Post-fire experimental trials of vegetation restoration techniques in the peatlands of Namadgi (ACT) and Kosciuszko National Parks (NSW), Australia

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Introduction

In January 2003, wildfires, ignited by lightning strikes, burnt approximately 2.1 million ha in the ACT, NSW and Victoria. These wildfires burnt a high proportion of subalpine peatlands, (both *Sphagnum*-shrub bog and sedge fens) across the Snowy Mountains, in New South Wales and in the Brindabella Ranges, in the ACT. These communities are widely distributed and cover about 5500 ha in the alpine and subalpine zones of Kosciuszko National Park, but are of limited area and occurrence in Namadgi National Park, where they total 320 ha. The bogs and fens occur above approximately 1000 m altitude at the heads of streams and along stream floodplains where annual precipitation is greater than 850mm and mean annual temperatures below 12°C (Hope 2003).

As *Sphagnum* and its underlying peats are known to be fire-sensitive (Good 2000; Whinam and Chilcott 2002; Walsh and McDougall 2004), there was considerable concern about the

long-term impacts of the fires on the bog and fen ecosystems. This concern, coupled with observation of active peat tunnelling and incision, as well as erosion of natural peat 'dams' in streams, prompted a program to monitor the recovery of the vegetation communities and to trial several techniques to initiate and enhance bog and fen vegetation recovery at selected bogs in Kosciuszko National Park and Namadgi National Park (Figure 1).

Figure 1. Location of sites mentioned in the text

The peatlands that burnt are an important functional component of the water supply to Canberra and to the Snowy Mountains Hydroelectric Scheme as they retain sediment and solutes and moderate flow discharges. The higher altitude sites also act as snow accumulation sites in winter, with the snow thawing in spring and saturating the underlying peatbeds. Most of these peatlands were recovering gradually from the effects of grazing that ended more than 50 years ago (Costin et al 1959; Wimbush and Costin 1979; Good 1992, 2000),

but the January 2003 fires reversed these gains. The few long-term studies of bog recovery trends in Australia have shown that recovery after fires and grazing takes decades (Carr and Turner 1959; Wahren et al. 1996; Wahren and Walsh 2000). *Sphagnum*-shrub bog-with-pool complexes are very slow to recover from disturbance (Ashton and Hargreaves 1993; Good 2000; Whinam and Chilcott 2002; Whinam et al. 2003). Although *Sphagnum* can grow rapidly in favourable circumstances, most undisturbed bogs are currently only accumulating organic matter slowly, or may be oxidising with net loss of bulk and carbon (Clark 1980; Clarke and Martin 1999).

Post fire, while the vegetation in the montane peatlands had been severely damaged, most underlying peat surfaces were scorched by the fires but remained intact. Residual moisture in the peat prevented burning of the peat except along channel edges and other dry sites. In these sites, peat burnt to depths of 5–20 cm, leaving sterile ash surfaces with a pH 6, leading to increased weed invasion, frost heave and peat and flowline erosion.

The *Sphagnum* mires of the Australian Alps are at the climatic limit for these peatlands (Whinam et al. 2003). Evapotranspiration in the hottest month is the limiting factor for the distribution of Australian *Sphagnum* peatlands (Whinam et al. 2003). Up to 70% natural shading by shrubs has been shown to favour *Sphagnum* moss growth (Whinam 1990; Whinam and Buxton 1997). A combination of reseedling with moss and the application of small amounts of low phosphorous fertiliser have been shown to improve recovery rates after *Sphagnum* moss harvesting (Rochefort et al. 2003; Cobbaert et al. 2004) and as a strategy in post-grazing alpine rehabilitation works (Good 1976, 1992, 2000).

The results after four years of trials of vegetation recovery techniques and post-fire monitoring of the peatland vegetation in selected sites in Namadgi and Kosciuszko National Parks are presented here (Figure 1, Table 1). Experimental treatments include (a) different types of shading, (b) addition of fertiliser, and (c) transplants of *Sphagnum* moss. The aim of these trials is to assess additional peatland revegetation techniques which can be incorporated into the extensive restoration and rehabilitation program underway in Namadgi and Kosciuszko National Parks. The restoration program is attempting to restore and rehabilitate the hydrological functioning of these disturbed peatlands (Hope et al. 2005; Good et al. In press). The results of these trials may help guide future peatland restoration and management across the Alps.

