Progress in the recovery of the flora of treeless subalpine vegetation in Kosciuszko National Park after the 2003 fires

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Abstract: The fires of January 2003 burnt much of the treeless high mountain country of Victoria, New South Wales and the Australian Capital Territory, and were the first extensive conflagration of this area since 1939. For this reason there are remarkably few studies of the response of alpine plants and vegetation to fire. A flora survey of treeless subalpine vegetation in the Kosciuszko area in late 2002 sampled 215 sites. Of the 119 sites that were burnt, 60 were relocated and re-sampled in late 2003 to assess the mode and extent of regeneration in a range of treeless plant communities. Twenty-four species (including 3 exotics) were recorded only in the pre-fire sampling. Fifty species (including 18 exotics) were recorded only in the post-fire sampling. One species, *Chenopodium erosum,* had not previously been recorded in Kosciuszko National Park, and is believed to be the first native chenopod recorded in alpine vegetation in Australia. There was no significant difference in mean number of species per quadrat between pre-fire and post-fire quadrats. The average number of weeds per quadrat was, however, significantly greater post-fire. Most of this difference was attributable to the significantly greater number of weeds per quadrat in bog vegetation after the fire. Of the 290 species recorded, 111 species regenerated from seed, 197 species regenerated from resprouting organs (roots, tubers and/or basal stems) and 49 species regenerated from both seed and resprouts. Based on the regeneration observed, most plant communities will return naturally to their pre-fire species composition and cover over a period between a few years and a few decades. Major exceptions will be those communities where the 'keystone' species appear to have been lost at least at a local scale. Principal amongst these are bog communities that incorporated significant biomass of *Sphagnum cristatum* pre-fire, *Podocarpus lawrencei* shrublands and *Celmisia costiniana* closed herbfields. Consideration might be given to augmenting their recovery. It will be important to exclude fire from these communities until their recovery is complete.

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Introduction

The fires of January 2003 burnt over 1.4 million ha in north-eastern Victoria, south-eastern New South Wales and the Australian Capital Territory. These fires were started by an intense electrical storm on January 8, igniting many small fires, some of which burnt unchecked before uniting into a massive and destructive fire front. The fires of 1939 are the only recorded fire event comparable in intensity and extent in the Australian Alps.

Few published accounts document the recovery of alpine and subalpine plant communities following fire in Australia (e.g. Kirkpatrick & Dickinson 1984, van Rees & Walsh 1985, Leigh et al. 1987, Lawrence 1999, Wahren & Papst 1999, Wahren & Walsh 2000). Studies that have had the benefit of pre-fire vegetation data are fewer (van Rees & Walsh 1985, Wahren, Papst & Williams 2001, Wahren & Walsh 2000). Other studies investigating response to disturbance in alpine or subalpine areas focus on disturbances that are basically anthropogenic (e.g. skifield or resort development or grazing, Keane et al. 1980, Wahren et al. 1994), these generally being different in nature, extent and response.

This study reports on responses of plants in treeless subalpine plant communities of Kosciuszko National Park (KNP) that were burnt in the January 2003 wildfires. The responses were recorded in quadrats first sampled in November and December 2002, and resampled during the summer of 2003–2004.

Study area

The study area was the treeless subalpine plains of KNP (Fig. 1). Treeless plains occupy valley bottoms from the lowest parts of KNP (c. 1100 m) to near the limit of tree growth (c. 1900 m). The absence of trees is attributed to the low temperatures and frost associated with cold air drainage and pooling, which limit tree establishment and survival (Harwood 1980). All of the sampled sites receive regular winter snow-falls but snow persists for long periods only on the higher sites, generally over 1400 m. The annual rainfall ranges from 1680 mm in the western part of the study area at Cabramurra to 1835 mm at Thredbo in the east. Soils range from alpine humus to peat and tend to be highly acidic. They overlay parent material of a range of types including granite, basalt, limestone and shale. The vegetation is largely grass-dominated, although some of the rocky rises within plains are shrubby. *Eucalyptus lacrimans* is an occasional dominant of ridges and hilltops in the Kiandra area. *Sphagnum*-dominated bogs are occasional in drainage lines. Subalpine treeless plains in KNP may be floristically highly diverse (McDougall & Walsh 2002).

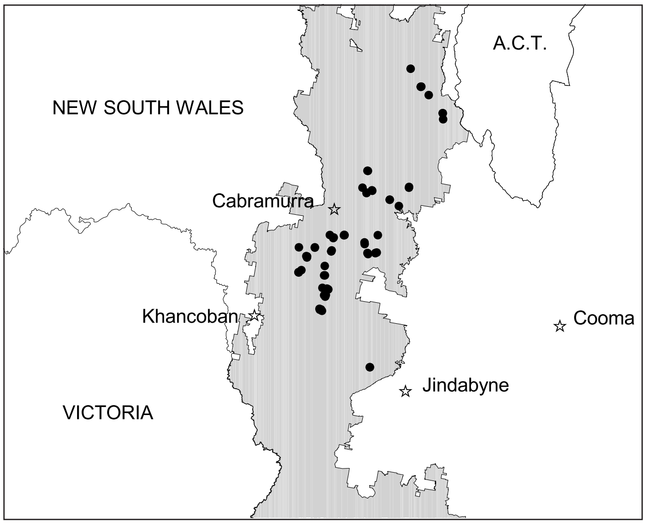

Fig. 1. Location of quadrats (circles) in Kosciuszko National Park (shaded).

Methods

In November and December 2002 we sampled areas of treeless subalpine vegetation in the Kosciuszko area with a view to constructing a community classification of these vegetation types throughout the south-eastern Australia mainland. This work would add to studies previously published for similar vegetation in Victoria (McDougall 1982, Walsh et al. 1984). Sites investigated during this study were based on 5 × 5 m quadrats, located using GPS coordinates (accurate to c. 3 m), and described using site attributes (such as slope, aspect and vegetation structure) and all vascular plant species recorded using the Braun-Blanquet cover/abundance index.

