluviatilis	2	1
Ranunculus sp	1	
**Salix* sp	+	
Stellaria flaccida		2

Table 12: Plant List for Bogong Creek
A = *Carex* fen and stream
B = Marginal shrublands
* = Introduced weed

The deep valleys on the eastern side of Namadgi National Park in the Australian Capital Territory contain *Carex* fens overlying large sedge peat deposits of 2–3 m of fibrous peat. Deeper layers consist of humified peat and peaty clays over valley fills of coarse sands which are a source of groundwater that maintains the fen. Bogong Creek Swamp, about 3 km southwest of Gudgenby Homestead, is about 2.5 km in length and appears to have several basins totalling 35 ha. Bogong Creek rises on Mt Gudgenby (ca 1500 m) and has a granitic catchment but after entering the fen it disperses through the sedges with little channeling. The swamp has formed on a gently sloping bench in the jointed granodiorite and is

Figure 12: Bogong Creek vegetation mapping (the pine plantation has since been removed). The entire swamp is *Carex* fen

Depth (cm)	Description
0–24	Fibrous tough rootmat with silt
24–30	Void with sedge roots
30–37	Black fibrous clayey peat
37–45	Dark gray fibrous peaty clay
45–80	Black coarse fibrous peat; small amount clay
80–200	Dark grey-brown coarse fibrous peat
200–284	Black coarse fibrous peat; some silt
284–329	Black organic silty clay (fine fibres some sand and occasional gravels)
329–372	Dark grey clayey coarse sand with gravels
372–380	Dark grey fine sandy silt
380–400	Greyish brown coarse sand (occasional gravels > 5 mm)
400–490	Dark grey changing gradually to black fine sandy clay (occasional sedge fibres and mica and quartz grains present)
490–514	Black sandy clay
514–575	Black organic silty clay
575–577	Grey clayey coarse sand

Table 13: Bogong Creek Swamp Core 2008C

surrounded by slope fans from steep ridges. Granidiorite tors occur around and in the swamp.

Although warmer than the higher altitude *Sphagnum* bogs, in winter the surface 10 cm may become frozen because it occupies an extreme frost hollow, and the actual mean temperature is probably colder than that estimated. The slopes are densely forested by *Eucalyptus dalrympleana* with alpine ash (*E. delegatensis*) on south facing slopes. The margin of the fen is an open *Danthonia* grassland with scattered remnant snowgums. It is likely that the marginal grassland has been extended by fire and grazing because it has been partially cleared and later planted to pine. The swamp itself has been grazed for many years as Gudgenby was grazed from around 1840. The 2003 fires did not affect the swamp and its catchment. Nearby Nursery Swamp was burnt but *Carex* re-sprouted there within a few weeks and erosion did not occur. This recovery indicates that the sedge fens are resistant to fire damage and can recover quickly if still moist.

The water course in the upper part of the swamp has a poorly developed channel with abundant aquatic *Ranunculus* and *Myriophyllum* species, but the fen is a very simple stand of 50 cm high *Carex gaudichaudiana* with only scattered *Hydrocotyle* sp. and *Epilobium* sp. around the sedge bases. In some places the cane grass *Phragmites australis* forms a seasonal element and the cutting sedge, *Carex apressa,* is also present. Numerous weed species have invaded the swamp, including willow, dock and the grass Yorkshire Fog (*Holcus lanatus*) (Table 12).

Stratigraphy and dating

A series of cores showed the presence of separate basins with sandier sediments upstream and organic-rich clays and silts down the swamp. A core taken in the deepest section towards the northern (downstream) end showed that a thick fibrous sedge peat overlay sands and peaty silts (Table 13).

The section may represent one or more phases of peat accumulation which was then oxidised and eroded to leave the black organic-rich clays and sandy layers. Ages of the section are shown in Table 14.

Pollen and charcoal analyses show that the site has been surrounded by eucalypt forest for the past 9500 years and that it has always been a *Carex* fen; However, some *Sphagnum* spores and epacrid shrubs suggest that shrub bog has been able to build up on the margins at times. Charcoal is present in all samples but fluctuates and is relatively low in the past 3500 yrs of rapid peat growth. While gross sediment accumulation rates of the lowest 200 cm are roughly similar to those at Ginini Swamp the much lower organic content shows that the fen has been less productive. Organic build up during the sedge peat phase is impressive, being ca 0.9 mm/year.

Depth (cm)	^{14}C age	SSAMS ANU#	Cal Age BP	Pretreatment
265	2510±40	3610	2515–2700	Fine fraction peat NaOH insol
320	3460±30	3611	3695–3809	Fine fraction peat NaOH insol
405	4290±40	3612	4844–4917	Fine fraction clay NaOH insol
577	9650±60	3613	10 860–11 147	Fine fraction sandy clay NaOH insol

Table 14: Dating of the Bogong Creek Swamp core

Figure 13: Bogong Creek being cored by Nick Porch and Peter Jones in 2008 for palaeoecological study

Peat and Organic-Rich Sediments

Peatland Ecology

Growth of peat deposits

The peat component of a mire will build up only if plant material production exceeds losses due to decay and removal. Whinam and Hope (2005) suggest that Australian montane peat deposits reflect 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, neutral pH, abundant water, light and nutrients and an absence of herbivores. However, the decay rate rises even more quickly with temperature, moderate pH and a good supply of mineral nutrients. In cool, humid climates the rate of plant production is reduced, but a relative absence of decay by soil bacteria and fungi allows accumulation. The breakdown of organic matter creates humic acids but mire plants are adapted to acid peats. In fact they can directly reduce the pH to levels that inhibit competition and limit decay. Parts of a bog may collect litter or grow *Sphagnum* hummocks 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. Short growing seasons and low nutrient supply mean that subalpine peat bogs may be very slow to regenerate, once stripped of vegetation.

Clark (1983) has reviewed growth rates for *Sphagnum* bogs and made observations of surface levels against fixed pins on Ginini Bog 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 in a century; for Ginini Bog the long-term growth rate is 3.5 cm per century. *Carex* fens in extremely good conditions may reach 10 cm per century. For example the upper 25 cm of peat at Nursery Swamp has accumulated in less than 150 years; However, decay and compression result in a long-term accumulation rate of less than 6.0 cm per century of fibrous sedge peat in Nursery and Bogong Creek swamps.

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. 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 in many bogs. 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 & Hargreaves (1983). They found that moss hummocks replaced shrublands several times over 4000 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. However, Good (2004) found that added zinc can lead to *Sphagnum* death some years after application. 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 in the ACT is too slow to allow peat to be 'farmed' on any commercial timescale (Whinam and Buxton 1997). The lack of moss regeneration on the area of Ginini Bog which was harvested in 1942 supports this view; However, the mires can accumulate significant amounts of carbon over time and thus be a component in a sequestration program.

Detecting whether a given peatland has a positive or negative carbon balance requires measurement of carbon flows. The net CO_2 respiration of a peatland ecosystem is measured to detect the balance between photosynthesis and respiration. Methane (CH_4) emissions from breakdown are measured and added to the total of carbon compounds leaving the profile in water flows to obtain a carbon budget. Complex flow models are then applied to estimate carbon flux and balance. Such experiments are difficult to maintain over several years and involve disturbing the system being measured (Limpens et al. 2008). Typically CO_2 net balance is measured on an instrumented 8 m tower which measures vertical and horizontal air velocities while simultaneously sending air to an infrared gas analyser to be measured for CO_2 (Roulet et al. 2007). Methane production is obtained by installing a series of fixed collars which are temporarily covered to allow an air sample to be taken several times per week (Bubier et al. 2005). Continuous stream gauging and automated sampling for dissolved organic carbon (DOC) is also required. Typically such measurements need to be set up semi-permanently and the mire protected with access board walks because of frequent visitation. The necessary resources for such a project have not yet been found in Australia although short-term measurements have been attempted in *Sphagnum* shrub peatlands in Victoria (Grover 2006).