Table 1. Sites for post-fire regeneration plots

Site Name	Locality	State	Altitude m	Lat Long
Boggy Plain	Northern Kosciuszko NP	NSW	1370	35°52.7' S, 148°36.0' E
Delaneys Bog	Northern Kosciuszko NP	NSW	1480	35°54.5' S, 148°33.7' E
Ginini Bog	Mt Ginini, Namadgi NP	ACT	1590	35°31.1' S, 148°46.3' E
Pengillys Bog	Central Kosciuszko NP	NSW	1680	36° 22.8' S, 148° 24.8' E
Rotten Swamp	Mt Kelly, Namadgi NP	ACT	1445	35°42.3' S, 148°53.2' E
Snowy Flat	Mt Gingera, Namadgi NP	ACT	1618	35°33.9' S, 148°51.85' E
Tom Gregory Bog	Upper Cotter, Namadgi NP	ACT	1024	35°38.9' S, 148°49.8' E

Methods

Bogs were visited between February and May 2003 to set up plots and assess the 2003 fire damage. As these sites are also localities for the threatened frog species (corroboree frog *Pseudophryne corroboree* and alpine tree frog *Litoria verreauxii alpina*), both of which are sensitive to Chytrid (*Batrachochytrium dendrobatidis*) fungal attack (Lintermans and Osborne 2002), all boots and tools were sterilised in bleach before entering each peatland. Care was also taken to avoid the use of zinc-coated products, given the known long-term problems of zinc toxicity in alpine humus soils (Johnston and Good 1996). Fire damage was measured in terms of the degree of preservation of the biomass and peat profile. The categories of damage were identified as (i) unburnt, (ii) burnt but moss cushion intact, (iii) burnt cushion margins, (iv) charred but root mat intact and (v) burnt and incised. Sketch maps of burn classes were made and photo survey points marked with wooden stakes. These are being used to prepare post-fire maps from rectified air photography flown a few weeks after the fires (Nanson and Hope unpubl. data).

Permanent plots

Permanent plots were established at seven sites (Ginini Bog, Snowy Flat, Tom Gregory Bog and Rotten Swamp in the ACT, and Pengillys Bog, Delaneys Bog and Boggy Plain in Kosciuszko) in April–November 2003 (Figure 1).

The plots sample a range of altitudes (1050–1740 m) in granidiorite catchments, except for Ginini and Tom Gregory bogs, which have shaley metasediment basements. All are located in national parks and catchment areas in which commercial grazing has been excluded for more than 50 years. Some feral stock has been present more recently at some localities (horses at Rotten Swamp and Tom Gregory until 1986 and at Boggy Plain currently). Before the fire, all plots were a mosaic of actively growing *Sphagnum*-epacrid shrub bog in which scattered areas of *Carex* and *Empodisma* fens and *Poa* tussock-dominated herbland (the *Baeckea gunniana*-*Callistemon ptyoides*-*Sphagnum cristatum* wet heathland and subalpine valley grassland communities of MacDougall and Walsh 2007). They were actively grazed by kangaroos, rabbits and rodents such as *Mastacomys fuscus*. The plots are located in open valley sites on gentle slopes on peats of medium depth (95% are on 40–125 cm of *Sphagnum* or humic peat with pH 4–5), subject to both surface-water run-on and runoff. Active streamlines and pools were avoided but waterlogging due to drainage lines varied between quadrat sites. Snow-patch areas were avoided but snow lie varied from a few months at Pengillys to shortlived cover at the other plots.

All plots were damaged severely by the 2003 fire (Table 2) but individual quadrats had variable damage, ranging from being unburnt to quadrats in which the surface peats had been ashed. Almost all quadrats were in damage classes 3 (36%), 4 (34%) and 5 (26%), hence had experienced complete death of vegetation above the surface. It is impossible to standardise quadrats from different localities, but similar settings and substrates are intended to allow comparisons for treatments, damage and other factors between plots.

