FIRE REGIMES AND BIODIVERSITY IN VICTORIA'S ALPINE ECOSYSTEMS

Richard J Williams[1], Carl-Henrik Wahren[2], James M Shannon[3], Warwick A Papst[2], Dean A Heinze[4], James S Camac[2,5]

1 CSIRO Ecosystem Sciences, PMB 44 Winnellie 0822 NT Australia
2 Research Centre for Applied Alpine Ecology, Department of Agricultural Sciences, La Trobe University, Victoria 3086 Australia
3 Research Centre for Applied Alpine Ecology, Department of Botany, La Trobe University, Victoria 3086 Australia
4 Department of Environmental Management and Ecology, La Trobe University, Wodonga Victoria 3689, Australia
5 Centre of Excellence for Environmental Decisions, School of Botany, The University of Melbourne, Victoria 3010, Australia

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Landscape-scale fires occur in Australian alpine ecosystems once or twice per century, primarily when ignition, regional drought and severe fire weather coincide. When alpine vegetation does burn, there is considerable variation in landscape flammability and fire severity. Regeneration following extensive fires of 2003 and 2006-07 across the Bogong High Plains is occurring in all plant communities (heathlands, grasslands, herbfields and wetlands). In heathland and grassland, vegetation composition has converged towards the long-unburnt state (> 50 years) eight years post fire. There was little effect of variation in fire severity on patterns of regeneration in heathland. In burnt wetlands, *Sphagnum cristatum* and other dominant species are regenerating; the cover of obligate seeding ericaceous shrubs two years post-fire was positively related to the cover of Sphagnum. The endangered mammal *Burramys parvus* is also capable of persisting in the alpine landscape after individual large, landscape fires. We conclude that there is no scientific evidence that these fires necessarily had 'disastrous' biodiversity consequences. After extensive landscape fires, the primary management objective should be to allow burnt alpine ecosystems to regenerate with minimal subsequent disturbance. Monitoring ecological change in the coming century will be essential for effective management of both fire and biodiversity in alpine ecosystems in Victoria and elsewhere in Australia.

Key words: alpine vegetation, grassland, heathland, fire severity, species diversity, conservation.

AUSTRALIAN alpine ecosystems are subject to recurrent fire. Alpine vegetation (hereafter we include the treeless vegetation above treeline, and floristically similar treeless vegetation at or below treeline in the high subalpine zone, in our definition of 'alpine'; Williams et al. 2006a) typically burns at landscape scales once or twice per century, under circumstances when ignition and severe fire weather coincide with widespread regional drought. Under these conditions, fire spreads to the treeless, alpine and subalpine vegetation via the foothill and montane forests and subalpine woodlands (Williams et al. 2008). Such fires occurred in the alpine regions of Victoria and New South Wales in 2003 and 2006-07. The 2003 fires burnt over 1 million hectares, the vast majority being forests and woodlands. About 10,000 ha of treeless, alpine vegetation was burnt, including about half of the Bogong High Plains (Williams et al. 2006b). The fires of 2003 and 2006-07 in north-eastern Victoria were the largest since 1939, when much of the Victorian Alps burnt (Carr and Turner 1959). There have been other substantial fires in Victoria's treeless sub-alpine vegetation since 1939, such as on Wellington and Holmes Plains in 1998 (Wahren et al. 2001), and on Mt Buffalo, parts of which were burnt in 1972, 1984, 2003 and 2006-07 (Coates and Walsh 2010).