Overseas studies such as that of Roulet et al. (2007) in Canada found large fluctuations in the carbon balance that were related to seasonal variations in the climate. Dry periods led to a reduction of the rate of peat growth and a rise in methane production. In the marginal peatlands of the ACT dry warm phases, particularly hot summers, probably cause most peatlands to record negative growth and become carbon sources. Grover (2006) found that while fresh peat was readily oxidised and lost its structure, this process slowed as the more resistant components such as waxes, phenols, cuticles and carbonised material made up a larger proportion of the peat. Hence the ACT peatlands can be resilient even under such negative growth conditions because the bulk of the deposit has already lost readily oxidisable components.

Hydrology

Raw peat consists of up to 92% water, and peatlands are very efficient at trapping rainwater or surface flow. Peat deposits are important in the subalpine catchments because they moderate runoff and, being

Figure 14: *Sphagnum* peat (0–30 cm Rotten Swamp), Sedge peat below organic clay (200–250 cm Nursery Swamp) and organic silt-clay above basal sands (380 cm Nursery Swamp)

thermally insulating, retain warmer groundwater than would otherwise be the case. Water moves through peatlands as groundwater, in narrow deep channels or across the surface in wide shallow channels floored by depressions; However, the oxidised humic peat at depth has extremely low hydraulic conductivity (Grover 2006) and so the water in the mires is often 'perched' or disconnected from the general water table. This has been demonstrated several times through the recent drought by piezometer measurements at Rotten and Cotter Source bogs. In some piezometers the underlying sands have become dry even though the peatland remained damp and retained water in pools. Western et al. (2008) studied the hydrology of several high altitude bogs in Victoria and concluded that the strong baseflows of peat catchment streams which are maintained into summer reflect storage in the underlying regolith, not releases from the peatland. Their modelling suggests that increasing or decreasing the area and condition of the peatland would have little effect on water yield; However, the very efficient interception of rainfall and the thermal properties that retain snow lie for several weeks longer than surrounding mineral soils were not considered in their study.

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). The *Carex* fens by contrast may have high hydraulic conductivity in the upper two metres of uncompacted fibrous sedge peat but they are similarly 'sealed' by the organic rich clays below. After rain the peat layer may swell and then deflate as water is gradually lost. In the four fens examined in the ACT there is a resistant sedge root mat at the surface and 15–30 cm of clay-rich peat which provides a resistant and tough surface layer. The clays have probably been derived from catchment disturbance by grazing as they have built up through European times.

The retention of moist vegetation and water sources through dry periods means that the mires at all altitudes are critical to the maintenance of biodiversity. They are an important resource for wildlife each summer and may prevent population extinctions across drought cycles.

Peat volumes and carbon storage

The ACT mires preserve characteristic profiles related to their vegetation and history. In Table 15 characteristic values are given for water content and loss on ignition (LOI) based on weighing, then drying, 20 g samples and then igniting them in a muffle furnace at 550°C for four hours. LOI provides

Bog Unit	Typical depth (cm)	Water content (%)	Organic content (% dwt)	Carbon (% dwt)
***Sphagnum* shrub bog (Pengillys Bog, Kosciuszko)**				
Sphagnum moss and litter	30–60	95 est	87.2	40.1
Fibrous *Sphagnum* peat	30–90	85 est	53.6	28.9
Humic sapric peat	20–40	65 est	86.1	53.3
Humic silty sands	10–50	30 est	7.1	5.1
***Empodisma* fen (Cotter Source Bog)**				
Tough sapric peat with rootlets	10–25	80 est	26.5	18
Silty humic peat	20	65 est	32	28
Organic rich clay	15	30 est	9.3	3.9
***Carex* sedge fen (Nursery Swamp)**				
Rootmat often clayey peat	20–35	83.3	37.8	17.6
Fibrous sedge peat	250–300	73.4	53.4	22.0
Organic rich silty clay	100–250	41.5	14.1	4
Humic silty sands	20–40	18.5	4.5	0.6
Sod tussock *Poa* grasslands				
Organic clay	20–40	35 est	8	3.5

Table 15: Organic and water content of mire peats and sediment based on average measurements in profiles

Area	Total mire Area (ha)	*Carex* peat (m3)	*Sphagnum* peat (m3)	*Empodisma* peat (m3)	Organic clays (m3)
Namadgi > 1400 m	226.7	50 400	1 039 500	164 250	906 800
Namadgi 600–1400 m	346.6	5 518 000	36 200	105 200	3 466 000
ACT ex Namadgi	9.3	27 900	0	0	93 000
ACT Total	573.3	5 596 300	1 075 700	269 450	4 465 800

Area	Total mire Area (ha)	*Carex* peat (as carbon t)	*Sphagnum* peat (as carbon t)	*Empodisma* peat (as carbon t)	Organic clays (as carbon t)
non-water		*0.25*	*0.13*	*0.22*	*0.8*
Dry density		*0.65*	*0.65*	*0.75*	*0.9*
C content		*0.25*	*0.45*	*0.28*	*0.04*
Factor		*0.0406*	*0.0380*	*0.0462*	*0.0288*
Namadgi > 1400 m	226.7	2 048	39 527	7 588	19 587
Namadgi 600–1400 m	346.6	224 169	1 377	4 860	69 875
ACT ex Namadgi	9.3	1 133	0	0	2 678
ACT Total	573.3	227 350	40 903	12 449	92 140

Table 16: Estimated peat volumes and carbon content of ACT Mires. Note: t = Carbon tonnes

an estimate of the organic content of a sample. Carbon content has been directly measured in some cases with CNH infrared gas chromatography but it can be estimated from LOI measurements by assuming that carbon is ca 0.35–0.48 of the mass of dry organic material.

Very general estimates of mire volume can be constructed from the above values by applying them to the area estimates for fen types (Table 16). These suggest that wet peat volume (*Carex*, *Sphagnum* and *Empodisma*) is 6 940 000 cubic metres. This can be converted, allowing for water content and carbon content averages derived from actual measurements on ACT sediments, as equivalent to 280 000 tonnes of elemental carbon. An additional 92 000 tonnes may be contained in the organic clays below the peats but the conversion factors are not well established.

It can be seen that the large sedge fens hold the bulk of the peat and carbon in the ACT even though the carbon content is lower in the sedge peat than in the bog peats (Figure 14). Although *Empodisma* fen is only slightly less extensive than *Sphagnum* shrub bog it occupies far less peat, reflecting its more marginal position on shallow peats on slopes.

Mire histories

Macroremains of the swamp vegetation are the basic components of peat and their variation through a deposit provides a good record of any changes at the site. Fossil pollen and spores which derive from both local and regional sources are also well preserved in a peat medium and may indicate regional environmental changes. Charcoal from fires on the swamp or washed in from catchments can provide an indication of fire frequency. Gravel or sand layers associated with charcoal are evidence of slope erosion following catchment fires. Preliminary analyses are available from cores and sections from nine dated sites in the ACT and these data provide a general indication of the formation of the mires and their subsequent growth.

Age of the peatlands

Current research suggests that the peatlands in the ACT post-date the last period of glaciation which occurred from 26–16 000 years ago (Barrows et al. 2002) and owe their origin to the post-glacial