Table 2. Distribution of damage classes by site

Damage class	Quadrats by damage class by site						
	Boggy Plain	Delaneys	Ginini Bog	Pengillys Bog	Rotten Swamp	Snowy Flat	Tom Gregory
0	0	0	1	0	0	0	0
1	2	1	0	1	0	0	0
2	1	0	0	0	0	2	0
3	4	4	3	21	7	10	4
4	2	4	2	29	7	4	1
5	1	1	4	24	1	4	0
Total number of quadrats	10	10	10	75	15	20	5

At each bog, between five and 75 x 0.25 m² quadrats were established and located by fixed stainless-steel pins driven into the basal gravels. This quadrat size has been used in *Sphagnum* peatlands to monitor natality and mortality rates (Whinam 1995). The quadrats were located in a range of sites with different degrees of fire damage, and sited on hummocks or in hollows. Each plot was assessed for fire damage, surface pH, peat depth and species regeneration. Individual plants were located by 5 cm squares within the quadrat to allow estimates of survival. Quadrats were remeasured twice a year for five years between 2004 and 2009 for plant cover, floristic diversity, peat accumulation/depth and pH values.

Fertilisation and transplants

At Snowy Flat and Pengillys Bog, additional quadrats were set up adjacent to the monitoring plots. Several had fertiliser applications (80 g) of low-phosphorous, slow-release pellets (Osmocote) to determine whether fertiliser would increase moss growth rates (Whinam and Buxton 1997; Rochefort et al. 2003). In March 2003 at Snowy Flat, transplants of fist-sized plugs of living *Sphagnum* cushion were placed in some quadrats to test whether they could act as nuclei for future growth, and some received both fertiliser and a transplant. In October–November 2003, larger transplants, approximately 20 x 20 x 30 cm, cut with a spade from living *Sphagnum* and the underlying peat, were placed in holes in shaded hollows at Tom Gregory and Pengillys bogs. These were hand-fertilised with 10 g of Osmocote at the time of transplant.

Shading

At Pengillys Bog, three shading treatments were established in burnt and partially burnt peat areas during October 2003, using 70% shade-cloth material and loosely spread straw (Figure 2, overleaf). Five plots were established, each one including a 20 m long and 1.6 m high 70% shade-cloth fence aligned east–west. Four quadrats were placed on each side of the vertical shade fence and solar radiation levels on northern and southern sides were recorded over the 2004 summer. The effect of shading was compared with a second treatment, in which 15 m lengths of shade cloth were pegged down horizontally, to lie loosely over the bog surface. A third shade treatment was established using sterilised grass straw spread at a rate equivalent to two tonnes per hectare (70% cover equivalent).

At Rotten Swamp and Ginini Bog, several lengths of shade cloth were laid out across areas of hummock which were exhibiting a small amount of natural regeneration, to enable subjective comparison with adjacent unshaded areas. At Rotten Swamp, five shaded quadrats can be compared with five unshaded quadrats placed 2–4 m away from the shade cloth. The shade treatments will demonstrate whether shading has a beneficial effect on recovery and allow us to differentiate between shade alone (vertical shade cloth) and shade with humidity/evapotranspiration control (mulch and horizontal shade cloth).

Data analysis

The number of plots and number of quadrats per plot at each site varied, largely due to logistical constraints (Table 3). In general, quadrats were remeasured each autumn and spring from 2003 until spring 2005, and then in autumn 2006 and 2007 (Table 4 and Table 5). At Delaneys Bog, which is immediately adjacent to the Snowy Mountains Highway in the north of Kosciuszko National Park, three of the quadrat markers had disappeared by autumn 2007.

Virtually all quadrats had no, or little, vegetative cover post fire, while some showed little regrowth over the entire period of observations. Even in quadrats where regrowth has occurred, there were taxa that showed little or no recovery in any quadrats. Formal statistical analysis was restricted to the analyses of data from those taxa, families, lifeforms and regeneration types for

Figure 2. Set up of shade, fertiliser and transplant plots at Pengillys Bog October 2003

Table 3. Number of plots and number of quadrats per plot at each site

	Site						
Plot	Boggy Plain	Delanceys	Ginini Bog	Pengillys Bog	Rotten Swamp	Snowy Flat	Tom Gregory
1	1	1	1	14	5	4	1
2	1	1	1	14	5	4	1
3	1	1	1	14	5	4	1
4	1	1	1	14		4	1
5	1	1	1	14		4	1
6	1	1	1	5			
7	1	1	1				
8	1	1	1				
9	1	1	1				
10	1	1	1				
Total number of quadrats	10	10	10	75	15	20	5

Table 4. Number of quadrats at which observations were made in each survey time

Year season	Site							Total
	Boggy Plain	Delaneys	Ginini Bog	Pengillys Bog	Rotten Swamp	Snowy Flat	Tom Gregory	
2003 Autumn	10	10	10	5	5	20	5	65
Spring			10	70	5	20	5	110
2004 Autumn			10	55	15	20	5	105
Spring			10	75	15	20	5	125
2005 Autumn	10	10	10	55	15	20	5	125
Spring			10	70	15	20	5	120
2006 Autumn			10	70	15	20	5	120
2007 Autumn	10	7	10	75	15	20	5	142
Total	30	27	80	475	100	160	40	912

The experimental design of treatments based on combinations of shading, fertiliser and moss transplants is shown in Table 5.

