A tale of two swamps: sub-alpine peatlands in the Kelly-Scabby area of Namadgi National Park

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Introduction

Shrub and twig rush peatlands with hummocks of *Sphagnum* moss are a characteristic feature on the valley floors of Namadgi National Park above 1400m. Most are spring-fed and can cover large areas, as at Ginini Flats, or line streams where gradients are low. *Sphagnum* stabilizes both the soil surface and stream banks and acts as a filter, removing suspended sediment. *Sphagnum* bogs alter the hydrology of streams by impeding flow and retaining water, thus preventing erosion downstream in what would otherwise be extreme runoff events, and by maintaining a more constant flow between events. These high mountain bogs and fens are important in maintaining water quality in the Cotter River catchment for Canberra's water supply.

The high altitude swamps form a complete contrast to the woodlands and tussock grasslands that make up the bulk of the high altitude vegetation. As sources of perennial moisture and green food they play a major ecological role for wildlife seasonally and especially during times of drought. The swamps also have strongly contrasting biota to the surrounding habitats and so add greatly to the biodiversity of the area. Their occurrence in Namadgi represents their northernmost limit in the Australian Alps (Whinam *et al.* 2003). It is apparent from our studies of several wetlands in the ACT (Hope 2006) that each peatland has a unique history of development that reflects its topographic setting, microclimate and historical variability such as fire impact. This paper reports on the contrasting structure and histories of Rotten Swamp and Cotter Source Bog, two shallow peatlands from the mountainous south-eastern boundary of the upper Cotter River catchment in the Australian Capital Territory. A key finding is that the peatlands have persisted for several thousand years and represent centres of resilience that allow a range of swamp and dryland biota to persist in a highly variable environment.

Rotten Swamp, in the central-south of Namadgi at 1445 m altitude and 35°42.35'S 148°53.18'E, is surrounded by high granodiorite peaks, Mt Namadgi, Mt Burbidge and Mt Kelly, the latter, at 1828 m, the highest point in the 240 ha catchment (Figure 1). The climate is sub-alpine with an estimated precipitation of 1038 mm and a mean annual temperature of 6.7°C. Frequent intense frosts and occasional snow falls are experienced in winter, with shaded parts of the swamp freezing to a depth of 30 cm for up to 3 months.

The swamp and associated tussock grasslands are broken into two areas, an upper flat about 28 ha in extent at the headwaters of Licking Hole Creek and a further swamp area of about 7 ha 1km downstream. Both east and west swamp areas are formed on gently sloping colluvial fans which are incised by Licking Hole Creek. Mire development currently occurs on lower slopes around the flat where groundwater emerges and there are areas of tussock grassland and snow gums (*Eucalyptus pauciflora* subsp. *debeuzevillei*) on drier areas with bedrock within the flat. Prior to the 2003 fire, *Sphagnum* was scattered but extensive around the mire, also following creek banks into the flattest area in a mosaic with sedge (*Carex gaudichaudiana*) fen, *Empodisma minus* and shrubs to form a bog in areas between the *Sphagnum*.

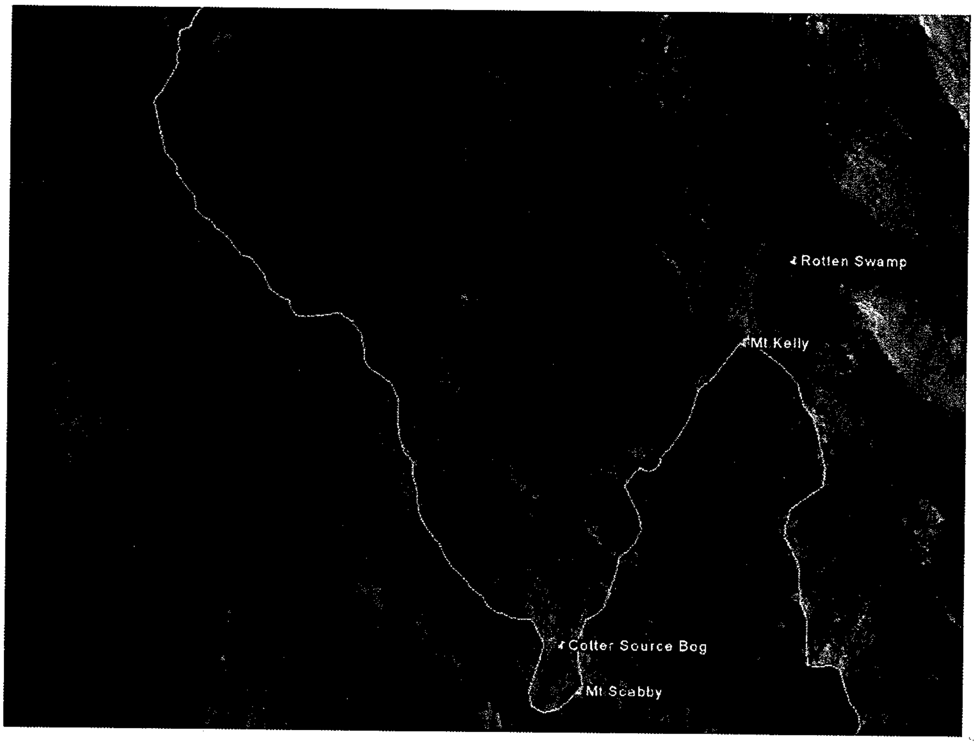

Figure 1. Location of Rotten Swamp and Cotter Source Bog in the southern ACT.

The second swamp studied in detail is Cotter Source Bog 6km to the south which occupies a shallow north-facing valley near the summit of Mt Scabby at 35°45.3'S 148°51.45'E. This swamp is higher (1718 metres) and smaller (5 ha) than Rotten Swamp and has a smaller catchment of only 25 ha. The site is subject to freezing temperatures and frequent snow lie, with an estimated annual precipitation of 1327 mm and mean annual temperature of 5.7°C. The swamp is confined to the valley floor and is largely a *Baeckea gunnii-Epacris brevifolia-Empodisma minus* shrub bog with *Sphagnum* mostly restricted to the edges of the stream and pools. It is unusual in having a complex of shallow ponds created by peat growth, but like Rotten Swamp, a single incised stream channel runs the length of the swamp. After the 2003 fire the stream started to cut away peat barriers to drain the ponds and remediation works were put in place in December 2003 to prevent further damage.