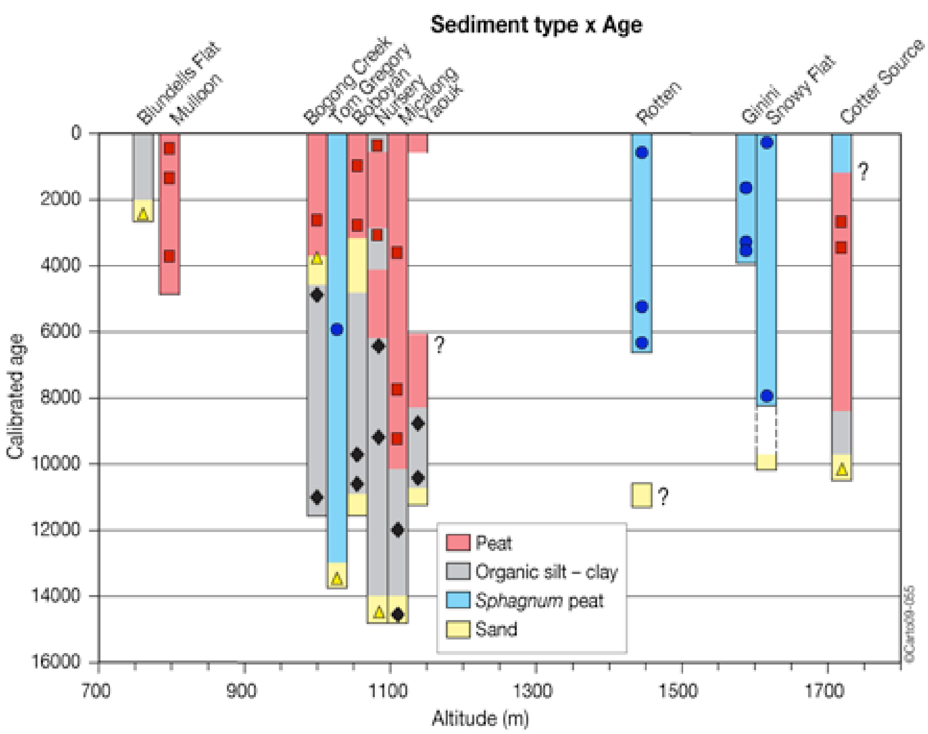


Figure 15: ACT and region dated sections by sediment type and altitude (Dated levels are indicated by the following: triangles = sand; diamonds = organics in silts; circles = *sphagnum* peat; squares = sedge peat fine fractions)

amelioration of climatic conditions. At the end of the Pleistocene about 14 000 years ago, the ACT lay above the treeline and montane streams were infilled by sands and gravels from active screes and bare slopes. Increasing temperature and precipitation stabilised the catchments allowing the establishment of tussock grasses and swamp plants on the river flats. The plants blocked streams and built up a layer of litter. Where conditions were wet enough organic breakdown slowed and peat accumulation followed. Table 17 shows basal dates from mires in the ACT and surrounds.

There is no clear correlation between the onset of peat formation and altitude in the ACT region confirming the observations of Kershaw and Strickland (1989) for the southern alps. While the oldest dates of ca 14 500 in the ACT come from Nursery Swamp and Tom Gregory Bog at 1100 m, early sites at 14–15 000 BP occur at all altitudes in the region and must reflect topographically favourable locations for early peat build up. Since most deposits are floored by gravels, sands or clays it is likely that peat-forming vegetation moved onto old slope deposits when these ceased to form. By 10 000 BP peat formation had commenced at Cotter Source Bog so we can conclude that slopes had become increasingly stabilised between 15 000 and 10 000 years ago. Dated pollen sequences from the Mt Kosciusko area show that forest vegetation developed in the region after 11 000 BP while in alpine sites around 2000 m original fjellmark was replaced by alpine herbfields or heaths by about 9500 BP (Martin 1999). At Bega Swamp, near Nimmitabel, the main early Holocene forest expansion occurs around 10 500 BP, with increased *Eucalyptus*, *Casuarina*, *Pomaderris* and *Cyathea* (Donders et al. 2007). A mid-Holocene wet phase, characterized by expansion of wet heath and ferns, started around 7500 BP, followed by eucalypt expansion and drier conditions after 3500 BP. Short centennial alternations between wet and dry taxa can be observed in the record. After 1700 BP assemblages remained relatively stable until, around 1850 AD (100 cal yr BP), forest cover slightly declined due to European grazing and deforestation.

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. However loss of early deposits may have been a factor at some sites.

Site Name	Locality	Alt (m)	Depth (cm)	Date (cal years BP)	Lab Number	Material	Source
ACT sites							
Lower Naas	Naas valley	640	430	14 000±2150	NR02014a	OSL sand	Eriksson et al. 2006
Blundells Flat	Condor Crk	762	190	2430 ± 70	Wk17023	Charcoal	Hope 2006
Bogong Crk Swamp	Gudgenby River	1000	577	11 005 ± 145	SSAMS-ANU 3613	Peaty sand	Hope unpubl.
Tom Gregory Bog	Upper Cotter	1024	240	13 455 ± 255	ANU 12023	Peat	Hope 2006
Nursery Swamp	40 km SW Canberra,	1092	298	14 470 ± 375	OZI 144	Peaty clay	Hope unpubl.
Boboyan Swamp	Upper Naas River	1154	535	10 515 ± 65	SSAMS-ANU 8311	Peaty silts	Hope unpubl.
Rotten Swamp	Northeast of Mt Kelly	1445	60	6300 ± 90	ANU 9484	Peaty sand	Clark & Hope 2008
Ginini Flat W-Trench	Mt Ginini	1592	110	3520 ± 80	GRN 249l	Sphagnum peat	Costin 1972
Ginini Flat W-core06		1590	128	3305 ± 50	Wk18654	Peaty clay	Hope unpubl.
Snowy Flat	Mt Gingera	1618	205	7950 ± 65	ANU 11464	Muck peat	Hope 2006
Cotter Source Bog	Mt Scabby	1720	115	10 150 ± 125	ANU 10194	Peaty sand	Clark & Hope 2008
NSW Sites							
Mulloon Swamp	25km W of Braidwood	799	345	3710 ± 115	ANU 10753	Peaty clay	Hope unpubl.
Micalong Swamp	35 km E Tumut	1100	390	14 550 ± 495	ANU-3342	Sedge peat	Kemp 1993
Yaouk Swamp	Scabby Nature Res.	1100	195	10 415 ± 80	ANU 11439H	Peaty clay	Keany unpubl.
Rennex Gap	Mt Kosciuszko	1575	150	12 470 ± 220	ANU-2177	Humic peat	Hope unpubl.
Club Lake fen	Mt Kosciuszko	1955	265	11 140 ± 245	SUA-1259	Peaty silts	Martin 1986

Table 17: Earliest dates for the initiation of sedimentation in ACT and nearby sites. Ages differ from those shown in Hope (2006) as they are calibrated by CalPal software and updated in some cases

Mid-late Holocene peatlands

Given the generally suitable conditions through the Holocene for peat accumulation, the very young ages for the initiation of peat growth at Rotten Swamp, Ginini Flat (West) and for peaty alluvium at Blundells Flat require an explanation. It seems likely that Ginini Flats and Rotten Swamp may have lost possible earlier Holocene fills. Both peatlands rest on gravelly slope deposits of probable late Pleistocene age. The dated *Carex* fens such as Nursery Swamp have preserved humic clays with bands of peaty silts during the early-mid Holocene (10 000–3500 BP). This phase is sometimes capped by lenses of sand. The fens then enter a phase of expansion of the peatland and rapid growth of fibrous peats over the last 3500–2700 years. Figure 15 plots the available radiocarbon dates for the ACT swamps and nearby deposits (Micalong Swamp, Yaouk Swamp, Mulloon) by the sediment type. While peat growth commences in some sites before 3500 cal years ago, the sand layer lying above early Holocene peaty silts shows up clearly. After this time peat accumulation becomes widespread and is in close agreement with the initiation of *Sphagnum* bog expansion at Ginini Flat.

The peatland histories also seem to broadly correlate with alluvial fill and cut cycles in the region. At 640 m in the lower Naas valley Eriksson et al. (2006) dated basal gravels to 14 000 cal year BP, but no early Holocene sediments (11 000–4000 BP) have been preserved. The major phase of alluvial buildup, infilling the valley with broad terraces of silt and sand alluvium, occurs from 3300–900 cal year BP.

The commencement of alluvial build up at Blundells Flat (760 m) before 2500 BP seems to be part of this phase. To the east of Canberra, Mulloon Creek (790 m) has similar Late Pleistocene alluvial fills with any early Holocene sediments removed prior to the commencement of peat formation that has built up 350 cm of sedge peat over the past 3800 years (Johnston and Brierly 2006). The peat growth was relatively aggressive as it covers stumps of *Eucalyptus sp*. Cohen and Nanson (2007) demonstrate that this pattern of an early Holocene 'gap' in alluvial deposits followed by a post 3500 BP build up of terraces is common in the highlands of southeastern Australia. They tentatively ascribe the period in the alluvial record with few or no dated alluvial deposits to an increase in water discharge but a decline in sediment yield (hence a marked increase in transport capacity accompanying little alluvial deposition). The absence of sediment supply would result from well-vegetated catchments. Such conditions of increased rainfall and decrease in evaporation should, however, accord with peat formation in the mires. The lack of much preserved peat and late initiation of some sites suggests that periods of drought and fire limited peat bogs in the early Holocene and may have eroded or oxidized deposits at times.