Of 215 sites sampled during the 2001–2003 period, 119 were burnt to some extent in January 2003. An attempt was made to accurately relocate as many of the burnt sites as possible by using GPS locations, field notes, memory, and the species lists previously compiled. Quadrats were only re-sampled if they could be confidently relocated and more than about 75% of the quadrat was burnt. Species that were present in quadrats only as 'fire-escapers' in partly burnt quadrats were noted but not included in data analyses. Sixty quadrats were re-sampled. Although it is possible that the re-sampled 5 × 5 m quadrats may not have precisely overlain the quadrats sampled in 2002, quadrats were initially carefully chosen to lie in uniform vegetation so the variance between the two sampling periods due to spatial incongruence alone should have been minimal. Species not recorded in the post-fire sampling may have been overlooked due to the diminutive or cryptic nature of seedlings, but we believe oversights of this nature are probably relatively insignificant in the overall analysis. Groups most likely to have been misidentified or overlooked were seedling grasses and sedges, different species of which are very similar at the young seedling phase. Juvenile forbs that were unable to be identified in the field were collected from outside quadrats and grown on to maturity under nursery conditions for subsequent identification.

The selected quadrats were pegged with a stainless steel marking pin for future reference and pairs of digital photographs, centred on each site, were taken from opposite directions. Within each quadrat, all species were recorded with an estimate of cover based on the Braun-Blanquet cover scale (Braun-Blanquet 1932). An estimate was also made of total percentage vegetative cover. The method of regeneration was recorded for each species (where possible) as was the phenological (flowering/vegetative) state. Opportunistic observations of species regeneration were made in similar vegetation in other parts of the Australian Alps during the summer of 2003/04.

Data analysis

The significance of differences in the numbers of species per quadrat and numbers of weeds per quadrat between the pre-fire and post-fire samples was determined using *t*-tests for paired samples for each broad vegetation group. The significance of differences in total % vegetative cover between broad vegetation groups post-fire was determined using a *t*-test. Although total % vegetative cover was not measured before the fire, all quadrats used in the analysis had close to complete cover at that time as is typical for similar undisturbed alpine and subalpine communities (Carr 1977, Williams & Ashton 1987a). Quadrats containing a large proportion of rock were excluded from the analysis.

Results and discussion

In broad categories, the 60 quadrats sampled comprised 13 bog/wet heath, 9 fen/wet grassland, 8 dry grassland, 16 open heath, and 14 closed heath vegetation examples. A total of 290 vascular plant species (including 27 exotics) were recorded (Appendix). Twenty-four species (including 3 exotics) were recorded only in the pre-fire sampling — five of these had been recorded in more than two pre-fire quadrats: *Cotula alpina* (3 quadrats), *Epacris celata* (3), *Epacris petrophila* (7), *Olearia algida* (6), *Richea continentis* (6). Fifty species (including 18 exotics) were recorded only during the post-fire sampling — six (including three exotics) of these were recorded in more than two post-fire quadrats: **Cerastium glomeratum* (5 quadrats), **Cirsium vulgare* (12), *Dichelachne crinita* (4), *Picris angustifolia* subsp. *merxmuelleri* (3), **Trifolium campestre* (3), *Veronica gracilis* (5). Although many of the new species found in quadrats were seen only occasionally, the grass *Dichelachne crinita* was abundant and obvious in the Broadway Plain area south of Tooma Dam. It was not observed at all there in the previous summer. Within the first year after burning, 39% of native species were observed to flower.

There was no significant difference in mean number of species per quadrat between pre-fire and post fire quadrats, although there were significantly more species per quadrat in open heathland quadrats before the fire than after (Table 1). The average number of weeds per quadrat was significantly greater post-fire. Most of this difference was attributable to the significantly greater number of weeds per quadrat in bog

Table 1. The number of species / quadrats and weeds / quadrat (± SE) in each broad vegetation grouping, pre- and post-fire. The significance of differences between means for each vegetation grouping and the total quadrats was determined by *t*-tests for paired samples; * *P* < 0.05; ** *P* < 0.01

	Species / quadrat		**Weeds / quadrat**	
Vegetation Grouping (n)	**Pre-fire**	**Post-fire**	**Pre-fire**	**Post-fire**
Bog / wet heath (13)	20.5 ± 0.7	22.6 ± 0.8	0.5 ± 0.2	2.3 ± 0.4**
Fen / wet grassland (9)	21.8 ± 0.8	19.7 ± 0.8	2.3 ± 0.5	3.0 ± 0.7
Dry grassland (8)	23.7 ± 0.9	26.6 ± 0.8	3.0 ± 0.6	3.6 ± 0.7
Open heathland (16)	30.6 ± 0.6	26.2 ± 0.7*	2.1 ± 0.3	2.6 ± 0.4
Closed heathland (14)	22.0 ± 0.6	22.8 ± 0.7	1.2 ± 0.3	1.6 ± 0.3
All quadrats (60)	24.3 ± 0.3	23.7 ± 0.4	1.7 ± 0.2	2.5 ± 0.2**

vegetation after the fire. Almost half of the exotic species newly recorded in quadrats after the fire were found in bog quadrats: *Acetosella vulgaris* (3 quadrats), *Agrostis capillaris* (1), *Bromus hordeaceus* (1), *Cerastium vulgare* (1), *Cirsium vulgare* (5), *Conyza bonariensis* (1), *Hypochaeris radicata* (3), *Salix cinerea* (1), *Taraxacum officinale* (1), *Trifolium arvense* (1), *Trifolium campestre* (2), *Trifolium repens* (3), *Vulpia bromoides* (1).

Fire behaviour

The fire burnt in all of the broad vegetation groups sampled. Its intensity and extent were variable, even at a very small scale, with small patches of vegetation escaping the fire within an otherwise charred landscape. Although the fire burnt much of the woody vegetation, there were some shrubs and trees that commonly escaped: patches of unburnt *Leptospermum grandifolium* were often observed in gullies in subalpine forest; the fire, although intense in the Happy Jacks Plain area, only partly burnt a large *Podocarpus lawrencei* shrubland bordering a block stream; small patches of snow gum (*Eucalyptus pauciflora* and *E. niphophila*) were apparently untouched next to patches that had had their crowns burnt.