A bridle track, and later a bulldozer track, led to Rotten Swamp there from the Naas Valley. The swamp was probably named by pastoralists seeking to use it for summer grazing and it may have been partially fenced and drained at some stage. It was certainly burnt frequently prior to the cessation of formal grazing in the Cotter catchment. 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. Cotter Source Bog is possibly too remote to have experienced deliberate stocking but wild cattle and horses have been common in the catchment until relatively recent times. 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 swamps without being noticed or recorded.

Both Rotten and Cotter Source were severely but partially burned by the January 1983 Gudgenby fire that affected the southern part of the ACT. Both also burned 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. Some areas of *Sphagnum* were completely removed by the fire. In 2003 both swamps were completely burnt but the fire was rapid and regeneration of the grassland and sedges took place quickly. However almost all areas of surviving *Sphagnum* were scorched and in places the dead hummocks have experienced replacement by *Empodisma minor* sedgeland. Regeneration trials using shade cloth to encourage *Sphagnum* regeneration were commenced at Rotten Swamp in October 2003 (Hope *et al.* 2005). Shade cloth has also been used to hinder *Sphagnum* dieback at Cotter Source Bog since May 2007. At both sites organic barriers have been placed in stream lines to encourage water retention, reduce erosion and wet the stream margins. Rigid barriers of plywood placed in 1983 at Rotten Swamp were in some cases burnt by the 2003 fire.

Several questions are posed by the two different swamp types which might reflect alternate successional states due to different disturbance histories. Following the fires, the question was asked: would the burned *Sphagnum* regenerate naturally or should measures be taken to encourage regeneration? Palaeoecology might provide part of the answer as it can define the types of peatland present through time and the fire history of the swamps. It can potentially indicate how long it takes for *Sphagnum* to regenerate. The study also seeks to investigate what the effects of post-European settlement have been on the extent of *Sphagnum* as well as trialling, with Namadgi National Park, a program for re-wetting the swamp areas to re-establish peat-forming vegetation.

Methods

A transect was surveyed in April 1984 by Clark through the largest area of *Sphagnum* on the northern slope of Rotten Swamp, from the tree line to the main stream channel (Clark 1986). The depth of peat along the transect was measured by probing. Cores were taken with a D-section corer where the peat was deepest (Figure 2) and at a site a few metres away where the underlying gravel was interspersed with clay. Samples from a section through the *Sphagnum* hummock above the peat were also collected. The stratigraphy of the cores was noted and density, water content and loss on ignition (for organic content) measured in contiguous 1ml samples over the length of the main core. Since 2003 the site has been visited several times by Hope and short cores taken from sedge areas to assess whether they are former sites of *Sphagnum* growth.

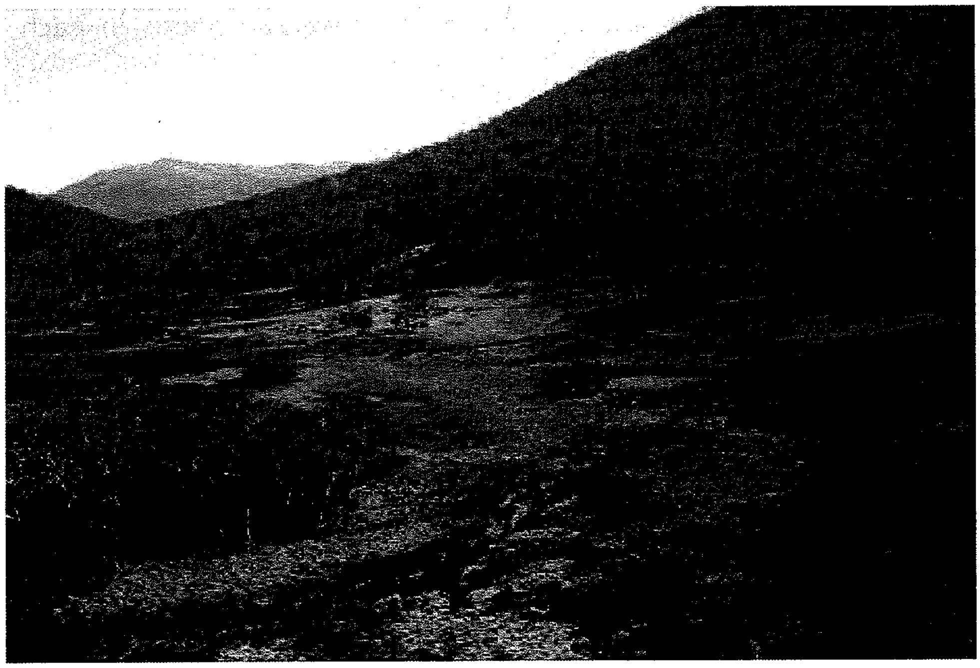

Figure 2. Rotten Swamp in June 1996 showing location of the core site.

At Cotter Source Bog a D-section core was taken in February 1996 from the centre of the bog and supplementary samples were obtained in May 1997 (Figure 3). About 80m to the northwest a pit was dug in the peat 9 m from the western margin and sampled at close intervals for pollen and dating samples. The bog has been visited frequently since the 2003 fires.

Figure 3. Cotter Source Bog December 2003. Centre site on left, Margin pit on right. 1983 bulldozer track visible in foreground.

Samples for pollen analysis were taken from the cores at approximately 10 cm intervals and the upper 15 cm of the pit was sampled at 2 or 4 cm intervals. Samples were processed by physical and chemical means to concentrate the pollen and remove as much other material as possible before microscopic examination. All pollen grains encountered on transects across microscope slides were identified and counted until a total of at least 150 grains in each sample was reached. The fraction of each sample retained on a 250 µm sieve was studied to identify large plant fragments, charcoal, seeds, insects and sand or gravel.