Fire Histories

Evidence for past fire in the mires is obtained from charcoal fragments preserved in the peat. All records contain some charcoal which may come from catchments or the burning of mire vegetation. Peat cores from *Sphagnum* bogs are of particular interest because they do not generally accumulate washed-in charcoal so that each record is a measure of strictly local fires. In general, the available records shows that fire has been present throughout the history of the ACT peatlands so it is not surprising that they are resilient to burning provided the underlying peat is moist. The most detailed record of charcoal comes from Rotten Swamp where Clark analysed 480 samples for microcharcoal (Hope and Clark 2008). Figure 16 shows this record with low resolution records from other sites for comparison.

The curve shows considerable cyclicity with phases of high charcoal influx at 6200–5700, 3900–1800 and 700–150 BP. The lowest fire phase is from 5500–3900 BP except for the last 80 years when influx has also been very low. These features may be present in the low resolution records from Cotter Source Bog and Nursery Swamp but such correlation remains speculative without further analyses. These charcoal records may record both large and minor fires and well-dated high resolution records from several sites will be needed to see if a regional pattern emerges. Worthy (2006) analysed sand layers from Coronet

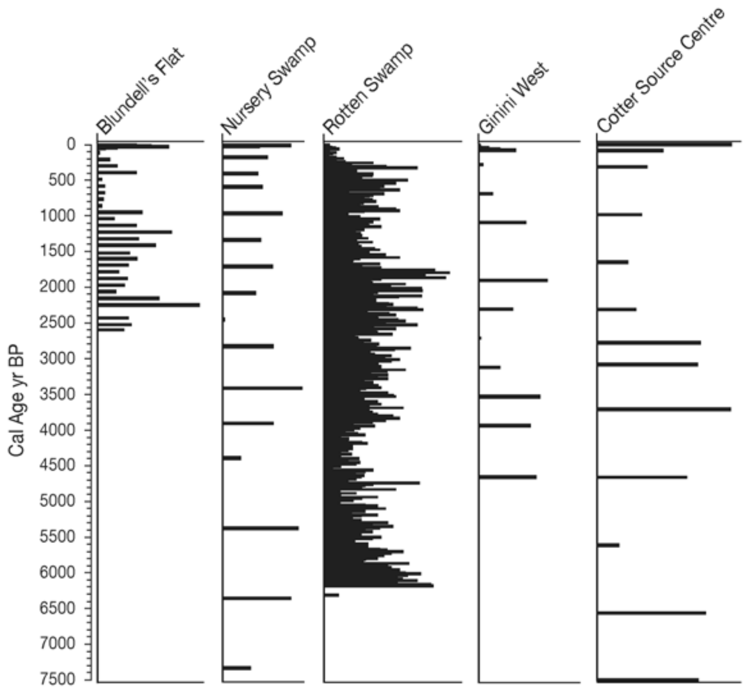


Figure 16: Charcoal records from Rotten Swamp and selected sites over the last 7500 years

Creek and the upper Cotter which he interprets as resulting from catchment erosion following fire events. He found significant build up at one or both sites at 410–440, 1100, 3800, 5400 and around 6500 years ago. These reflect significant 2003-scale fire events but the erosional response to the 2003 fires was very patchy and hence the sedimentary records are not a complete set of serious fires.

Zylstra (2006) compared a charcoal record from Club Lake on Mt Kosciuszko to climatic fluctuations. He suggests that there is a strong climate control on fire in that the charcoal record reflected the cooler times of the Little Ice Age (300–100 BP) with lower influx. The warm periods saw higher charcoal influxes, although fire supression over the past 60 years has reduced this peak. At this stage the Rotten Swamp record shows irregular but generally increased fire in the Little Ice Age period. In the ACT, fire is more likely to reflect the degree of variability in climate which is thought to have altered through time. Annual coral records of oxygen isotopes from the Huon peninsula of PNG show damped El Niño magnitude and decreased El Niño frequency from 7600 to 5400 years BP and both extreme (2 times the amplitude of the 1997–1998 event) and prolonged (4–7 years) El Niño events between 2500 and 1700 years BP (Gagan et al. 2004; McGregor and Gagan 2004). While the history is different to southeastern Australia these changes indicate the possible range of variability that the ACT mountains have experienced. These events have a strong influence on the spread of fires and their penetration of normally moist forest.

A feature of the last few centuries in several charcoal records (Cotter Source, Rotten, Snowy Flat, Top Flat) is a rise in charcoal influx that coincides with the appearance of weed pollen, indicating European arrival (Figure 17). These peaks then decline to historically low values in the 1920s after exotic pine pollen becomes significant. The records thus seem to reflect widespread deliberate ignition associated with grazing practices of the late 19th century followed by fire suppression in the catchments in the 20th century. Zylstra (2006) finds a similar result based on tree ring records of fire scars from Mt Ginini. One interesting correlation is for reduced *Sphagnum* spore incidence associated with the charcoal peaks and increased *Sphagnum* spore levels at low fire frequencies, seen in the Rotten, Ginini and Snowy Flat records. At Snowy Flat very rapid *Sphagnum* growth occurs in the low fire phase following catchment protection. Pine pollen is evident at 70 cm depth demonstrating expansion of the cushion by this amount in about 70 years. Under compression this probably equates to about 4–7 cm of fibrous moss peat or about 2–3 times the long term accumulation rate determined at Ginini (West).

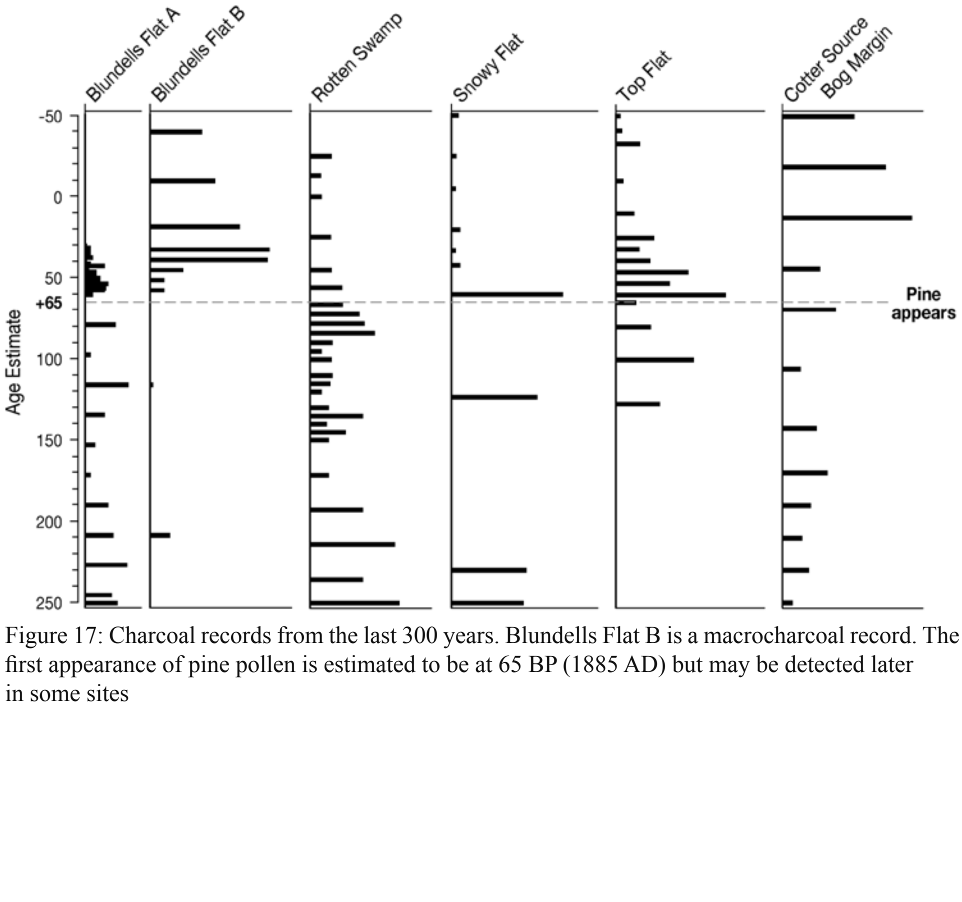


Figure 17: Charcoal records from the last 300 years. Blundells Flat B is a macrocharcoal record. The first appearance of pine pollen is estimated to be at 65 BP (1885 AD) but may be detected later in some sites