Table 5. Treatments based on combinations of physical support and regrowth aids employed at different sites, with the number of replications of factor combinations employed at individual sites

Regrowth aid	Cover	Site							Total
		Boggy Plain	Delaneys	Ginini Bog	Pengillys Bog	Rotten Swamp	Snowy Flat	Tom Gregory	
Fertiliser	Horizontal shade cloth				5				5
	Mulch				5				5
	None						5		5
	Vertical shade cloth north side				10				10
	Vertical shade cloth south side				10				510
Fertiliser and moss transplant	Horizontal shade cloth				5				5
	Mulch				5				5
	None						5		5
	Vertical shade cloth north side				5				5
	Vertical shade cloth south side				5				5
Moss transplant	None						5		5
Nil	Horizontal shade cloth				5	5			10
	Mulch				5				5
	None	10	10	10	5	10	5	5	55
	Vertical shade cloth north side				5				5
	Vertical shade cloth south side				5				5
Grand total		10	10	10	75	15	20	5	145

which there is at least one time of observation when more than 50% of observations is greater than zero (G. McPherson, pers comm.). Even with this restriction, it was necessary to group taxa into families and lifeforms to obtain sufficient non-zero data for treatment comparisons to be possible.

There was substantial variance heterogeneity and evidence of inconsistency among like-treated plots. Statistical analysis was based on the use of a linear, additive and apply repeated-measures analysis of variance (ANOVA) across the time periods for which observations are available, employing the Huynh-Feldt correction for serial correlation. To allow for possible violations in model assumptions, a conservative approach is taken in the interpretation of findings. Only where p-values are less than 0.01 are significant differences assumed, with p-values less than 0.001 assumed to identify strong evidence of differences. It is not judged appropriate to apply any pairwise comparison because the p-values are highly sensitive to model violation.

Results

For illustrative purposes, cover values of plant species are shown for different treatments over time (Figures 5, 6, 8). These cover values have been calculated by dividing the sum of cover percentages of a species in a set of quadrats by the number of quadrats in the set multiplied by 100 in order to standardise the cover estimates derived from variable numbers of quadrats.

Climate of the study period

During the study period (between 2003 and 2007), daily rainfall at the Bureau of Meteorology station at the Perisher Valley Ski Centre, 1712 m, provided a reasonable estimate of precipitation at Pengillys Bog, which is 2.78 km to the north of the centre, at 1680 m, and is the highest, wettest and most southerly site. Annual precipitation values for all years of the study were below the local average (1754 mm per annum), with 2008 recording the lowest annual rainfall (1061 mm) since the local station was established in 1976 (Figure 3). Since the fire, only 2005 recorded precipitation above 1500 mm. Further, the period of study had the most consecutive years with below-average rainfall since records commenced, indicating a very dry period for the local area. The rainfall was predominantly received in spring and winter, with the spring months receiving the most. The temperature for the same period did not show any significant trends, although the mean maximum temperature for the summer months for 2003 and 2006 was three degrees above average (Bureau of Meteorology, 2009), which could have hindered the rate of *Sphagnum* recovery through bleaching. However, there is evidence that the temperature in the alpine areas in Australia has been increasing over the past 35 years (Hennessy et al. 2003).

Daily rainfall figures from automated gauges are available from the ACT mountains, and annual precipitation from Tom Gregory Bog, the lowest and driest study site, is also shown in Figure 3. Rainfall has been below the 1960-1990 mean (981 mm) since 1997 at this site, but the 2002-2003 pre-fire year was not as markedly dry as at Perisher. The other ACT sites track these results, with reasonable spring rain but dry, late summers occurring in most years.