The severity of the fire was not always obviously correlated with the amount of fuel present. Two sparsely vegetated rocky outcrops near Happy Jacks Plain were burnt so severely that even many resprouting species could not be located after the fire, and of the 76 species recorded in two quadrats before the fire, only 40% were relocated. A wet area adjoining one of the outcrops, where a quadrat had been sampled before the fire, was completely devoid of vegetation and had eroded to a depth of about 3 cm below the original soil surface (Fig. 2). The quadrat could not be accurately relocated as there were no hints of its original position.

In some grasslands where the fire had been less severe, burning had apparently only occurred where shrubs had grown and in their immediate vicinity. Many such grasslands were otherwise untouched by the fire. The severity of the fire in grasslands appeared, in places, to be related to the density of the dominant *Poa* species — some dense *P. costiniana* grasslands being lightly singed whilst more open *P. hookeri* and *P. clivicola* grasslands being more comprehensively consumed. Bog vegetation, when burnt at all, was commonly burnt severely, even when the adjoining grassland communities were unburnt or barely singed. A very light fire in bog vegetation was often enough though to kill plants such as *Richea continentis*, which were sometimes found dead with their leaves intact and no indication of burning.

The patchiness of the fire has important implications for the way its impact is evaluated now and in the future. Spatial studies of fire impact (where the vegetation on opposite sides of a fire boundary are compared) must assume that the burnt and unburnt vegetation were of equal fire risk and that both sides of the boundary were floristically similar before the fire. From our observations many fire boundaries would not make for reliable comparisons of burnt and unburnt vegetation. As recovery occurs and the signs of the fire disappear, patches of fire-escaped vegetation will blend into the overall burnt landscape. Maps of fire extent will probably not be at sufficient resolution to allow detection of fire-escaped patches so there is a danger that future assessments of fire recovery will assess both burnt and unburnt vegetation. Aerial photography might be used as a future check on fire status.

Regeneration strategies

Of the 290 species recorded, 111 species regenerated from seed, 197 species regenerated from resprouting organs (roots, tubers and/or basal stems) and 49 species regenerated from both seed and resprouts (Appendix).

In general, grassland species (e.g. *Poa* spp., *Austrodanthonia* spp.), sedges (*Carex breviculmis*, *C. hebes*), daisies (e.g. *Brachyscome* spp., *Craspedia* spp., *Leptorhynchos squamatus*, *Senecio* spp.) and other forbs (e.g. *Plantago euryphylla*, *Ranunculus graniticola*) were largely or entirely resprouters. The vegetative cover in wet and dry grasslands was significantly higher 10 months after the fire than in the other broad vegetation types assessed (Table 2). By that time, short grasslands dominated by *Poa hookeri* had apparently more or less returned to their pre-fire vegetative cover and species composition.

Shrublands were dominated by a relatively high proportion of species that were dependent on seedling recruitment (e.g. *Phebalium squamulosum*, *Grevillea australis*, *Asterolasia trymalioides*, *Westringia lucida*), although some shrubs were noted only as resprouters (e.g. *Hakea microcarpa*, *Orites* *lancifolia*, *Tasmannia xerophylla*, *Olearia* spp.), and some exhibited both strategies (e.g. *Bossiaea foliosa*, *Hovea montana*, *Oxylobium ellipticum*, *Podolobium alpestre*). Shrublands appeared to have burnt at very high temperatures, presumably due to their architecture and the inherent flammability of the plants themselves. Much of the woody material and usually all leaf litter was burnt (in contrast to most other broad vegetation types), resulting in the lowest cover of vegetation following fires (Fig. 3, Table 2). This group of communities is probably most prone to soil loss in the immediate (up to c. 2 years) post-fire period.

Table 2. Mean and range of total % plant cover (± SE) in each broad vegetation grouping post-fire. The significance of differences in means between vegetation groupings was determined by multiple *t*-tests. Means with the same superscript letter are not significantly different, *P* > 0.05.

	Total plant cover (%)	
Vegetation Grouping (n)	**Mean (± SE)**	**Range**
Bog / wet heath (13)	31 ± 6^{ac}	5–75
Fen / wet grassland (9)	56 ± 10^{b}	10–95
Dry grassland (8)	58 ± 8^{b}	25–90
Open heathland (11)	38 ± 8^{a}	2–70
Closed heathland (13)	16 ± 4^{c}	1–40

Open heathlands showed a regenerative response somewhere in between those of the grasslands and shrublands, sharing many of the species of those structural types, but generally, extreme soil exposure was limited to those areas underlying non-resprouting shrubs (chiefly *Grevillea australis* and *Asterolasia trymalioides*).

Bog vegetation, dominated by *Sphagnum cristatum*, showed perhaps the greatest loss of important structural species following fire. Apart from *Sphagnum* itself, which is generally dependent on remnant unburnt fragments for regeneration (fertile plants having been very rarely reported in the Australian high country), the woody epacrids (*Epacris celata*, *E. gunnii*, *E. petrophila*, *Richea continentis*) are almost entirely dependent on seedling recruitment for re-establishment following fire. Studies of burnt bog vegetation in Victoria (NGW pers. obs.) have shown the time for germination in these species may be as much as 18 months. These data are consistent with the responses of this group of plants in KNP. Conversely, other shrubs in bogs such as *Baeckea gunniana* and *Callistemon pityoides* are strong resprouters. The peats underlying the bogs and wetter patches of *Sphagnum* generally retained some moisture and, in most cases, resisted complete combustion, but in the most severely burnt examples, the peats burnt down to mineral soils (Fig. 4).

Overall, there were very few species that were found much less frequently in post-fire quadrats than in pre-fire quadrats (Table 3). Several of these were the obligate seeding shrubs mentioned above. The species found less frequently in post-fire quadrats may simply be the slowest to regenerate. *Kunzea muelleri*, for instance, which forms large, layering mats had only begun to resprout in occasional patches at the time of

Fig. 2. Erosion in a damp area near Happy Jacks Plain following the fire. The quadrat at this site could not be relocated as all plant material had disappeared.

Fig. 3. There was often almost no plant cover in shrub dominated communities one year after the fire. Sites such as this will be vulnerable to soil loss for much longer than surrounding grasslands.