Management Considerations

While the peat-forming mires of the ACT cover only 0.4% of Namadgi National Park they have received substantial management attention and expenditure because of their critical role in biodiversity maintenance and perceived fragility in the face of disturbance, fire, and climate warming expressed as reduced summer rainfall and increased temperature and radiation loads. The long-term goal of management is to maintain biodiversity and geomorphological stability of the catchment in order to maximise the resilience of the ecosystems. It is extreme events, such as severe fire, extreme drought, and 100 or 1000 year precipitation events which cause major landscape change. The best defences against these events are balanced, diverse and fully functioning ecosystems that provide cover, seed or germination stores for recovery.

The peat-forming mires are unusual in retaining their own history of gradual accumulation since the last event that exceeded their capacity to resist destruction. Their status (increase, maintenance or decline) is thus a measure of the effectiveness of management in the face of environmental variation caused by both natural and human processes. Given that Namadgi must be managed to protect natural values, active management of mires aims to re-inforce natural processes of vegetation succession and retention of sediment stores. Control of access, feral animal control and fire supression are included in the plan of management for the park and in consultations with relevant land managers in NSW.

Stability and threats

The ACT peatlands have survived in a difficult environment but are liable to change in a number of ways (see Table 18).

Change	Possible Causes	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 e.g. *Sphagnum*, weed growth
Increased drainage	Gullying or drains; growth of trees; pig rooting	Growth ceases, top layers dry out, become water repellent, liable to fire
Clearance in catchment	Agriculture or forestry; roading	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 foot traffic	Infiltration reduced, increased surface runoff and erosion, elimination of taxa
Loss of surface peats	(1) Fire following lowered watertable	Peat fires that are slow but not hot, totally kill all surface plants, erosion follows
	(2) Oxidation	Peat decays to ash, and becomes compacted 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

Table 18: Peatland Instability

Fires can totally remove peat deposits and are very difficult to stop once established. The experience of the ACT 2003 fires showed that damp peat will not burn but that peats that had dried out would burn completely. Small areas of dried peat burnt at Ginini, Snowy Flat, Top Flat and Cotter Source bogs and in a drained fen area near the upper Naas (Figure 18). Except for Snowy Flat the peat had dried because of drains or disturbance to water flows. The *Carex* fen at Sheep Station Creek had dried in 2003 but fortunately was not burnt as the upper metre of sedge mat may have been destroyed.

Increased drainage also allows peat to oxidise and become compressed. Collapse of peat surfaces by up to 30% of total volume can follow drainage of sedge fens and fibrous peat will decay to organic loams. However, fibrous peat is quite resistant to streamflow erosion. Ditches cut in Mulloon Swamp still retained the scoop marks after 12 years, although the ditches have precipitated headward erosion. Headward erosion, in which large blocks of peat fall into gullies as they propagate headwards, has removed large parts of fens and bogs on the Monaro, for example Jacksons Bog near Delegate NSW. Drains or holes in peat swamps permit large amounts of groundwater to flow rapidly through the trench sides. Catastrophic peat losses are known to occur when undercutting of the trenches is followed by slumping. Because peat is light and easily transported, the slumped material is washed downstream and further slumping can then occur. This does not seem to be a problem in the shallower subalpine bogs.

Trampling by stock compressing the soft surface of a mire may prevent the watertable from being maintained near the surface and their trackways may drain the mire. This renders the peat liable to burning and erosion following surface drying. Stock will feed on the soft herbs between hummocks and cause changes in species composition, and an increase in shrubbiness or tussock, as shown by Wimbush and Costin (1979) on Mt Kosciuszko. In the ACT the main risk is from horses and pigs. McDougall and Walsh (2007) echo these concerns, noting that pig rooting exposes peats and dries them and that horses break down stream banks and pond edges. Pig and horse populations are causing fen and bog decline in northern Kosciuszko National Park adjacent to Namadgi (Figure 19).

The ACT peatlands are delicately balanced, and relatively minor environmental changes may have large responses. In the nomination of *Sphagnum* bogs as endangered communities DEWHA (2009) states:

> The main identified threats to the Alpine *Sphagnum* Bogs and Associated Fens ecological community include fire, exotic weed invasions, grazing and trampling by non-native animals, tourism and increased human infrastructure. These threats all severely impact on the structural and functional integrity of the ecological community, as well as its already limited geographic extent. The other significant threat to the Alpine *Sphagnum* Bogs and Associated Fens ecological community is climate change. Australia's alpine and subalpine regions face growing pressure as a result of warmer temperatures. Even a small increase in mean ambient temperature is likely to result in the loss of more bogs and fens due to changes in snowfall and snowmelt regimes (Pickering et al. 2004).

In a survey of *Sphagnum*-dominated communities in the ACT and NSW, Whinam and Chilcott (2002) noted that their extent had declined over the past 40 years due to an apparent decline in available water and that summer bleaching of hummocks had become more pronounced. The ACT, having a relatively lower rainfall than the subalpine areas of NSW and Victoria, is likely to experience more contraction of bog extent and its conversion to *Empodisma* fen or sod tussock. One expression of climate change may be increased variability leading to periods of drought and increased likelihood of lightning strikes during extreme fire weather. Increased fire frequency will also lead to retreat of the bogs and elimination of fire sensitive elements, especially *Sphagnum cristatum*. As we have seen this moss controls bog processes, and its recolonisation of new sites is very slow.

Rehabilitation

The ACT has been in the forefront of attempts to trial rehabilitation methods for mires affected by the 2003 fires, which burnt almost all the peatlands. Observation after the fires suggested that prevention of erosion was the most critical concern together with re-wetting areas of peatland that appeared to be drying out.

Figure 18: Peat fire damage at Top Flat showing bank collapse in 2004. The partially burnt board is a barrier placed after the 1983 fire

Figure 19: Extensive horse damage has collapsed stream banks and wiped out a former *Sphagnum* bog at Dunns Flat NSW, only 2 km from Murray Pass ACT

Figure 20: a) Straw bales in stream lines at Cotter Source Bog in 2003. b) Coir logs at Cotter Source Bog in 2007

Namadgi, along with Kosciuszko National Park trialled the use of steam sterilised straw bales to block stream ways and spread water onto the peatland at several *Sphagnum* shrub bog sites, notably Rotten, Little Bimberi and Ginini and the pool complex at Cotter Source Bog on Mt Scabby (Good 2006). Coir 'logs' were later introduced as they lasted better and could be tailored to fit variable gaps (Figure 20). These

Figure 21: Shade cloth removed for monitoring at Rotten Swamp, March 2007

barriers are intended to emulate the growth of vegetation and peat by choking small channels, and thereby save decades or centuries in repairing erosion damage. They also may prevent instability that would see headward erosion and the loss of sediments from a catchment. Materials used are intended to gradually degrade and be overgrown by the mire. The choice of straw bales was made after a trial of marine plywood barriers at Top Flat and Rotten Swamp following the 1983 Gudgenby fire. The plywood did not effectively block channels that had permanent flows (T. MacDonald personal communication, Figure 18), but did allow peat accumulation across small drainage lines at Top Flat. At Blundells Flat Ecowise ACT has proposed the installation of permanent barriers, using rock gabions to spread water across the flat. These will trap sediment and re-wet the mire.