For detailed charcoal analysis, 5 µl samples of peat were taken at contiguous 2.5 mm intervals from the 1984 Rotten Swamp core, mounted in water on microscope slides and the coverglasses sealed with varnish. The amount of charcoal in each sample was estimated by point counting (Clark 1982) and the same technique was used to determine the amount of charcoal remaining in the pollen samples from each site.

Radiocarbon dates were taken from short sections (2-7 cm) of peat core. The material was sieved and the <150 µm fine fraction treated with 10% HCl and 10% NaOH washes. A bulk sample of basal sandy gravels under the Rotten Swamp core were shaken in distilled water several times and organic debris collected after the sand had settled.

Results

Rotten Swamp

The main transect from the northern slope to the Licking Hole Creek revealed the maximum depth of peat to be 150 cm about midway along the transect, so the main core (core A Clark 1986) was taken near this point (Figure 2). 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. The corer could be pushed no further than 1.5 cm into a basal layer of silty sand. A supplementary core was taken 12 m to the north-east of the main core site. It had 63 cm of peat with some gravel layers overlying 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.

Composite sediment section, Rotten Swamp	
Depth cm	Sediment
	Living *Sphagnum* hummock 66cm thick
0-18	Brown fibrous *Sphagnum* peat
18-100	Very dark grey fibrous and humic peat
100-136	grey gravelly sandy clay

Sample	**Depth cm**	**Age C14 yr BP**	**Lab no**	**Cal yr BP**	**68% range calBP**
-	Top of hummock	-23 (1983 AD)			-23 (1983 AD)
-	10 (Pine)	40			40 (1910 AD)
-	20	100			100 (1850 AD)
ROT-1	20-22	620 ± 110	ANU 9483	610 ± 65	544 - 675
ROT-2	83-88	4570 ± 110	ANU 4227	5243 ± 180	5063 - 5423
ROT-3	99-102	5500 ± 90	ANU 9484	6300 ± 89	6210 - 6389
ROT-4	102-130	166.7 ± 4.9%	ANU 9485B		Modern

The loss on ignition values show a slow decrease in organic content with depth and the clear transition from peat to gravel at 100 cm.

Dating. The most recent chronology can be inferred from the appearance of weed and pine pollen in the core, marking European impact and the spread of pine in SE 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 1 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 after about 1850.

All these estimates are consistent with measured growth rates of *Sphagnum* in Australia (Clark 1980) and known events, such as the establishment of pine forests near Canberra and Tumut in the 1910s and 1920s. Radiocarbon dates have been corrected against tree-ring sequences using CalPal 1.5, (http://www.calpal-online.de) to provide calibrated ages before present (1950AD).

Further dating of the core since the initial report (Clark 1986) does not support a model of logarithmic decrease in sediment accumulation rates that she proposed. The peat accumulation commenced about 6400 cal years ago. The sediment accumulation rates between the three dated levels are 1.42 and 1.23 cm/100yr suggesting that the organic build up was fairly regular. The age of 670 ±140 yr BP from about the inferred level of European settlement (100 yr BP) also requires explanation. The bog may have been burnt at that time and about 9 cm of peat been removed leaving a hiatus in the record. Alternatively, disturbance by stock or other bioturbation may have mixed older material into younger peats.

The attempt to use radiocarbon to date the basal clays and gravels, which preserve an older pollen signature, failed when a modern date was obtained, reflecting active groundwater transport and possibly root activity in the sands and gravel aquifer. Similar results have been found at Micalong Swamp and Rennex Gap Bog (Kemp 1993). At Rotten Swamp tubes installed in 2003 to check the water table showed that even when the peatland was wet the gravels could be drained. The very low hydraulic connectivity at the base of the peat thus seals the bog from the underlying aquifer.

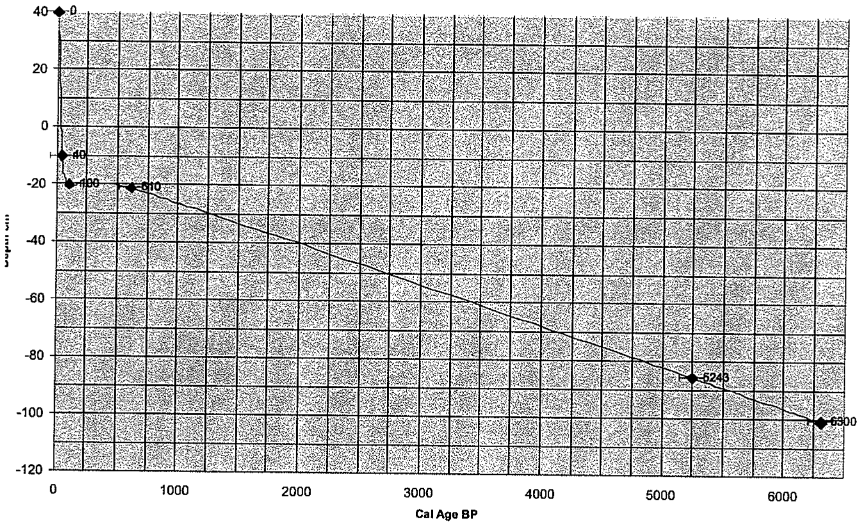

Figure 4. Sediment accumulation graph for Rotten Swamp.