Table 3. Species apparently disadvantaged by fire in the year after the fire (pre-fire frequency more than twice the pre-fire frequency and occurring in at least 4 quadrats pre-fire). Species records for escapes from the fire are not included in the post-fire frequency.

Species	f pre-fire	f post-fire
Epacris gunnii	19	2
Epacris petrophila	7	1
Euphrasia collina subsp. *paludosa*	12	3
Grevillea australis	21	6
Hypericum japonicum	8	2
Kunzea muelleri	14	4
Luzula flaccida	13	6
Melicytus dentatus	8	3
Olearia algida	7	1
Oreomyrrhis ciliata	13	3
Pimelea biflora	7	1
Prasophyllum sphacelatum	5	2
Ranunculus millanii	6	2
Richea continentis	6	0
Scleranthus biflorus	25	4

Fig. 4. The complete cover of *Sphagnum cristatum* at this bog on Rennix Plain was severely disprupted by the fire and some hummocks have been left isolated from their water supply. The fire commonly burnt along the stems of epacrids through the *Sphagnum* layer and deeply into the peat below. Photo: Colin Totterell.

Fig. 5. Although the majority of stems of *Podocarpus lawrencei* plants were killed in this population, some branch tips survived. These may allow the rapid regeneration of this species in such sites. The tussocks adjoining the shrubland were untouched by the fire.

the post-fire survey. More extensive regeneration was observed later in the summer of 2003–2004 (c. 15 months after the plants were burnt).

Although there is no reason to expect that regeneration will not ultimately be seen in all of the species disadvantaged in the short-term – there have been other fires in the high mountain areas even in the 20th Century — some long-lasting effects are likely. Resprouting of completely burnt *Podocarpus lawrencei* shrubs, some subsequently found to be more than 200 years old (A. Schatunowski, Australian National University pers. comm.), has not yet been observed. The large stems of burnt veterans of this species appear to be dead. Short leafy branchlets resprouted along lightly burnt *Podocarpus* stems in the Perisher Ski Resort in KNP but most of these had died by March 2004 (KLM pers. obs.). Abundant *Podocarpus* seedlings were observed at Perisher at that time and these were also observed in areas burnt by the 2003 fires on the Cobberas Mountains, Victoria (F. Coates pers. comm.). Significant recovery of many of the *Podocarpus* shrub communities on block streams, the primary habitat for the Mountain Pygmy Possum, may only be seen by the next generation of plant ecologists. Another fire before the current cohort of *Podocarpus* seedlings have matured could be catastrophic for the species and the community in which it dominates. Fortunately, in most of these communities some *Podocarpus* shrubs escaped the fires, probably due to the sparse cover of shrubs amongst the rocky scree (Fig. 5). These mature escapees should contribute seed both to the bare surrounding soils and to the Mountain Pygmy Possums that feed on the species.

Although not recorded in the current study, *Celmisia costiniana* is a species that looks likely to be affected in the long term in areas where it was burnt. This species forms large patches, often in areas of late lying snow. It is strongly rhizomic and, intuitively, would be expected to resprout following fire. Many of the large patches of *C. costiniana* we have observed in KNP and on the Bogong High Plains have shown no signs of regeneration from perennating shoots or from seed. The failure of regeneration from seed is not so surprising as plants in these mono-specific patches rarely flower and in years when flowering occurs seed set is commonly very low through endogenous or exogenous (e.g. predation by insect larvae) factors. The bases of burnt plants can now be easily dislodged and there would seem to be little chance that future resprouting will occur. As this species fills, as the overwhelming dominant, an important niche in the alpine landscape, it will be interesting to see what replaces it or if there is a latent seed reserve still awaiting an opportunity for germination.

Table 4. Species apparently advantaged by fire (post-fire frequency more than twice the pre-fire frequency and occurring in at least 4 quadrats post-fire).

Species	f pre-fire	f post-fire
Carex hebes	8	17
**Cirsium vulgare*	0	12
Drabastrum alpestre	2	5
Neopaxia australasica	2	6
Stellaria multiflora	7	15
Viola fuscoviolacea	1	10

Of the species commonly found more frequently after the fire, four were perennials (Table 4). In the case of *Carex hebes* it is possible that it was overlooked in the pre-fire sampling, as many species flowered poorly at that time. *Drabastrum alpestre*, *Neopaxia australasica* and *Stellaria multiflora* all appear to be disturbance-loving and have been found to be frequent colonisers of soil up-heaved by pigs at Nungar Plain in KNP (McDougall & Walsh 2002). *Cirsium vulgare* does seem to have been advantaged by the fire and is now common in many plant communities, especially bogs. It will be worth monitoring its abundance in coming years to determine if it has used the fire to gain a foothold in KNP or if it is simply a transient species. Some species were highly conspicuous after the fire but were not found in additional quadrats by us. For example, *Stellaria pungens* was a locally dominant plant following the fire and, when in flower, was one of the most prominent species present in subalpine areas. It was, however, found in as many of our quadrats before the fire as it was after (Appendix), suggesting that its prominence was due to an increase in cover rather than in distribution.

Species of conservation significance

Interestingly, a number of species of conservation significance were encountered post-fire but not recorded before the fires. Within the quadratted areas, these included *Barbarea grayi* (1 site), *Pelargonium helmsii* (1 site) and *Taraxacum aristum* (2 sites). *Wahlenbergia densifolia* (1 site) had been recorded in a few pre-fire quadrats, but also appeared in one of the burnt quadrats in which it was previously not recorded. These species were noted more commonly in treeless areas generally (i.e. as well as in quadrats) following the fires. *Chenopodium erosum*, a species not recorded in quadrats, was noted as a common species in burnt shrublands, often in association with *Pelargonium helmsii*. It was especially common between Guthega and Mt Jagungal and extended into the alpine zone (to about 1900 m above sea level). This species was hitherto not recorded for KNP. *Drabastrum alpestre*, a species recorded occasionally in disturbed sites (mainly caused by pig foraging) before the fires, was abundant post-fire. *Pelargonium helmsii* (Fig. 6) and *P. australe* had been rarely collected in the subalpine and alpine areas of KNP before the fire. Both species were found to be locally abundant after the fire. Although these species were indistinguishable in their vegetative state, the leaves of *P. helmsii* were found to have a strong smell when crushed, intensely reminiscent of Coriander (*Coriandrum sativum*). Those of *P. australe* had a more familiar *Pelargonium*-like odour.