More experimental has been the post-fire temporary use of 70% shade cloth to cover burnt *Sphagnum* shrub bog. The cloth can be removed once shade plants have regenerated, usually 2–3 years. Trials were undertaken after the 2003 fires at Ginini, Rotten and Cotter Source Bogs (Figure 21). The effectiveness of this technique is still being assessed (Whinam et al. in press) but a comparison of adjacent treated and untreated areas showed enhanced moss regeneration and regrowth of shrub and restiad cover. A major effect seems to be the maintenance of a humid layer under the cloth, limiting bleaching of the moss in summer and enhancing growth rates. Re-measurement of study plots will show if this effect has long-term benefit in accelerating regeneration.

In addition to shade, the effects of moderate fertiliser application is being tested at Snowy Flat at permanent plots set up in 2003. A light application of Osmocote low phosphorous fertiliser has not led to statistically significant response due to the extreme heterogeneity of the test plots. It is likely to be most useful on lightly burnt sites to enhance *Sphagnum* growth but does not assist on severely burnt plots.

Sphagnum is readily killed by fire and has been shown to have retreated from former areas such as parts of Rotten Swamp after fire (Clark 1986). As its re-colonisation is extremely slow the possible role of transplants has been investigated (Hope et al. 2005; Whinam et al. in press). Slabs of *Sphagnum* bog, 25 cm square and spade-depth were taken from live bog and inserted in holes in burnt bog. Variable results have been achieved but the most successful have been in minor stream ways, and when placed in hollows in burnt bog that are shaded or given litter shading. Invasion of the transplant by grasses and

Figure 22: Little regeneration and failed sedge transplants after five years at Ginini Flat West.
Peat collapse means that water now flows under the peat

Juncus species has been a problem except in very wet areas. The transplants have also allowed shrubs and restiads to develop. *Empodisma* mats transplant well and were used to regenerate pond barriers at Cotter Source Bog. An attempt to transplant *Baloskion australe* into ponds at the same site failed (D. Whitfield personal communication). Dry burnt peat areas, such as the formerly harvested surface at Ginini Flats, have proven resistant to transplanted sedges and grasses probably due to hydrophobic properties of the peat (Figure 22). Advanced peat tube stock may be necessary to allow the plant to reach the water table, now below the peat layer.

Transplanting holds some promise in returning bogs to their known former extent (Figure 23); However, transplants should have local provenence and some bog areas may not have remaining healthy mire to provide materials. The occurrence of delayed natural regeneration of *Sphagnum* up to three years after the fire suggests that transplanting may be left until the long term loss of shrub bog is apparent. As such programs would be carried out at individual bog scale, good mapping of former *Sphagnum* boundaries is essential.

Fire protection

It is hard to see how the mires can be directly protected from fire during large events such as the January 2003 bushfires although they could be made a target for individual fire supression efforts if conditions are suitable. Unlike some forest areas, fire on peatlands tends to proceed slowly and to take a long time to consume the vegetation (Figure 24). A team may therefore be able to put out spot fires and break fire fronts using local water sources, with the aim of achieving a mosaic burn. Protection of 'islands' of intact bog will enhance overall mire recovery after the fire. Sections of riparian vegetation might also be protected to maintain stream integrity. The occasional use of fire retardent on bog margins should not have long-term effects (J. Whinam personal communication) and might be used to hinder fire entry to bogs. By contrast fens do not need special measures, unless the fen has dried out.

Figure 23: Successful *Sphagnum* transplant after 4 years in the ditch at Ginini Flat West

Accordingly fire plans are needed for selected individual mires that assess the most valuable elements and best means for protecting them, together with 'assets' such as stream barriers and resources such as stream ponds. The possibility of modifying marginal vegetation to act as buffer zone might be considered but this raises ecological questions for fauna utilising the mires, such as the Corroboree Frog. Monitoring of mire condition is needed to keep the strategies up to date and identify risks such as drying of surface peats. The best overall protection for the mires is the retention of available moisture. This may require the installation of temporary artificial barriers in streams and by growing the mire vegetation across drainage lines. Feral animal control is an important aspect for achieving mire resilience.

Knowledge gaps

While the areal extent and location of peat-forming mires in the ACT is now reasonably well established we have only a preliminary idea of the stratigraphy and peat characteristics. We also have mainly anecdotal evidence for historical changes to the extent of mires. The mapping of the mires and their vegetation boundaries to 2003 as a reference year is the first stage in understanding the dynamics of these systems. Mapping against older air photo sources, maps and former peatland extent established by analysis of sediments could be used to establish the pre-European extent and historical changes in the dominant vegetation of the peatlands. As an example, the assessment of apparent *Sphagnum* peat under the extensive valley bottom fen at Rotten Swamp could be checked for indicator fossils and dated to establish the former extent of shrub bog. This would then provide a target for rehabilitating the mire to its former extent. Future mapping against the 2003 boundaries will allow management success in maintaining or expanding mire area to be quantitatively measured. There is potential for further modelling research to assess the environmental controls on mire formation and persistence. This could include studies of the microclimate of the mires and their catchments.

Figure 24: Fire front entering Ginini Flat West on 16th January 2003 (Photo Geoff Cary)

We do not know whether the mires are currently carbon sinks or sources although the historical data suggests that under present management the bogs and especially the fens have good potential to act as sinks. More precise historical data is needed, involving high resolution analysis of a range of proxies (i.e. pollen, charcoal, testate amoebae, algae) supported by detailed chronology. The mires are appropriate as study sites for carbon balance studies as they are likely to be very sensitive to climate variability. Although not highly accessible, the mires are the closest in mainland Australia to groups with the capacity to undertake such research (e.g. ANU, University of Canberra or CSIRO). Refinements of the carbon balance estimates need to be combined with improved estimates of the carbon held in the mires to allow the mires to be included in a total carbon budget for the ACT.

Long-term monitoring of plant ecology at a limited number (50) of mire sites has been commenced and this program should be extended and possibly expanded to non-*Sphagnum* mires. Further testing and monitoring of rehabilitation methods is desirable together with ongoing assessment of the rehabilitation works already carried out in 1983 and 2003–8. The instrumentation of some mires with weirs and piezometers recording to data loggers would allow the water balances to be assessed in relation to climate change. There are detailed daily meteorological records from several sites in the Cotter catchment held by the water authority which would provide valuable modelling inputs if they could be made available publically.

Education of the public about the mires and their unusual historical archives has been commenced with information boards and displays. There may also be scope for board walks and on-site interpretation in both fens and bogs. The negative perception of mires as ‘waste land’ should be replaced by a new appreciation of the fascinating processes, environmental services and aesthetic highlights of these natural treasures of the ACT.

Figure 25: Poster at the Namadgi Visitors Centre, Tharwa which interprets peatland and restoration issues to the public

Vascular Plant Species Recorded in the ACT Mires

List based on quadrat data from Helman, C. E. and Gilmour, P. M. (1985) and Helman et al. (1988) together with additional records. Names have been updated to conform with Lepschi et al (2008).