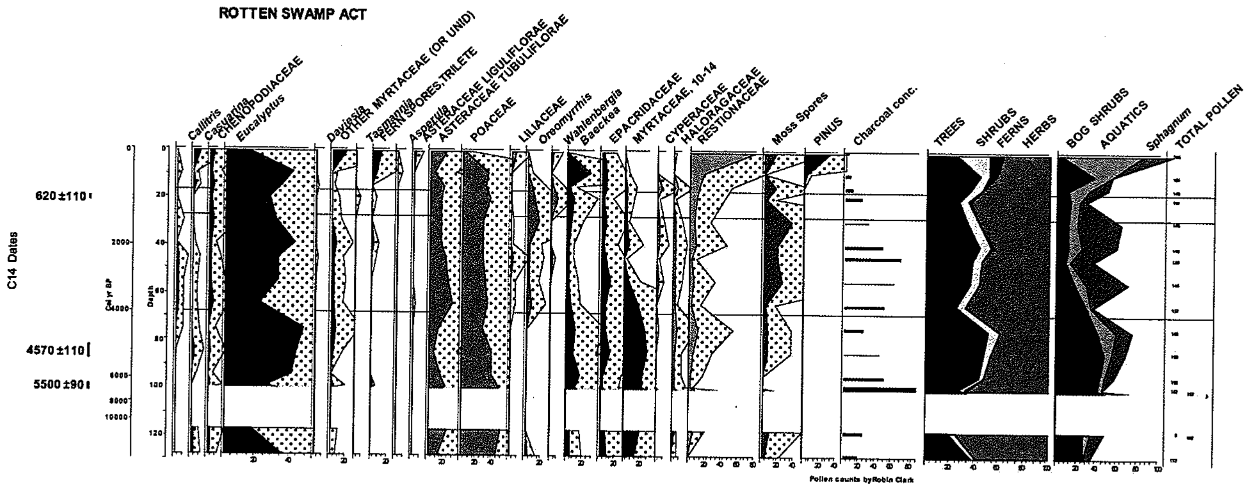

Figure 5. Pollen diagram from Rotten Swamp.

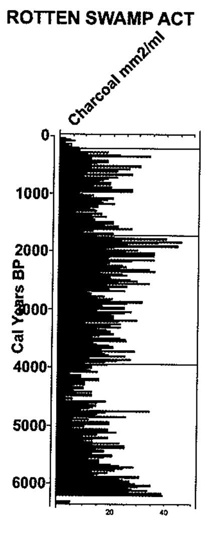

Figure 6. High resolution charcoal record from Rotten Swamp.

Vegetation history. Results of pollen analyses are illustrated in Figure 5, which shows changes with depth in the major taxa through the main core and in the clay layers of the supplementary core. The pollen sum is made up of dryland taxa including ferns and herbs. From this, vegetation history can be reconstructed from the earliest times at the base to the more recent at the top.

The pollen in the clay layers shows a moderate level of tree pollen and a predominance of grasses (Poaceae), daisies (Asteraceae) and sedges (Cyperaceae). The presence of alpine genera such as *Neopaxia*, *Gentianella* and *Ranunculus* (not shown on the diagram) suggests that at the time the clays were deposited the climate was colder than at present and, by analogy with other sites (Kershaw and Strickland 1989, Donders *et al.* 2007, Hope 2006), was probably around more than 9500 years ago. The few eucalypt and *Casuarina* pollen grains would have blown in from forests at lower altitudes.

Eucalypt woodland became established around Rotten Swamp before the commencement of peat accumulation. The basal peat age supports this as forest reaches its present limits between about 11,500 and 9000 years ago at other highland sites in south-eastern Australia (Kershaw and Strickland 1989, Hope 2003). 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 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. Of the major pollen types, eucalypts, grasses and daisies were probably growing on the hill slopes surrounding the swamp and on drier areas within it, although some grasses and daisies probably grew within the *Sphagnum* areas. Most *Eucalyptus* pollen is of the type produced by snow gums (*E. pauciflora*). Abundant phytoliths (silica bodies formed by the cells of some plants, particularly grasses) throughout reflect the importance of grasses in the local vegetation. The other major pollen types came from plants growing at or near the core site and are representative of species growing on alpine or sub-alpine bogs and wet heaths today (e.g. *Baeckea gunniana*, *Empodisma minus*, *Epacris paludosa*, *Restio australis* and *Richea continentis*).

Over the period of peat accumulation there has been little change in the relative abundance of taxa in the vegetation surrounding Rotten Swamp. There is an increase in grasses and daisies above 70 cm in the core (ca. 3500 years ago) and a decrease in daisies in the topmost sample (ca. 60 years ago).

In contrast to the surrounding vegetation, that on the bog itself changed markedly between 60 cm and 70 cm (ca. 3200-3600 years ago) and at the top (ca. 60 years ago). The earlier change saw a marked reduction in *Baeckea* and another myrtaceous shrub (as yet unidentified), a smaller decrease in Restionaceae pollen and an increase in bryophyte (moss) spores, most of which are not *Sphagnum*. These changes may have been due to local vegetation succession but, with the appearance of Cyperaceae (sedges) and *Oreomyrrhis* (caraway) pollen, they suggest that the core site became wetter. This may have been due to increased precipitation, decreased evaporation or changes in local hydrology. Between 10 cm and 15 cm (ca. 60-85 years ago) there is a sharp increase in *Baeckea* and Restionaceae pollen (which also dominates in the hummock above the peat, providing about 70% of the pollen) and reductions in, or the disappearance of, other swamp taxa. Again, these changes suggest plant succession or a change in effective precipitation or local hydrology, this time to drier conditions.

Fire history. Changes occur to the charcoal concentration with depth and the presence of large charcoal fragments (>0.1 mm long) in the fresh peat samples. The amount of charcoal remaining in the pollen preparations was less than in the corresponding fresh samples taken directly from the core. Depending on the original degree of carbonization of charcoal, more or less may be removed by the physical and chemical procedures used to prepare pollen samples (Clark 1984). In only the lowermost sample did the results from the two methods differ markedly and this is probably because most of the charcoal was in large fragments (>0.25 mm) that were sieved out before pollen processing.

If the high resolution charcoal record (Figure 6) reflects the real fire history, the base of the peat records significant fire, but the bog at this time may also have experienced more washing in of charcoal than later, when there is almost no water flow across the moss surface. Then there was an early period, 5500-3900 years ago, when fires were less frequent. After that time the number of fires in the region or the area they burned increased to a peak about 1800 years ago. A short stable period followed (37-26 cm; ca. 1600-900 years ago), then a further increase (26-16 cm; ca. 900-120 years ago), with many large fresh-looking charcoal fragments being preserved in the peat above 23 cm. Above 16 cm the amount of charcoal decreases markedly.