The occurrence of alpine or subalpine fire ephemerals is surprising. The longevity of seeds of these species would appear to be measurable in decades, perhaps approaching a century or more. The alternative to this perspective is that the frequency of fires in the alps is currently underestimated. It is possible that relatively small-scale lightning-ignited fires are moderately frequent, perhaps particularly at scattered lightning-prone sites. The scatter of these sites across the landscape may be sufficient to allow the persistence of the fire-ephemerals noted above.

Some species (*Bossiaea* sp. aff. *riparia*, *Hovea* sp. aff. *heterophylla*, *Swainsona monticola*) appeared to have been disadvantaged by the fires, at least in the short term. *Bossiaea* sp. aff. *riparia* is probably simply an obligate seeder and will hopefully return in abundance. *Hovea* sp. aff. *heterophylla* may also be an obligate seeder but many plants were observed to be under stress or dead at the time of the pre-fire sampling,

Fig. 6. There were few collections of *Pelargonium helmsii* in NSW prior to the 2003 fire. In December 2003, it was the dominant ground cover in many burnt shrub communities between Mt Blue Cow and Mt Jagungal.

as were plants of many other species, presumably as a result of the drought. The taxonomy of these latter two species is currently under review (I.R. Thompson and J.H. Ross, both National Herbarium of Victoria, pers. comm.). The combination of the drought and severe fire may produce outcomes not expected based on the reproductive ecology of the species alone. Other rare species (e.g. *Rutidosis leiolepis*, *Galium roddii*, *Xerochrysum palustre*) appeared to have been relatively unaffected by the fires within the first year.

Implications for recovery

It is not possible to predict with great accuracy to what extent and when vegetation might return to pre-fire conditions. The observed recovery of most species suggests that there is little evidence for local extinction, although 24 species noted in quadrats before the fire were not relocated up to 12 months following the fire. A few of these, however, were observed regenerating in sites outside quadrats. The apparent losses may be due to a number of reasons: e.g. our inability to find or identify very young seedlings; seeds requiring more than one year of dormancy post-fire before germination; absence of seeds in soil within the quadrat, but possibly extant in the immediate vicinity etc.

The recovery and performance of all species depends largely on conditions that are experienced in the critical immediate post-germination phase. Extended periods of extreme weather (high/low temperature/precipitation) will result in higher levels of mortality in some species than in others, resulting in a dramatic tilting of the abundance of those species in the mature vegetation relative to its pre-fire state. Even under benign or 'normal' conditions changes are to be anticipated for the foreseeable future. Studies of post-fire recovery of treeless subalpine vegetation in Victoria — at Mt Buffalo (van Rees & Walsh 1985, Wahren & Walsh 2000), and on the Snowy Range (Wahren, Papst & Williams 2001) suggest a trend toward increased shrub frequency over the short- to medium-term in grasslands, open heathlands and closed heathlands. This increase in shrubbiness is attributed to the germination requirements of many shrub species. Studies in many alpine/subalpine areas (e.g. Williams & Ashton 1987b) indicate a need for exposed soil for recruitment of non-resprouting shrubs. These conditions are common and widespread following wildfire. The effects of high temperatures in promoting germination particularly in hard-coated species such as *Asterolasia, Bossiaea, Grevillea, Oxylobium, Podolobium* and *Phebalium* further increases their abundance in the post-fire landscape. An eventual return to less shrubby conditions is anticipated as species with limited longevity, such as *Asterolasia trymalioides*, *Grevillea australis*, and *Phebalium squamulosum*, reach the end of their life. On the Bogong High Plains, Victoria, this period has been documented at about 50 years (Wahren et al. 1994) after which other herbaceous species are able to dominate microsites in which they have become established during the moribund phase of the shrubs. At Mt Buffalo, heathland communities had returned to broadly similar floristic and structural composition after 15 years following wildfire whereas grassland sites were still shrubbier after this period (Wahren & Walsh 2000). In both heathlands and grasslands the percentage of bare ground had returned to levels considered satisfactory for adequate soil protection (<5%) after 15 years.

The recovery of bog vegetation is likely be a slower process. The epacrids which are common in wetland communities (e.g. *Epacris celata*, *E. gunnii*, *E. petrophila* and *Richea continentis*), are obligate seed-regenerators, are slow to germinate and early growth rates are quite slow relative to many other species. These are often important structural components of bogs, particularly *Richea continentis*. The rope-rushes *Baloskion australe* and, particularly, *Empodisma minus* are, conversely, rapid resprouters from rootstocks. These plants had appeared only a few weeks after the fires and continued to grow vigorously to the 2003–2004 recordings. Victorian studies cited above recorded a significant and persistent increase in cover of *Empodisma* for 15 years post-fire. The Mt Buffalo study showed a return to pre-fire levels at one site for *Sphagnum cristatum* in this same period but lower than pre-fire levels for *Richea continentis* and higher than pre-fire levels for *Baeckea gunniana* at the same site.

A badly degraded bog on the Bogong High Plains fenced from grazing cattle in 1945 had regenerated so that in 2002 the cover of *Sphagnum* and *Richea continentis* was high, and generally believed to reflect or at least approach conditions in a 'pristine' bog (pers. obs. authors). *Empodisma minus*, although present at the site, was in relatively low abundance. These observations suggest that a period between 15 and 45 years might be required for *Sphagnum*-dominated alpine/subalpine bogs to recover from a disturbed state. Wimbush & Costin (1979) reported that *Sphagnum* bogs were 'nearing the climax stage' under benign conditions 19 years after the cessation of grazing at Gungartan (KNP), but in areas of persistent erosion after grazing no or little recovery of *Sphagnum* had occurred. Their monitoring of the recovering mossbed vegetation showed similar trends to those reported by the Victorian studies i.e. an initial increase then decline of the rushes *Baloskion australe* and *Empodisma minus*, and a slow, but steady increase of 'hygrophilous shrubs' (e.g. *Baeckea* spp., *Epacris* spp., *Richea continentis*). In areas where *Sphagnum* has been completely lost from a site, unless there is importation of live plant parts (either by fragmentation and movement by water down the catchment, or by human intervention), both the moss and the bogs which are dependent on it for development of permanently moist conditions may become locally extinct.