* Introduced. SA = Subalpine bogs and fens   M = Montane fens

	FERNS and FERN ALLIES		
ASPIDIACAE	*Polystichum proliferum* (R. Br.) Pr.		M
BLECHNACEAE	*Blechnum penna-marina* subsp. *alpina* (R.Br.) T.C.Chambers & Farrant	SA	M
BLECHNACEAE	*Gleichenia dicarpa* R. Br.	SA	
GRAMMITIDACEAE	*Grammitis billardieri* Willd.	SA	
LYCOPODIACEAE	*Lycopodium fastigatum* R. Br.	SA	M
OPHIOGLOSSACEAE	*Botrychium australe* R. Br.	SA	

	ANGIOSPERMS-MONOCOTYLEDONS		
ANTHERACEAE	*Arthropodium milleflorum* (DC.) Macbride	SA	M
CYPERACEAE	*Baumea gunnii* (Hook. f.) S.T. Blake		M
CYPERACEAE	*Carex appressa* R. Br.	SA	M
CYPERACEAE	*Carex blakei* Nelmes	SA	
CYPERACEAE	*Carex breviculmis* R. Br.	SA	M
CYPERACEAE	*Carex capillacea* Boott	SA	
CYPERACEAE	*Carex fascicularis* Soland. ex Boott		M
CYPERACEAE	*Carex gaudichaudiana* Kunth	SA	M
CYPERACEAE	*Carex inversa* R. Br.	SA	
CYPERACEAE	*Carex polyantha* F. Muell.		M
CYPERACEAE	*Eleocharis acuta* R. Br.	SA	M
CYPERACEAE	*Eleocharis gracilis* R. Br.	SA	M
CYPERACEAE	*Gahnia subaequiglumis* S.T. Blake	SA	
CYPERACEAE	*Isolepis crassiuscula* Hook. f.	SA	M
CYPERACEAE	*Isolepis fluitans* (L.) R. Br.		M
CYPERACEAE	*Isolepis habra* (Edgar) Sojak		M
CYPERACEAE	*Isolepis montivaga* (S.T. Blake) K.L. Wilson	SA	
CYPERACEAE	*Isolepis subtilissima* Boeck.	SA	M
CYPERACEAE	*Oreobolus distichus* F. Muell.	SA	
CYPERACEAE	*Oreobolus oxycarpus* S.T. Blake subsp. *oxycarpus*	SA	M
CYPERACEAE	*Schoenus apogon* Roem. et Schult.		M
CYPERACEAE	*Uncinia flaccida* S.T. Blake	SA	
ERIOCAULACEAE	*Eriocaulon scariosum* Sm.		M
HYPOXIDACEAE	*Hypoxis hygrometrica* Labill.		M
JUNCACEAE	*Juncus australis* Hook. f.	SA	M
JUNCACEAE	*Juncus brevibracteus* L. Johnson	SA	M
JUNCACEAE	*Juncus falcatus* E. Meyer	SA	M

JUNCACEAE	*Juncus filicaulis* Buchen.		M
JUNCACEAE	*Juncus holoschoenus* R. Br.		M
JUNCACEAE	*Juncus phaeanthus* L. Johnson	SA	M
JUNCACEAE	*Juncus sandwithii* Lourteig	SA	M
JUNCACEAE	*Juncus sarophorus* L. Johnson	SA	M
JUNCACEAE	*Juncus subsecundus* N.A. Wakef.		M
JUNCACEAE	*Luzula australasica* Steud.	SA	M
JUNCACEAE	*Luzula australasica* x *L. novae-cambriae*	SA	M
ORCHIDACEAE	*Diuris monticola* D.L.Jones	SA	M
ORCHIDACEAE	*Prasophyllum sphacelatum* D.L.Jones	SA	
ORCHIDACEAE	*Prasophyllum suttonii* R.S. Rogers et Rees	SA	
ORCHIDACEAE	*Pterostylis falcata* R.S.Rogers		M
ORCHIDACEAE	*Spiranthes alticola* D.L.Jones		M
ORCHIDACEAE	*Thelymitra cyanea* (Lindl.) Benth.	SA	
POACEAE	*Agrostis parviflora* R.Br.	SA	
POACEAE	*Agrostis* sp. (aff. *hiemalis*)	SA	
POACEAE	**Agrostis venusta* Trin.	SA	M
POACEAE	*Austrodanthonia alpicola* (Vickery) H.P. Linder	SA	
POACEAE	*Austrodanthonia eriantha* (Lindl.) H.P.Linder		M
POACEAE	*Austrodanthonia laevis* (Vickery) H.P.Linder		M
POACEAE	*Austrodanthonia monticola* (Vickery) H.P. Linder	SA	
POACEAE	*Austrofestuca hookeriana* (F.Muell. ex Hook.f.) S.W.L.Jacobs	SA	M
POACEAE	*Deyeuxia brachyathera* (Stapf) Vickery	SA	M
POACEAE	*Deyeuxia carinata* Vickery	SA	
POACEAE	*Deyeuxia gunniana* (Nees) Benth.	SA	M
POACEAE	*Deyeuxia quadriseta* (Labill.) Benth.		M
POACEAE	*Hierochloe redolens* (Vahl) Roem. et Schult.	SA	M
POACEAE	**Holcus lanatus* L.	SA	M
POACEAE	*Lachnagrostis aemula* (R.Br.) Trin.		M
POACEAE	*Lachnagrostis filiformis* (G.Forst.) Trin.		M
POACEAE	*Lachnagrostis meionectes* (Vickery) S.W.L.Jacobs	SA	
POACEAE	*Phragmites australis* (Cav.) Trin ex Steud.		M
POACEAE	*Poa clivicola* Vickery	SA	M
POACEAE	*Poa costiniana* Vickery	SA	M
POACEAE	*Poa helmsii* Vickery	SA	M
POACEAE	*Poa labillardieri* Steud. var. *labillardieri*		M
POACEAE	*Poa sieberiana* var. *cyanophylla* Vickery	SA	
POACEAE	*Rytidosperma nudiflorum* (P.Morris) Connor & Edgar	SA	
POACEAE	*Themeda triandra* Forssk.		M
POTAMOGETONACEAE	*Potamogeton ochreatus* Raoul		M
RESTIONACEAE	*Baloskion australis* (R. Br.) L. Johnson et DF Cutler	SA	M
RESTIONACEAE	*Empodisma minus* (Hook. f.) L. Johnson et B.G. Briggs	SA	M

ANGIOSPERMS- DICOTYLEDONS			
APIACEAE	*Aciphylla simplicifolia* (F. Miell.) Benth.	SA	M
APIACEAE	*Eryngium vesiculosum* Labill.		M
APIACEAE	*Gingidia harveyana* (F. Muell.) Dawson	SA	
APIACEAE	*Hydrocotyle sibthorpioides* Lam.	SA	M
APIACEAE	*Hydrocotyle tripartita* R. Br. ex A. Rich.	SA	M