Figure 3. Annual precipitation (mm) 1977-2007 at the wettest site (Perisher Valley near Pengillys) and driest site (Tom Gregory, ACT). Long-term means are 1960-1990

Vegetation response

The data are characterised by the sparseness of presence of most taxa – of the 125 taxa recorded, only five taxa have more than 50% non-zero readings for at least one of the monitoring periods. Only by grouping taxa (families, lifeforms) is there sufficient data for meaningful analysis, and even after this grouping, there tends to be many zero readings. Figure 4 shows that mean floristic diversity (flowering plants, ferns and mosses) increased from three species/quadrat after the fire to eight species/quadrat after 32 months, and has remained stable from 32 to 50 months.

Figure 4. Floristic diversity change through time in mean species per quadrat for seeders and resprouters

Over four years, almost all quadrats recorded increases in cover due to both seed germination of grasses, sedges and epacrids and resprouting by *Empodisma minus* and myrtaceous shrubs. The ratio of resprouters to seeders has declined slightly over this time. Across all sites and treatments, the greatest number of post-fire observations of live taxa on our plots was of graminoids (32% of observations) in autumn 2003, and they retained that dominance throughout the monitoring until autumn 2007 (96% of observations).

There is insufficient data to quantitatively analyse the benefits of the restoration techniques on the recovery of *Sphagnum* moss (predominantly *S. cristatum*). However, *Sphagnum* recovery does provide some broad indication of trends (Figure 5), with total *Sphagnum* cover in non-

transplant plots under all other treatments increasing from 100 m²/ha to 850 m²/ha after 32 months, and stabilising after this to 50 months.

Figure 5. Total non-transplanted *Sphagnum* moss cover through time, shown as m²/ha. The contribution of plots with >10% and plots with <2% is shown

Figure 5 shows that most *Sphagnum* regeneration occurs by the expansion of the larger patches (>10% cover) of *Sphagnum* after 20 months. Many quadrats did not regenerate over 50 months, and low-cover patches (<2%) did not always persist. At 20 months, some sheltered and moist sites showed signs of regeneration and recruitment of moss, but exposed burnt hummocks remained dead. The proportion of non-transplant quadrats containing live *Sphagnum* rose from 10% after the fire to 62% at 32 months and has since declined to 50% at 50 months. This may reflect continuing below-average rainfall at all sites.

There is no strong evidence that between-site variability in respect of changes in percentage cover is greater than within-site variability for any taxa or broader grouping that could be analysed ($p > 0.01$). Statistical analysis does indicate that the pattern and extent of recovery is dependent on the treatment or treatments employed for some taxa and broader (family and/or lifeform) groupings. Based on total percentage vegetation cover for all native species (not graphed here), there is evidence of treatment difference ($p < 0.001$), with the earliest and most extensive recovery associated with horizontal shade cloth combined with the addition of fertiliser. This treatment favoured species that can resprout after fire when compared with species that are seed obligates. While different treatments have favoured different taxa, in general revegetation treatments that include the addition of fertiliser provide the fastest rate of recovery of vegetation cover. A range of taxa contributed to increases in vegetation cover, including *Poa costiniana*, other grasses, graminoids, bryophytes and shrubs. The combination of fertiliser and moss transplants had the greatest impact on the cover of *Poa costiniana*, however horizontal shade cloth alone provided for the greatest increase in the vegetation cover of *Empodisma minus*.

and *Baloskion australe*, while assisting the early establishment and regeneration of remnant *Sphagnum* plants. Straw mulch favoured only the Cyperaceous graminoids.

Figure 6 shows the response of *Sphagnum* to the shading treatments, with controls for comparison. Horizontal shade appears to maintain *Sphagnum* cover, in comparison with the small increases in cover values seen in the controls after 30 months.

Figure 6. Comparison of treatments in terms of *Sphagnum* cover m²/ha: 1. Control, 2. Horizontal shade without transplants, 3. Mulch straw (no transplants), 4. Fertiliser, transplants and all shade treatments

Where plots were treated with horizontal shade cloth, there was good recruitment and the greatest expansion of transplants after 20 months. Both horizontal and vertical shade treatments showed declines in some transplant cover in the first six months, but then a continuous increase in cover to 50 months. When shade cloth was removed, the exposed vegetation was thicker, taller and greener than adjacent unshaded plots, but further measurements will reveal whether these effects persist over time (Figure 7, overleaf).