Cotter Source Bog core A

A series of holes across the bog at its widest point showed great variability in depth, presumably reflecting an uneven boulder field below. Peat was generally shallower to the east, where it overlay a scree slope from Mt Scabby. The centre of the bog (CSBA96 site) was dominated in 1996 by shrubs, *Empodisma* and discrete areas of *Sphagnum* hummocks 30 cm in depth. A core taken between the hummocks provided a column of homogenous peat to a depth of 115 cm above clays and coarse sands to 140 cm. The 1997 core was collected about 3 m from the 1996 one and sampled an overlying 35 cm of fresh *Sphagnum* and 75 cm of the humic peat. A composite stratigraphy assumes that the top of the 1996 core corresponds with ca 30 cm in the 1997 core, an assumption borne out by the dating (Figure 7).

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.

Sample	Depth	Date	Lab No.	Cal yr BP	68% range calBP
CSBA97-1	0-10	100.8 ± 2.6			
(Modern)	ANU 10815				
Pine	10	40	-	40 (1910AD)	
CSBA97-2	42-48	2600 ± 110	ANU 10816	2658±152	2506 - 2810
CSBA96-3	61-69	3220 ± 140	ANU 10193	3450 ± 168	3281 - 3618
CSBA96-4	121-131	9,040 ± 80	ANU 10194	10149 ± 123	10025 - 10272

The long–term sediment accumulation rate is 1.14 cm/100yr but it is somewhat slower (0.88 cm/100yr) in the lower part of the section, which may reflect organic decay but also leaves the possibility that there may be a gap of up to 1500 years there. However, the dates show that there is a relatively complete Holocene sequence preserved in the Cotter Source centre. The sandy silts probably built up more quickly than the overlying peat, indicating a basal age of around 11,000 cal yr BP. An extrapolation of the upper dates confirms the approximate position of the surface levels.

Vegetation history. The pollen diagram (Figure 8) suggests relatively stable vegetation on the bog over the Holocene. The bog has gradually changed from restionaceous-grass bog to a possibly more shrub-rich bog in which *Sphagnum* may have replaced *Empodisma* to some extent. However, spores of *Sphagnum* were not found. There may have been a gradual trend towards wetter conditions on the swamp indicated by increased *Myriophyllum* which could reflect the slow development of staircase ponds that characterise the present bog. *Carex* fen has never dominated, nor have myrtaceous thickets invaded. The basal clays record sparse eucalypt pollen but a woodland has been present on the surrounding slopes from the start of the peatland about 10,000 years ago. It is thus likely that the site is intiated as the tree line reaches Mt Scabby. Eucalypt pollen increases in the last 2000 years although the importance of daisies and grasses (Asteraceae, Poaceae) shows that a herb-rich grassland understorey seems to have persisted. European disturbance is indicated by pine pollen within the upper *Sphagnum* peat.

Fire history. Charcoal rises once peat and good local cover is achieved and is common over the whole record. An apparent generally reduced influx over the last 2,800 years may reflect more regular fires on the bog but if there has been increased *Sphagnum* growth that would have impeded charcoal transport. Charcoal influx increases in the surface sample, but the only marked change is an increase in sedges, possibly reflecting trampling in the bog.

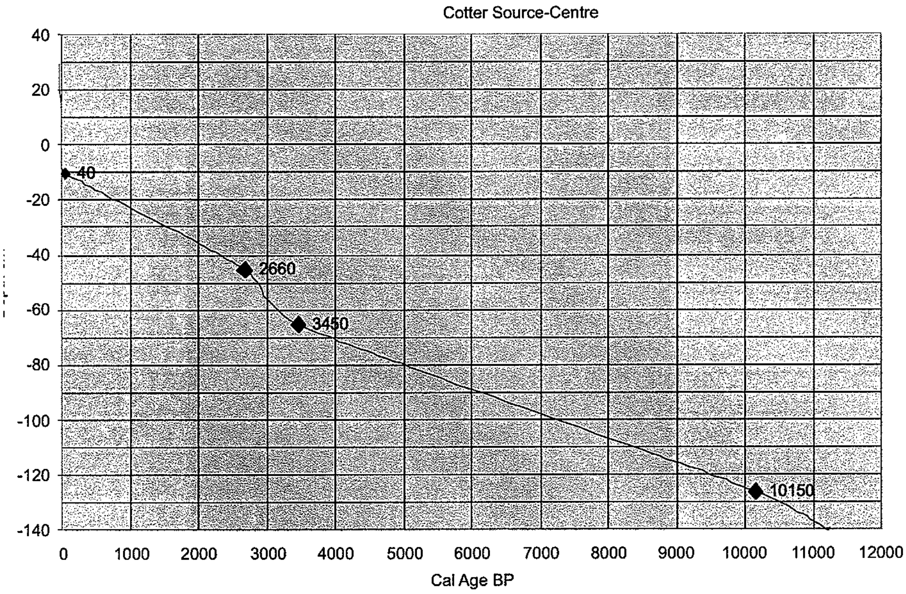

Figure 7. Sediment accumulation graph for Cotter Source Bog.