Management recommendations

In most situations, it is believed that most plant communities will return naturally to their pre-fire condition over a period between a few years and a few decades. Major exceptions will be those communities where the 'keystone' species appear to have been lost at least at a local scale. Principle amongst these are communities that incorporated significant pre-fire biomass of *Sphagnum* (bogs), *Podocarpus lawrencei* (shrublands) and *Celmisia costiniana* (closed herbfields). Consideration might be given to augmenting the recovery of these communities by stabilising exposed ground, and by artificial reintroduction of their dominant species to the sites. Some of this work, if attempted, will be pioneering. Methods for the revegetation of bogs have been developed that include slowing water movement across damaged areas by installation of slow-decomposing barriers and by artificial reintroduction of *Sphagnum* and other dominants. These techniques have been undertaken in both KNP and Victoria with promising results (Brooks & Stoneman1977, McPhee 2003).

Other communities on exposed, steep and/or otherwise unstable sites may be particularly prone to soil (and soil-stored seed) loss, potentially leading to recruitment by opportunistic plants with seeds capable of medium to long-distance dispersal (e.g. *Cirsium vulgare* as noted above, and other daisies, native or exotic) rather than the original occupants. Return to pre-fire conditions on these sites may be slow and involve several stages but as long as colonisation does occur and the colonists are not predominantly exotic, recovery should proceed. Such sites should be monitored to check on the nature of the colonising plants and consideration given to eradication of weeds and re-establishment of the components of the pre-fire communities there.

Future monitoring

We believe that the fires of 2003, while in one sense destructive, have provided a rare opportunity for recruitment of apparently short-lived fire- and/or disturbance-dependent species (e.g. *Barbarea grayi*, *Chenopodium erosum*, *Drabastrum alpestre*, *Pelargonium* spp.) as well as an opportunity to document the recovery of a suite of highaltitude plant communities conventionally believed to have evolved under a regime of very low fire frequency. Potentially informative avenues for future monitoring and/or research are outlined below.

- Using the methods outlined above, continue monitoring all or a representative sample of the 60 pairs of pre- and post-fire quadrats investigated in this study. Based on responses following fire in broadly similar vegetation in Victorian, appropriate periods of monitoring would be 1, 2, 5, 10, 15 and 20 years post-fire.
- Monitoring populations of the rare and apparently short-lived *Barbarea grayi*, *Chenopodium erosum*, *Drabastrum alpestre*, *Pelargonium helmsii* to ascertain the longevity and phenology of these poorly understood species.
- Undertaking landscape-scale monitoring using satellite imagery and/or aerial photography. This method should help to indicate return to vegetated cover, if not the composition of recovering vegetation. Sites that continue to register low vegetated cover should be targeted for closer on-ground monitoring.

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Appendix: Frequency of all species recorded in 60 quadrats pre- and post-fire with their mode of regeneration (where observed) and record of flowering.

Records where the presence of a species in a quadrat was attributable solely to escape from the fire rather than regeneration are shown in parentheses. [a] indicates an observation for mode of regeneration or flowering in a species observed outside the quadrats. * indicates an introduced species.

	Frequency		Regeneration		
Taxon	**Pre-fire**	**Post-fire**	**Seed**	**Resprout**	**Flower**
Anthericaceae					
Arthropodium milleflorum	8	11		+	+
Caesia alpina	7	4		+	+
Apiaceae					
Aciphylla simplicifolia	21	26	+	+	+
Gingidia harveyana	1	1		+	
Hydrocotyle algida	7	7		+	
Hydrocotyle sibthorpioides	4	5		+	
Hydrocotyle tripartita	1	1	+		
Oreomyrrhis argentea	13	12	+	+	
Oreomyrrhis ciliata	13	3	+	+[a]	+
Oreomyrrhis eriopoda	9	6	+	+	+
Asphodelaceae					
Bulbine bulbosa	4	3		+	+
Asteliaceae					
Astelia alpina var. *novae-hollandiae*	1	1		+	
Astelia psychrocharis	3	3		+	
Asteraceae					
Argyrotegium poliochlorum	1		+		
Brachyscome aculeata	8	8		+	+
Brachyscome decipiens	14	21		+	+
Brachyscome obovata	7	8		+	+
Brachyscome radicans		1		+	
Brachyscome rigidula	2	1		+	
Brachyscome scapigera	13	15		+	+
Brachyscome spathulata	10	9		+	+
Calotis glandulosa	1	1		+	+
Cassinia monticola	26	20	+	+	
Cassinia sp. 'Cave Creek'		1		+	
Celmisia pugioniformis	14	21		+	+
Celmisia sp. aff. *pugioniformis* (bogs)				+[a]	
Celmisia tomentella	3	3		+	
Chrysocephalum semipapposum	1	1		+	+
**Cirsium vulgare*		12	+		
**Conyza bonariensis*		1	+		+
Cotula alpina	3			+	
Craspedia aurantia	8	8		+	+
Craspedia coolaminica	14	15		+	+
Craspedia crocata	7	8		+	+
Craspedia jamesii	20	20		+	+
Craspedia lamicola	1	1		+	
Craspedia sp. aff. *crocata* 'Bogong Swamp'	4	3		+	+
**Crepis capillaris*	2	3	+	+	+
Erigeron bellidioides	6	7		+	+
Erigeron nitidus	4	4		+	+
Erigeron paludicola	2			+	
Euchiton argentifolius	2		+		
Euchiton collinus	1				
Euchiton involucratus		1	+		
Helichrysum rutidolepis	5	8		+	
Helichrysum scorpioides	3	3		+	
**Hypochaeris radicata*	20	19	+	+	
**Lactuca serriola*		1	+		
Lagenifera stipitata	1				
Leptorhynchos squamatus	19	19		+	
Leucochrysum albicans subsp. *alpinum*	3	3		+	
Microseris lanceolata	20	18		+	+