APIACEAE	*Lilaeopsis polyantha* (Gand.) Hj. Eich.	SA	M
APIACEAE	*Oreomyrrhis ciliata* Hook. f.	SA	M
APIACEAE	*Oreomyrrhis eriopoda* (DC.) Hook. f.	SA	M
APIACEAE	*Trachymene humilis* (Hook. f.) Benth. ssp. *humilis*	SA	M
ASTERACEAE	*Brachyscome decipiens* Hook. f.		M
ASTERACEAE	*Brachyscome graminea* (Labill.) F. Muell.		M
ASTERACEAE	*Brachyscome obovata* G.L. Davis	SA	M
ASTERACEAE	*Brachyscome radicans* Steetz ex Lehm.	SA	M
ASTERACEAE	*Brachyscome scapigera* (Sieb. ex Spreng.) DC.	SA	M
ASTERACEAE	*Brachyscome spathulata* Gaudich. subsp. spathulata	SA	
ASTERACEAE	*Celmisia pugioniformis* M. Gray & Given	SA	
ASTERACEAE	*Celmisia tomentella* M. Gray & Given	SA	
ASTERACEAE	*Centipeda cunninghamii* (DC.) A. Br. et Aschers.		M
ASTERACEAE	**Cirsium vulgare* (Savi) Ten.	SA	M
ASTERACEAE	**Conyza bonariensis* (L.) Cronq.		M
ASTERACEAE	*Cotula alpina* (Hook. f.) Hook. f.	SA	M
ASTERACEAE	*Craspedia crocata* J.Everett & Joy Thomps.	SA	M
ASTERACEAE	*Erigeron bellidioides* (Hook.f.) S.J.Forbes & D.I.Morris	SA	
ASTERACEAE	*Euchiton limosus* (D.G. Drury) Holub	SA	
ASTERACEAE	*Euchiton sphaericus* (Willd.) Holub.		M
ASTERACEAE	*Euchiton traversii* (Hook.f.) Holub	SA	M
ASTERACEAE	**Hypochoeris radicata* L.	SA	M
ASTERACEAE	*Lagenophora montana* Hook.f.	SA	
ASTERACEAE	*Lagenophora stipitata* (Labill.) Druce	SA	M
ASTERACEAE	*Leptorhynchos squamatus* (Labill.) Less.	SA	M
ASTERACEAE	*Microseris* sp. (D.E.Albrecht 123)	SA	M
ASTERACEAE	*Olearia algida* N.A.Wakef.	SA	M
ASTERACEAE	*Olearia glandulosa* (Labill.) Benth.		M
ASTERACEAE	*Ozothamnus hookeri* Sond.	SA	M
ASTERACEAE	*Ozothamnus rosmarinifolius* (Labill.) Sweet		M
ASTERACEAE	*Senecio gunnii* (Hook. f.) Belcher		M
ASTERACEAE	*Senecio hispidulus* A. Rich. var. hispidulus	SA	M
ASTERACEAE	*Senecio pectinatus* DC. var. *major* F. Muell. ex Belcher	SA	
ASTERACEAE	*Senecio quadridentatus* Labill.	SA	M
ASTERACEAE	**Taraxacum officinale* F.H.Wigg.	SA	
BORAGINACEAE	*Myosotis laxa* Lehm. ssp. *caespitosa* (K.F. Schultz) Hyl. ex Nordh.	SA	M
CAMPANULACEAE	*Lobelia gibbosa* Labill. var. *gibbosa*	SA	
CAMPANULACEAE	*Pratia pedunculata* (R. Br.) Benth.	SA	
CAMPANULACEAE	*Pratia surrepens* (Hook. f.) F. Wimmer	SA	
CAMPANULACEAE	*Wahlenbergia ceracea* Lothian	SA	M
CARYOPHYLLACEAE	*Scleranthus biflorus* (J.R.Forst. & G.Forst.) Hook.f.		M
CARYOPHYLLACEAE	*Scleranthus fascicularis* (R.Br.) Hook.f.	SA	
CARYOPHYLLACEAE	*Stellaria angustifolia* Hook.		M
CARYOPHYLLACEAE	*Stellaria pungens* Brongn.		M
CLUSIACEAE	*Hypericum japonicum* Thunb.	SA	M
DROSERACEAE	*Drosera peltata* Thunb.	SA	
EPACRIDACEAE	*Epacris breviflora* Stapf	SA	M
EPACRIDACEAE	*Epacris microphylla* R. Br. var. *microphylla*	SA	M
EPACRIDACEAE	*Epacris paludosa* R. Br.	SA	M

EPACRIDACEAE	*Richea continentis* Burtt	SA	
FABACEAE	**Lotus corniculatus* L. var. *corniculatus*		M
FABACEAE	*Podolobium alpestre* F. Muell.	SA	
FABACEAE	*Pultenaea fasciculata* Benth.	SA	
FABACEAE	**Trifolium dubium* Sibth.		M
FABACEAE	**Trifolium repens* L. var. *repens*	SA	M
GENTIANACEAE	**Centaurium erythraea* Rafn		M
GENTIANACEAE	*Chionogentias cunninghamii* L.G.Adams subsp. *cunninghamii*	SA	M
GENTIANACEAE	*Chionogentias muelleriana* subsp. *jingerensis* L.G.Adams	SA	
GERANIACEAE	*Geranium neglectum* Carolin		M
GOODENIACEAE	*Velleia montana* Hook. f.	SA	
HALORAGACEAE	*Gonocarpus micranthus* Thunb. Subsp. *micranthus*	SA	M
HALORAGACEAE	*Myriophyllum pedunculatum* Hook. f. ssp. *pedunculatum*	SA	M
HALORAGACEAE	*Myriophyllum variifolium* Hook. f.		M
LAMIACEAE	*Mentha diemenica* Spreng.		M
LAMIACEAE	*Prostanthera cuneata* Benth.	SA	
LENTIBULARIACEAE	*Utricularia dichotoma* Labill.	SA	M
LINACEAE	*Linum marginale* A. Cunn. ex Planch.	SA	M
LOGANIACEAE	*Mitrasacme serpyllifolia* R. Br.	SA	
LYTHRACEAE	*Lythrum salicaria* L.		M
MENYANTHACEAE	*Nymphoides montana* Aston		M
MYRTACEAE	*Baeckea gunniana* Schau.	SA	
MYRTACEAE	*Baeckea utilis* F. Muell. ex Miq.	SA	M
MYRTACEAE	*Leptospermum lanigerum* (Ait.) Sm.	SA	
MYRTACEAE	*Leptospermum myrtifolium* Sieb. ex DC.		M
MYRTACEAE	*Melaleuca paludicola* Craven		M
MYRTACEAE	*Melaleuca pityoides* (F.Muell.) Craven	SA	
ONAGRACEAE	*Epilobium billardiereanum* subsp. *cinereum* (A.Rich.) P.H.Raven & Engelhorn	SA	M
ONAGRACEAE	*Epilobium billardiereanum* subsp. *hydrophilum* P.H.Raven & Engelhorn	SA	M
ONAGRACEAE	**Epilobium ciliatum* Raif.		M
ONAGRACEAE	*Epilobium gunnianum* Hausskn.	SA	M
PLANTAGINACEAE	*Plantago antarctica* Decne.	SA	M
POLYGALACEAE	*Comesperma retusum* Labill.	SA	M
POLYGONACEAE	**Acetosella vulgaris* Fourr.	SA	M
POLYGONACEAE	**Persicaria hydropiper* (L.) Spach		M
POLYGONACEAE	**Rumex crispus* L.		M
PORTULACACEAE	*Neopaxia australasica* (Hook. f.) Nilss.	SA	
PROTEACEAE	*Grevillea australis* R. Br.	SA	
PROTEACEAE	*Grevillea lanigera* A. Cunn. ex R. Br.		M
PROTEACEAE	*Hakea microcarpa* R. Br.	SA	M
RANUNCULACEAE	*Ranunculus amphitrichus* Colenso	SA	M
RANUNCULACEAE	*Ranunculus collinus* R. Br. ex DC.		M
RANUNCULACEAE	*Ranunculus graniticola* Melville	SA	
RANUNCULACEAE	*Ranunculus lappaceus* Sm.		M
RANUNCULACEAE	*Ranunculus millanii* F. Muell.	SA	
RANUNCULACEAE	*Ranunculus pimpinellifolius* Hook.	SA	M
RANUNCULACEAE	*Ranunculus pumilio* R. Br. ex DC. var. pumilio		M

ROSACEAE	*Acaena novae-zelandiae* Kirk	SA	M
ROSACEAE	*Acaena ovina* A. Cunn.	SA	
RUBIACEAE	*Asperula gunnii* Hook. f.	SA	M
RUBIACEAE	*Asperula pusilla* Hook. f.	SA	M
RUBIACEAE	*Coprosma nivalis* W.R.B. Oliver	SA	
RUBIACEAE	*Galium gaudichaudii* D.C.	SA	
RUBIACEAE	*Galium nigrans* Ehrend. et McGill.		M
SALICACEAE	**Salix* sp.		M
SANTALACEAE	*Exocarpos nanus* Hook. f.	SA	
SCROPHULARIACEAE	*Euphrasia caudata* (J.H.Willis) W.R.Barker	SA	
SCROPHULARIACEAE	*Euphrasia collina* R. Br. ssp. *paludosa* (R. Br.) W.R. Barker	SA	
SCROPHULARIACEAE	*Glossostigma diandrum* (L.) Kuntze		M
SCROPHULARIACEAE	*Gratiola nana* Benth.	SA	M
SCROPHULARIACEAE	*Gratiola peruviana* R.Br.		M
SCROPHULARIACEAE	**Mimulus moschatus* Douglas ex Lindl.		M
SCROPHULARIACEAE	*Veronica gracilis* R. Br.		M
SCROPHULARIACEAE	*Veronica serpyllifolia* L.	SA	
STYLIDIACEAE	*Stylidium graminifolium* Sw. ex Willd.	SA	M
VIOLACEAE	*Viola betonicifolia* Sm. ssp. betonicifolia		M
VIOLACEAE	*Viola fuscoviolacea* (L.G. Adams) T.A.James	SA	

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Bibliographic Note

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