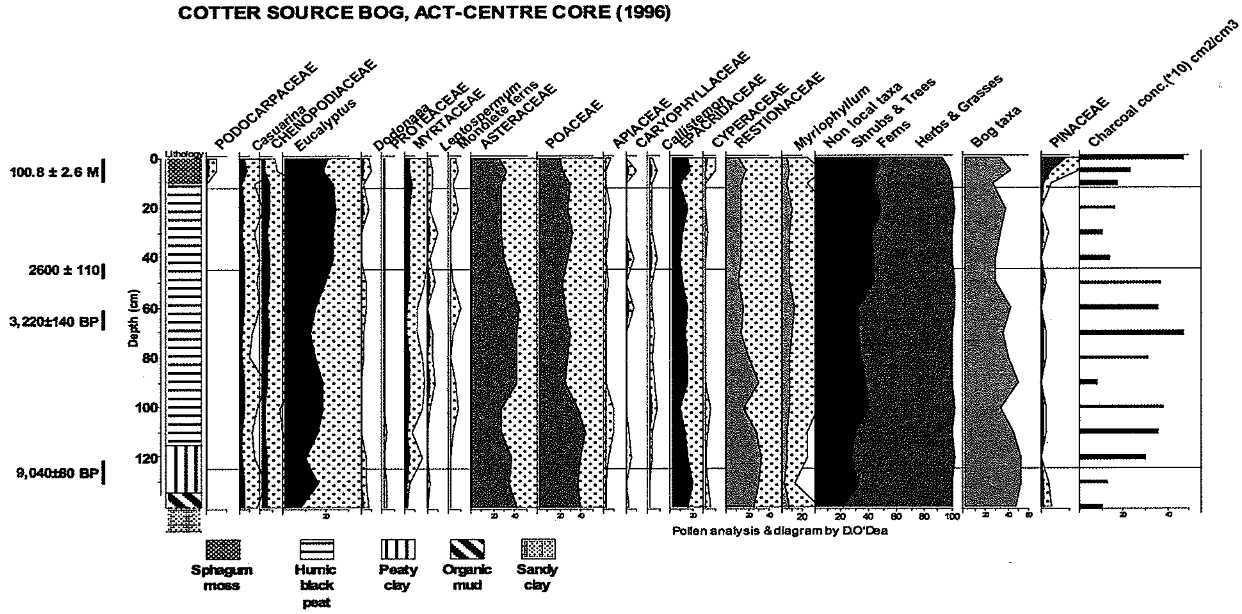

Figure 8. Pollen diagram from the centre of Cotter Source Bog.

Cotter Source Bog margin

An archaeological survey located stone tools around the bog and a putative stone arrangement. To look for episodes of slope erosion that might reflect human occupation a pit was dug close to the western margin of the bog, about 80 m from the centre core site.

The site is vegetated by a dense sward of twig rush (*Empodisma minus*) that extends slightly up slope to a boundary with tussock grassland. A series of holes in a transect from margin to the centre of the bog established the underlying profile and the hole was dug where peat first reaches a significant depth of 65cm.

One cm thick slices were cut from the pit wall for radio carbon dating and pollen was also sampled at close intervals.

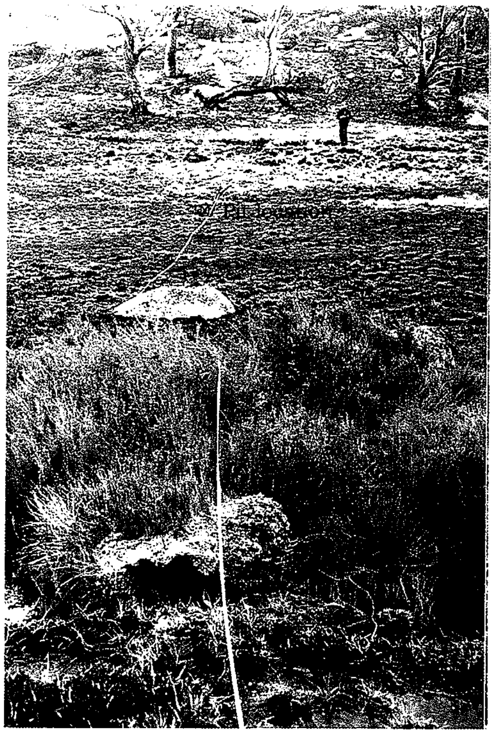

Figure 9. Transect from the western margin of Cotter Source Bog in October 2003.

The section presents remarkable inversions, with older material overlying younger sediments. The lowest date at 44.5 cm seems anomalously young given that it lies just above the base of the section. The date from 30 cm may be more reliable as it comes from a thick peat unit that lacks inwashed slope material. If it is correct that peat has been buried by old slope wash, that means that the age obtained for the sandy peat at 21.5 cm is at least 3000 years too old. Given that the slope soils must be younger than 11,000 BP, and might have had an average age of perhaps 6,000 BP when washed in within the last 1500 years, the date of 5,000 BP at 21.5 cm represents very substantial inputs of old organics.

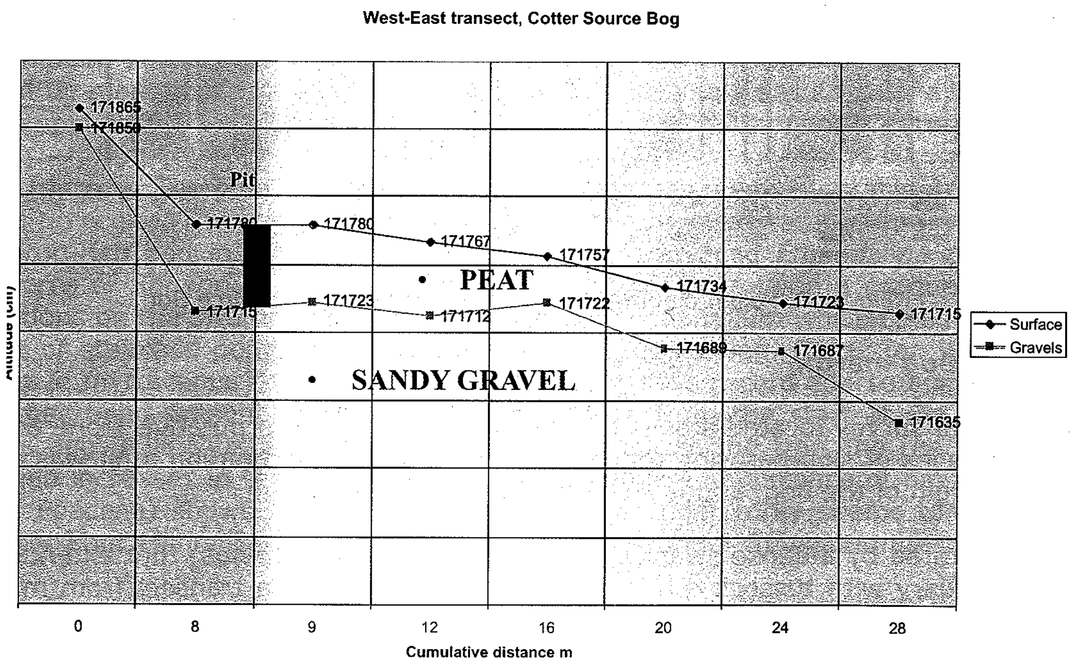

Figure 10. Section from the western margin of Cotter Source Bog.