Olearia algida	7	2(2)	+		
Olearia brevipedunculata	2	3		+	
Olearia myrsinoides	2	1		+	
Olearia phlogopappa subsp. _flavescens_	6	6		+	
Olearia ramulosa		1	+		
Ozothamnus hookeri	2				
Ozothamnus secundiflorus	4	3	+	+	
Picris angustifolia subsp. _merxmuelleri_		3	+		
Podolepis hieracioides	2	4		+	+
Podolepis jaceoides	4	4		+	+
Podolepis robusta	2	3		+	+
Rhodanthe anthemoides	8	6		+	+
Rutidosis leiolepis	1	1		+	
Senecio gunnii	13	15	+	+	
Senecio pinnatifolius var. _pleiocephalus_	14	11		+	+
Senecio extensus	4	4		+	
Senecio lageniformis	1			+	+
Senecio longipilus		1		+	+
Solenogyne gunnii	2				
Taraxacum aristum		2		+	+
*_Taraxacum officinale_ spp. agg.	8	5	+	+	+
*_Tragopogon dubius_	4	3	+	+	
Vittadinia cuneata	1	1			
Xerochrysum palustre	1	1		+	+
Xerochrysum subundulatum	11	10		+	+
Xerochrysum viscosum	1	1		+	+
Blechnaceae					
Blechnum penna-marina	1	1(1)			
Boraginaceae					
Myosotis australis		1	+		
*_Myosotis caespitosa_		1	+		
*_Myosotis discolor_		2	+		+
Brassicaceae					
Barbarea grayi		1	+		+
Cardamine astoniae	7	4		+	+
Cardamine lilacina	12	7	+	+	+
Cardamine papillata	1	3	+		+
Drabastrum alpestre	2	5	+		+
*_Rorippa palustris_	1	2	+		+
Campanulaceae					
Wahlenbergia ceracea	1	1	+		
Wahlenbergia densifolia		1		+	
Caryophyllaceae					
*_Cerastium glomeratum_		5	+		+
*_Cerastium vulgare_	7	8	+		+
*_Petrorhagia nanteuilii_		1	+		+
Scleranthus biflorus	25	6(2)	+	+	
Scleranthus fascicularis	4	4(1)			
Scleranthus singuliflorus	1	1		+	
Stellaria angustifolia	5	7	+	+	+
Stellaria multiflora	7	15	+		+
Stellaria pungens	17	16	+	+	+
Chenopodiaceae					
Chenopodium erosum			+[a]		
Clusiaceae					
Hypericum japonicum	8	2		+	
Convolvulaceae					
Convolvulus erubescens sens. lat.	1	1		+	
Dichondra repens	1		+		
Crassulaceae					
Crassula peduncularis		1	+		+
Crassula sieberiana	1	1	+	+	

**Sedum acre*	1				
Cyperaceae					
Carex appressa	5	3		+	
Carex blakei	2	3		+	+
Carex breviculmis	36	32	+	+	+
Carex capillacea	2	1		+	+
Carex chlorantha	2	2		+	+
Carex gaudichaudiana	20	19		+	+
Carex hebes	8	17		+	+
Carex incomitata	1	1		+	
Carex jackiana	5	7		+	
Carpha nivicola	1			+	
Isolepis aucklandica	1	2	+		+
Isolepis crassiuscula	2	4	+		
Isolepis habra		1			+
Oreobolus distichus	3	1		+	
Oreobolus oxycarpus	1	1		+	
Dryopteridaceae					
Polystichum proliferum	1	1		+	
Epacridaceae					
Epacris celata	3				
Epacris gunnii	19	2	+		
Epacris paludosa	9	6(1)		+	
Epacris petrophila	7	1(1)			
Leucopogon fraseri	1	1		+	
Leucopogon hookeri	18	21		+	
Leucopogon montanus	1	1		+	
Richea continentis	6	2(2)			
Euphorbiacae					
Poranthera microphylla	14	18	+	+	+
Fabaceae					
Bossiaea foliosa	15	12	+	+	
Bossiaea sp. aff. *riparia*	1				
Daviesia ulicifolia	2	1		+	
Dillwynia palustris	2	1	+		
Hovea montana	19	16	+	+	
Hovea sp. aff. *heterophylla*	2	1	+	+	
Oxylobium ellipticum	10	5	+	+	
Podolobium alpestre	2	2	+	+	
Pultenaea fasciculata	4	1		+	
Pultenaea polifolia	1				
Swainsona monticola	1				
**Trifolium arvense*		1	+		
**Trifolium campestre*		3	+		+
**Trifolium dubium*	1	1	+		
**Trifolium repens*	9	8	+		+
Gentianaceae					
Chionogentias muelleriana subsp. *alpestris*	1		+	+	+
Geraniaceae					
Geranium antrorsum	13	19	+	+	+
Geranium potentilloides	9	15	+	+	+
Geranium sp 'alpine swamps'	1	1	+		
Pelargonium australe			+[a]		+
Pelargonium helmsii		1	+		+
Goodeniaceae					
Goodenia hederacea subsp. *alpestris*	4	4	+	+	
Scaevola hookeri	1	1	+		
Velleia montana	2	2		+	
Haloragaceae					
Gonocarpus micranthus	7	12(1)	+		
Gonocarpus montanus	3	2	+		
Myriophyllum pedunculatum	2	2	+	+	+