The assessment of the effects of all horizontal shade-cloth-only treatments on species cover combines Rotten Swamp and Pengillys Bog data for comparison with controls at these sites. When compared with unshaded plots, there is significant difference in recovery of all native plant species (percentage vegetation cover) treated with horizontal shade cloth over time ($p=0.001$), although forbs are the only lifeform that show significant increases in cover over time ($p=0.005$). Although the overall results from Rotten and Pengillys are similar, the data from Rotten Swamp are obtained from limited plot data and so results rely heavily on an assumption that the observations there are typical of the entire site. There was considerable inter-plot variability at Pengillys Bog, showing that not all shaded quadrats shared a positive response and that some unshaded quadrats recovered strongly on their own. Straw mulch, used only at Pengillys, had less effect than the controls, and had largely disappeared by 32 months and was undetectable at 50 months. Strong winds removed the mulch from some quadrats.

Figure 7. Shade cloth at Rotten Swamp removed for survey March 2007

The effects of fertiliser, transplants and shade on *Sphagnum* cover (m^2/ha) are shown in Figure 8 (opposite). Low overall survival rates of the fist-sized transplants at Snowy Flat prevent a comparison of transplant-only and fertilised transplants. Only the larger transplants were successful, but all transplants at Tom Gregory and Pengillys received fertiliser.

For all fertilised plots, the continuing rise in moss cover after 32 months is largely due to moss expansion in quadrats with shade, but unshaded plots showed stable or declining cover. Hence, fertiliser on its own may not outperform the controls. However, fertiliser seems to support transplant growth, with most transplants also responding to shade. Analysis of plots that had no treatment applied showed there were no differences in cover of any species over time by site. However, when analysing changes in vegetation cover by only the time variable, *Empodisma minus*, *Balaskion australe* and *Luzula* sp. all showed significant increases in changes of percentage cover over time ($p < 0.01$).

Discussion

In our study, tussock grasses (*Poa* spp.) and rhizomatous restiads (*Empodisma minus* and *Balaskion australe*) have rapidly regenerated from stools and underground rhizomes and they are replacing areas of dead *Sphagnum* moss. Shrubs of *Baeckea gunniana* and *Callistemon sieberi* were resprouting within 20 months, but epacrids, particularly *Richea continentis*, only started to appear in our plots after 20 months, suggesting that they will only regenerate from seed, as also noted by Keith (2002). In several plots, moss species, notably *Polytrichum* sp., are growing on burnt peat and dead *Sphagnum* cushions, a phenomenon noted in other burnt peatlands (Huber and Markgraf 2003).

Sphagnum regeneration has been shown to be complex and delayed. Long-term recovery to pre-fire *Sphagnum* cover will require significant colonisation and spread of *Sphagnum* beyond

Figure 8. Effects of fertiliser and transplants on *Sphagnum* cover by comparison with controls. The quadrats include both shaded and non-shaded values. The initial steep rise is an artifact, as the earliest transplants were small and the larger transplants were not placed until month eight

the regeneration achieved in the first 32 months. Drought may in part explain the levelling out of the overall extent of *Sphagnum* cover after 32 months, but hummocks with shaded flanks and in moist shaded hollows have often continued to expand. These favourable micro-habitats seem to have enhanced survival and subsequent recovery of large patches of *Sphagnum* moss, in some cases not until more than 25 months after the fire. It is also clear that *Sphagnum* has not been able to regenerate on some plots. Such plots are typically severely burnt, or located on the exposed tops of dead hummocks, or located on drying sites where water flow has gone underground. However, after 18 months, many dead hummocks became crusted and hydrophobic and some had completely eroded down to hollow level by 50 months. These results indicate that very long recovery times are needed to restore *Sphagnum* bog structure. Hence, implementing a specific and appropriate fire-protection program for bogs and fens, particularly for high to very high intensity wildfires, may be necessary if long-term loss of bogs is to be avoided.

Peat where *Sphagnum* moss has been completely killed by the fire reached pH values of 5–7 shortly after the fire, but most moist sites returned to normal long-term values (pH 4–4.5) in the four years after the fire. The success rate of the large moss transplants at Tom Gregory is already less than 40% and it is recognised that site choice for transplants is critical, with shaded wet hollows offering the best chance for establishment and growth. The combination of transplants and fertiliser appears to be the most successful treatment at this time (2010). Ninety percent of the transplants at Pengillys Bog were successful in 2007, but site setting in wet hollows appeared to be more critical than any shade treatment. Figure 9 shows *Empodisma* expanding above a healthy transplant in a badly burnt plot with little other regeneration. In some transplants *Sphagnum* was outcompeted by tussock grasses or sedges that responded to fertiliser. These results show that transplants have some potential for re-establishing *Sphagnum*

in areas from which it has been largely excluded, but are subject to a high rate of failure and probably not worthwhile where early natural recovery is observed.