Vegetation history. In the pollen diagram, pine pollen was found to be restricted to the top 3 cm of the site, indicating that pollen-sized particles are not being mixed through the peat. Changes ascribable to European settlement occur only slightly lower, providing an age of about 60 BP at 4 cm. This suggests that the date at 10.5 cm is indeed around 190 cal yrBP and that the upper 13 cm of the section has built up normally.

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

Sample	Sample depth cm	Date	Lab No	Cal yr BP	2σ cal age range
	3	40		40 (AD1910)	
	4	60		60 (AD1890)	
CSBM-1	10-11	150 ± 140	ANU 10818	188 ± 155	33 - 343
CSBM-2	20-23	4960 ± 200	ANU 10191	5703 ± 219	5484 - 5922
CSBM-3	30-31	2750 ± 160	ANU 10817	2907 ± 198	2708 - 3105
CSBM-4	43-46	1400 ± 130	ANU 10192	1317 ± 135	1182 - 1452

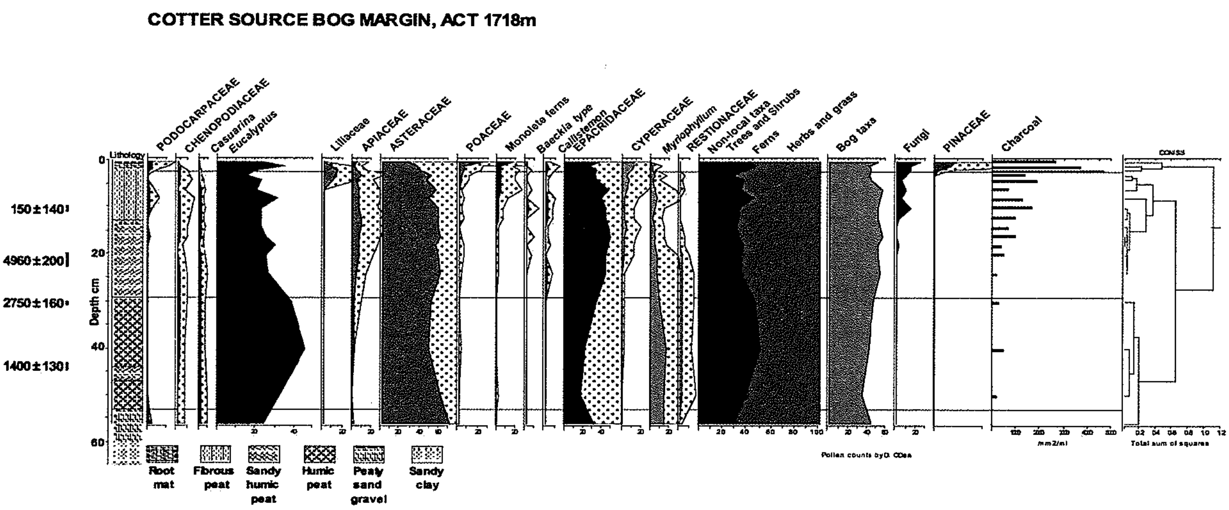

Figure 11. Summary pollen diagram from the margin of Cotter Source Bog.

The pollen diagram does not show very great changes across the suggested inversion boundaries, even though old pollen might have been brought in from the humic soils and would certainly be incorporated in peat. A classification of the main taxa shows very low variability in the two sandy horizons (13-29, 44-47 cm), suggesting some mixing may have been occurring in these. Spectra in the sandy peats tend to match those from the base of the sequence, with relatively reduced *Eucalyptus* and increased Asteraceae. The bog type also changes, with increased Apiaceae and *Epacris* and reduced Restionaceae and *Myriophyllum*. This reflects a trend to a drier, more marginal shrub bog type in which *Sphagnum* would have played little part. This is also suggested by the absence of *Sphagnum* peat anywhere in the profile. Above 13 cm the bog has increasing levels of Cyperaceae and shrubs which are maintained to the present. Compared to the centre core, grass pollen is at very low levels through most of the diagram but it increases above 13 cm 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. The European phase, marked by pine and other changes at 5 cm, is the largest vegetational change found in the record, with a possible grassland expansion and increased sedge fen.

Fire history. There is a major contrast in the charcoal history compared to the centre core and more detail is available as the top of the section has been counted at high resolution. Charcoal is at low concentration through the lower half of the section and increases in the upper part of the inwash section at 16 cm, possibly more than a thousand years ago. This is surprising as the likeliest mechanism leading to deposition of slope material on the bog would seem to be wildfire, yet little charcoal is preserved in levels that have mineral slopewash and evidence of significant catchment erosion. The European phase is marked by a considerabe increase with a gradual decline in the top few centimetres, perhaps reflecting reduced fire in the catchment.