Myriophyllum variifolium	1	1(1)			
Juncaceae					
Juncus alexandri		1			
Juncus brevibracteus	3	2		+	
**Juncus effusus*	1	1		+	
Juncus falcatus	3	1		+	
Juncus sandwithii		1			
Luzula alpestris	3	3		+	+
Luzula flaccida	13	6		+	+
Luzula modesta	19	19	+	+	+
Luzula novae-cambriae	3	1		+	
Lamiaceae					
Ajuga australis	6	10		+	+
Prostanthera cuneata	1				
Westringia lucida	4	3	+		
Lentibulariaceae					
Utricularia monanthos	1	2		+	+
Linaceae					
Linum marginale	10	5	+	+	
Lobeliaceae					
Pratia pedunculata	3	6		+	+
Pratia surrepens		2		+	+
Mimosaceae					
Acacia alpina	3	1	+		
Myrtaceae					
Baeckea gunniana	11	8(1)		+	
Baeckea utilis	1	1		+	
Callistemon pityoides	1	1		+	
Eucalyptus lacrimans	2	2		+	
Eucalyptus niphophila	1	1		+	
Kunzea muelleri	14	5(1)		+	
Leptospermum myrtifolium	2	2(1)		+	
Onagraceae					
Epilobium billardiereanum	12	8		+	+
Epilobium curtisiae	2	2	+	+	
Epilobium gunnianum	9	8		+	+
Orchidaceae					
Caladenia alpina		1		+	
Diuris monticola	2	1		+	+
Prasophyllum sphacelatum	5	2		+	+
Thelymitra cyanea	1	3		+	+
Oxalidaceae					
Oxalis exilis	2				
Phormiaceae					
Herpolirion novae-zelandiae	1	1		+	
Pittosporaceae					
Rhytidosporum alpinum	6	4		+	
Plantaginaceae					
Plantago antarctica	4	3		+	
Plantago euryphylla	3	5		+	+
Plantago varia		1			
Poaceae					
**Agrostis capillaris*		1			
Agrostis venusta	1				
**Aira elegantissima*	1	3	+		+
**Anthoxanthum odoratum*	6	7		+	+
Australopyrum velutinum	2	3		+	+
Austrodanthonia eriantha	1	1		+	+
Austrodanthonia laevis	1	2		+	+
Austrodanthonia oreophila	2	3		+	+

Austrodanthonia penicillata	1	2		+	+
Austrodanthonia pilosa		1		+	
Austrofestuca hookeriana		2		+	+
Austrostipa nivicola	7	6	+	+	
**Bromus hordeaceus*		1	+		
Deyeuxia crassiuscula		1		+	
Deyeuxia monticola	2	2		+	+
Dichelachne crinita		4	+		+
Elymus scaber	4	7		+	+
Festuca asperula	5	4		+	+
Festuca muelleri	4	1	+		+
**Festuca rubra* subsp. *rubra*		1		+	+
Hierochloe redolens	1	4		+	+
**Holcus lanatus*	1		+		
Lachnagrostis aemula		1	+		
Microlaena stipoides		1		+	
Poa clivicola	13	13	+	+	
Poa costiniana	29	31	+	+	+
Poa ensiformis	1	1		+	
Poa fawcettiae	6	6	+	+	+
Poa hiemata	23	23	+	+	+
Poa hookeri	3	3	+	+	+
Poa labillardierei var. *labillardierei*	1	2		+	
Poa petrophila	2	1		+	
Poa phillipsiana	9	9	+	+	+
**Poa pratensis*	2	3		+	
Poa saxicola	2	1		+	+
Rytidosperma nudiflorum	3	2		+	+
Themeda australis	5	4		+	
Trisetum spicatum	12	14		+	+
**Vulpia bromoides*	3	4	+		+
Podocarpaceae					
Podocarpus lawrencei	1	1(1)	+[a]		
Polygalaceae					
Comesperma retusum	2	1	+		
Polygonaceae					
**Acetosella vulgaris*	30	41	+	+	+
Muehlenbeckia axillaris	1	1		+	
**Polygonum arenastrum*		1	+		+
**Rumex conglomeratus*	1	1		+	
Portulaceae					
Neopaxia australasica	2	6	+	+	+
Proteaceae					
Grevillea australis	21	6	+		
Grevillea lanigera	1	1	+		
Hakea microcarpa	22	18		+	
Orites lancifolia	6	5		+	
Persoonia chamaepeuce	2	1		+	
Ranunculaceae					
Ranunculus collinus	1				
Ranunculus graniticola	30	24	+	+	+
Ranunculus millanii	6	3(1)		+	+
Ranunculus pimpinellifolius	4	4	+		+
Restionaceae					
Baloskion australe	10	7		+	
Empodisma minus	20	22	+	+	
Rhamnaceae					
Cryptandra amara	2	1		+	
Rosaceae					
Acaena echinata	4	5		+	+
Acaena novae-zelandiae	13	8		+	+
Acaena ovina		1		+	

***Aphanes arvensis**		2	+		+
Geum urbanum		1		+	
**Potentilla recta*		1	+		+
**Rosa rubiginosa*	1	1			
Rubiaceae					
Asperula conferta		1		+	
Asperula gunnii	37	48	+	+	+
Asperula pusilla		2	+		
Asperula scoparia	3	3	+	+	
Galium roddii		1(1)			
Nertera granadensis	1	1		+	
Rutaceae					
Asterolasia trymalioides	2	1	+		
Nematolepis ovatifolia	1				
Phebalium squamulosum subsp. *alpinum*	8	7	+		
Salicaceae					
**Salix cinerea*		1	+		
Scrophulariaceae					
Derwentia perfoliata	1	1	+		
Euphrasia collina subsp. *diversicolor*	1	1		+	
Euphrasia collina subsp. *paludosa*	12	3		+	+
Gratiola nana	1	1(1)			
Limosella australis		1	+		+
**Linaria vulgaris*		1	+		+
**Verbascum virgatum*	1	1(1)			
**Veronica arvensis*		1	+		
Veronica gracilis		5		+	
Stackhousiaceae					
Stackhousia monogyna	1	1			
Stylidiaceae					
Stylidium montanum	20	17	+	+	+
Thymelaeaceae					
Pimelea alpina	3	1	+	+	
Pimelea biflora	7	2(1)		+	
Pimelea bracteata	2	2	+	+	
Pimelea linifolia subsp. *caesia*	20	17	+	+	+
Pimelea pauciflora	1				
Tremandraceae					
Tetratheca bauerifolia	1	1		+	
Violaceae					
Melicytis dentatus	8	3		+	
**Viola arvensis*	1		+	+	+
Viola betonicifolia	16	18		+	+
Viola fuscoviolacea	1	10	+	+	+
Winteraceae					
Tasmannia xerophila subsp. *xerophila*	2	1		+	