Figure 9. Successful *Sphagnum* transplant and fertiliser treatment in severely damaged area at Pengillys

Differences were observed between horizontal and vertical shading. The horizontal shade cloth and litter not only provided shade protection, but also reduced evaporation and wind movement over the burnt vegetation. The vertical shade cloth benefited species number, but only provided a benefit for a small area adjacent to the shade structure. Straw mulch was reasonably persistent after one year and effective in shielding moss hummocks, but after 12 months had packed down into mats, and after two to three years had decomposed. Neither shade treatment seems to be effective in encouraging moss development when compared with controls (Figure 6). However, shading had beneficial effects for most other lifeforms, with vegetation under shade cloth observed to have increased vigour and growth when compared with unshaded plots. Straw commonly has been used in restoration projects as a protective mulch and was initially used in these trials. However, the difficulty of transport and effective spreading of the straw at the required rate make it difficult to use in large field restoration programs. The use of shade cloth was found to be a suitable alternative and is now recommended, as it provided a uniform 70% shade cover and could be readily rolled out over large areas, or laid out by slinging under a helicopter.

Recent field rehabilitation and restoration work (post 2003 fires) in the NSW and Victorian alps (Good 2006; Good et al. In press) and the field experiments reported here indicate the importance of shading for *Sphagnum* growth and recovery. Shrubs (*Epacris* spp. *Baeckea gunniana* and *Richea continentis*) and taller herbs (*Empodisma minus* and *Baloskion australe*) provide shading in stable natural mires. *Sphagnum* regenerates very slowly, if at all, after severe burning of *Sphagnum* hummocks, but artificial shading provides the critical level of protection from solar radiation (high UV levels) and wind desiccation for any surviving plants, and a considerable enhancement of the rate of regeneration of *Sphagnum*. From the

results of this study, *Empodisma minus* has also benefited from artificial shading, but is not dependent on it for survival and regeneration.

While there were a significant number of weed species recorded post fire, none of the treatments appears to have differentially favoured the weeds, although some plots have become dominated by weed species, such as *Acetosella vulgaris*, *Cirsium vulgare*, *Holcus lanatus*, *Hypochaeris radicata* and *Taraxacum officinal*. These are largely the most damaged plots where surface peats were burnt. The enhancement of *Sphagnum* regeneration and its water-retention capacity is likely to minimise colonisation of the fire-damaged bogs and fens by particular weed species. Dead *Sphagnum* and the drying of the underlying peat potentially provide a suitable environment for active colonisation by weeds and native herbaceous species from the surrounding grasslands. Our data, and observations post fire, indicate that bog and fen ecosystems can be readily transformed to grassland if the ecosystem dries out, indicating the importance of ensuring appropriate moisture/water regimes are maintained or recovered.

The trials sought to establish the potential and value of early intervention to accelerate the natural succession to mature *Sphagnum*-shrub bogs. It is still too early to fully quantify the value of artificial shading, transplants and fertiliser applications to the regeneration of bog communities. Although considerably altered from the pre-disturbance state, regeneration of damaged bog and fen vegetation is possible, and can be enhanced by rehabilitation techniques, such as the addition of fertiliser and the provision of shading. Transplants may have a limited role in some cases. Our experimental and monitoring programs aim to support the choice of techniques that will enhance regeneration and guide future management of these peatlands.

This analysis after only four years indicates that bog and fen vegetation, particularly the significant and functionally important *Sphagnum*, can be enhanced in its rate of recovery, thus shortening the long regeneration time of bog and fen ecosystems that would occur under 'natural' regeneration. The restoration of the water-retention capacity and the functional hydrological role of the underlying peats is an extremely long process (up to 30 years). The implementation of vegetation restoration techniques is only the starting point to full recovery of these systems, which will require sensitive ecologically based management for many years. Remeasurement of plots in the future will allow the longer-term efficacy of the trials to be assessed more fully.

Bogs and fens have a fundamental role in catchment hydrology in the Alps and should be maintained in a condition that ensures catchment stability, water yield, water quality and stream flow regimes. This is likely to become an even greater management issue as the importance of bogs and fens for catchment management becomes clearer, with climate-change predictions – including increases in bushfire intensity and occurrence – for the Alps being realised in the next decade or two (Zylstra 2008).

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