Discussion

Although experiencing similar settings and histories, Cotter Source Bog has a more complete record that demonstrates that it has been a restionaceous shrub bog throughout the Holocene, with staircase ponds for most of that period. By contrast, the Rotten Swamp record is a *Sphagnum*-shrub bog extending back to only the mid-Holocene. While further research on cores from the floor of Rotten Swamp valley might uncover older peats comparable to Cotter Source, observation of peat types from central cores suggests that only a relatively shallow deposit of *Sphagnum* peat is preserved, now changed to a *Carex* fen by post-European disturbance. Other sequences from Namadgi (Hope 1996) show similar dichotomies. New dating at two locations on Ginini West (1590 m) have confirmed that the well-developed *Sphagnum* peat there started to accumulate around 3500 cal yr BP at marginal sites fed by groundwater spring lines (Hope unpublished). It is thus likely that erosive episodes have affected the *Sphagnum* bogs through the Holocene. Long-term drought and associated fire would seem to be the likeliest candidates. The base of Rotten Swamp is significantly older than Ginini West, so more than one such event may have occurred, as shown from dated slope wash sequences studied by Worthy (2006). The 2003 fire, though extensive, caused almost no damage to the fabric of the bogs because they retained significant moisture despite a lengthy drought. Hence the presumed complete loss of mires in past events possibly reflect different climatic controls that completely dried the mires to a point where peat could burn. The preservation of some longer sequences might be expected by chance. However, *Sphagnum* peat may be more vulnerable because it is less compacted than humic peat and hence more prone to drying. It is also possible that valley floor deposits are wetter and less liable to drying.

Because *Sphagnum* hummocks are raised above the water table and surface run-off, the charcoal they contain comes from two sources only: airborne charcoal from fires in surrounding vegetation or at some distance and charcoal from fires burning the *Sphagnum*, its associated heath vegetation and sometimes the peat beneath. As large charcoal particles fall out from smoke very rapidly (Clark 1983), their abundance in *Sphagnum* peat indicates nearby or in situ fires. Such fires have occurred throughout the history of Rotten Swamp. Cotter Source has also experienced continuous charcoal influx but some of the fires may have been in the surrounding catchment.

The charcoal concentrations at Rotten Swamp suggest that there was a real increase in charcoal about 3850 cal yr BP, a decrease around 1800 cal yr BP and a substantial decrease at 16 cm of the core. Both these changes correspond with vegetation changes. Cotter Source Bog has high charcoal influxes through most of the record with an possible reduction after ca 2800 cal yr BP and a major increase in post-European times. It should be noted that neither sequence is well dated at this stage.

There are three alternative explanations: changing fire regimes caused a shift in vegetation composition; altered vegetation led to a change in fire regime; or both fire regimes and vegetation changed in response to climate. Vegetation might change as individuals of one species replaced those of another after senescence and death, disturbances such as fire, changed climatic conditions or alterations to local hydrology. Fire regimes might change if vegetation changes resulted in different types and accumulation rates of fuel; if climatic changes altered fuel production, fuel moisture conditions or the frequency and seasonality of lightning strikes; or if people ignited, prevented or suppressed fires.

Human fire management. Aborigines used both areas in summer, collecting Bogong moths on the surrounding peaks and constructing large stone arrangements for example on Namadgi Peak, thought to be used for initiation ceremonies (Flood 1996). A natural route from the Murrumbidgee and the Gudgenby valley to the Cotter valley and the main Brindabella Range and beyond is up Bogong Creek, over Bogong Gap, through Rotten Swamp and down Licking Hole Creek. Stone tools are common around both swamps but no dated sequences are known. Increases in charcoal around 3800 cal yr BP may possibly correlate with intensification of Aboriginal occupation after about 3500 BP, recorded at Nursery Rock Shelter (Rosenfeld and Winston-Gregson 1983). The decrease in charcoal around 2000 years ago could reflect increasing sophistication in fire management that resulted in frequent but non-intensive fires. This has been postulated for records from islands where episodic occupation seems to correlate with regular lower level charcoal influx and non-occupation to large fire events and associated slope erosion (eg Hope 1999).

The most significant changes in the vegetation and fire records at both sites occur with European arrival and the change in fire regime brought about both by European stockmen setting fires and the loss of Aboriginal fire management practices. There is an initial increase in charcoal followed by a decrease which is also observed at nearby Top Flat (Hope 2006). The decrease in fires about 90 years ago coincides with the end of the major period of burning in the high country, associated with summer grazing (1850-1880; J. Banks, pers. comm.). Subsequent land-use changes, the creation of parks and reserves and fire prevention and suppression measures have all reduced the number of fires.

Climate control. There is evidence from the high country of south-eastern Australia for increased rainfall, perhaps resulting from lower temperatures, after about 2500 years ago (Costin 1972; Macphail and Hope 1984). Martin (1986) argues from his studies of sites on the Kosciuszko Plateau that such a drop in temperature would have been minimal, but found evidence of environmental, and perhaps climatic, instability between about 3000 and 2000 years ago and of drier conditions after about 1800 years ago. At both Crystal Bog (Williams 1980) and Bunyip Bog (Binder and Kershaw 1978) on the Buffalo Plateau in Victoria, there are distinct charcoal layers dating from the same period. It is likely, then, that the changes in both vegetation and fire regime after 3000 years ago at both sites were due to widespread changes in climatic conditions, rather than Aboriginal burning, but the latter may have also been a factor. In a recent analysis of fire scar records Zylstra (2006) provides a case for overall climate control with the Little Ice Age (ca 450-100 cal yr BP) marked by lower fire frequencies due to cool conditions and possibly fewer dry lightning ignition events. The episodically drier conditions after that are associated with increased fire. This also seems to be the conclusion of Dodson *et al.* (1994) who analysed carbon influx in a marginal bog at alpine Club Lake and demonstrated that the period prior to the Little Ice Age was one of higher charcoal influx.

Vegetational response. After initial development of peatland from a cold and dry Pleistocene alpine environment, vegetation changes at both bogs has probably resulted from altered hydrology. The gradual thickening of the peat increasingly seals off the system from the underlying free-draining coarse sands and clays resulting in a long-term trend towards peat-dammed ponds and structural complexity. Fire reverses these trends but has evidently not been able to prevent the slow accumulation of peatland systems. It remains an open question whether the shorter records from *Sphagnum* bogs (Rotten 6000, Ginini West 4000 cal yr BP) are due to late initiation on slopes or whether they are replacing earlier bogs that have been burnt or eroded.