Much of the alpine and treeless subalpine vegetation burnt by the large fires of 1998, 2003 and 2006-07 occurred in national parks within the Victorian Alps. Well-informed fire management within national parks is essential to achieve nature conservation goals, but is controversial, with competing views concerning the ecology and management of large fires in south-eastern Australia. One view (e.g. House of Representatives 2003; Adams and Attiwill 2011) is that (a) fires such as those that occurred in 2003 were unnatural, and are (b) the resulted of inadequate fuel management in the surrounding forests, and are (c) a major threat to biodiversity and other natural values within national parks, because of their size and intensity. On the other hand, there is evidence that large, intense fires are a natural part of the historical fire regimes of the temperate landscapes of south-eastern Australia, and the associated biota are resilient to individual large, intense fires (Bradstock 2008). According to this view, large individual fires, because they are a part of the historical fire regime, may not necessarily threaten conservation values in these landscapes. Evidence from the alpine and high subalpine ecosystems of SE Australia suggests that large fires, such as the 2003 fires, are part of the historical alpine fire regime (Williams et al. 2006b; 2008). Furthermore, regeneration following such fires, across a broad suite of taxonomic groups, can be both rapid and substantial (Wahren et al. 2001; Walsh and McDougall 2005; Williams et al. 2008; Camac et al. 2012).

Driscoll et al. (2010) highlighted key questions in relation to fire regimes (*sensu* Gill 1975) and their management for biodiversity conservation. They stressed the importance of natural experiments (e.g. studying major fires), studying species-level responses to variation in fundamental fire regime components (e.g. time since fire, intervals between fires, fire intensity) and the value of long-term monitoring. Victoria's alpine areas thus present a valuable opportunity to further this understanding, because (a) variation in occurrence and severity of fire across a diverse array of plant communities provides a robust natural experiment, (b) knowledge about species-responses to time since fire and fire severity is increasing and (c) the alpine vegetation of Victoria has been monitored systematically since the 1980s.

In this paper we explore the effects of recent, extensive fires on the major treeless plant communities (grasslands, heathlands and wetlands) from the alpine zone and high subalpine zone in the Victorian Alps. We draw on long-term monitoring data to make inferences about the effects of large fires on variation over time in key ecological attributes such as vegetation cover, species diversity and populations of species. We also present data on the ecological effects of variation in fire severity (a proxy for fire intensity; Keeley 2009). We also present data on post-fire recovery of an endangered small mammal, the alpine endemic Mountain Pygmy-possum (*Burramys parvus*).

DATA SOURCES, SELECTION AND ANALYSES

Victoria's alpine and treeless subalpine vegetation is a mosaic of shrub- and grass/herb-dominated communities. The major structural formations are closed- and open heathlands, herbfields, tussock grasslands and wetlands. We present data from monitoring sites in closed heathland, open heathland, grassland and wetlands, which collectively account for >95% of the treeless vegetation in alpine and high subalpine landscapes. Detailed community descriptions are found in Williams et al. (2006b). We use data from long-term, permanent monitoring sites established over the past 25 years across the Victorian alpine region (Papst et al. 1999). 'Burnt' monitoring sites were established within 2-4 weeks at sites affected by the fires of 1998, 2003 and/or 2006-07. Some 'unburnt' sites were established at the time of these extensive fires; others were established in the 1970s, 1980s and 1990s, as part of a wider as part of a wider program of long-term ecological monitoring. We present vegetation data from the 2003 and 2007 fires on the Bogong High Plains and the 2007 fires on Bennison-Moroka-Snowy Range. Sites were monitored at ca. 1-5 year intervals. For the purposes of this paper 'unburnt' refers to sites that were not burnt by any of these fires, and which have been unburnt since at least 1939. The data on *Burramys parvus* come from population monitoring sites across the Bogong High Plains-Mt Hotham region (Heinze 2010) established in the 1990s. Logistical constraints precluded assessment of all sites in all years. Nevertheless, our data are from a representative subset of monitoring sites from which we can derive robust measures of pre-fire state for a range of taxa, and change in state in those variables from immediately after the fire until 8 years post-fire.

Plant community data from heathlands and grasslands were collected from 11 monitoring sites, based on point quadrats along multiple (usually 10) 10m-long transects per site. Attributes collected include cover of vascular plant species, species diversity and composition, and the amount of bare ground (Wahren et al. 1994; 2001). Following the 2003 fires on the Bogong High Plains, fire severity in open and closed heathland was determined using 'minimum twig diameter', a proxy measure for fire severity (Williams et al. 2006b). In 2008, cover of vascular plant species, species diversity (measured as both richness and evenness; Jost et al. 2010) and

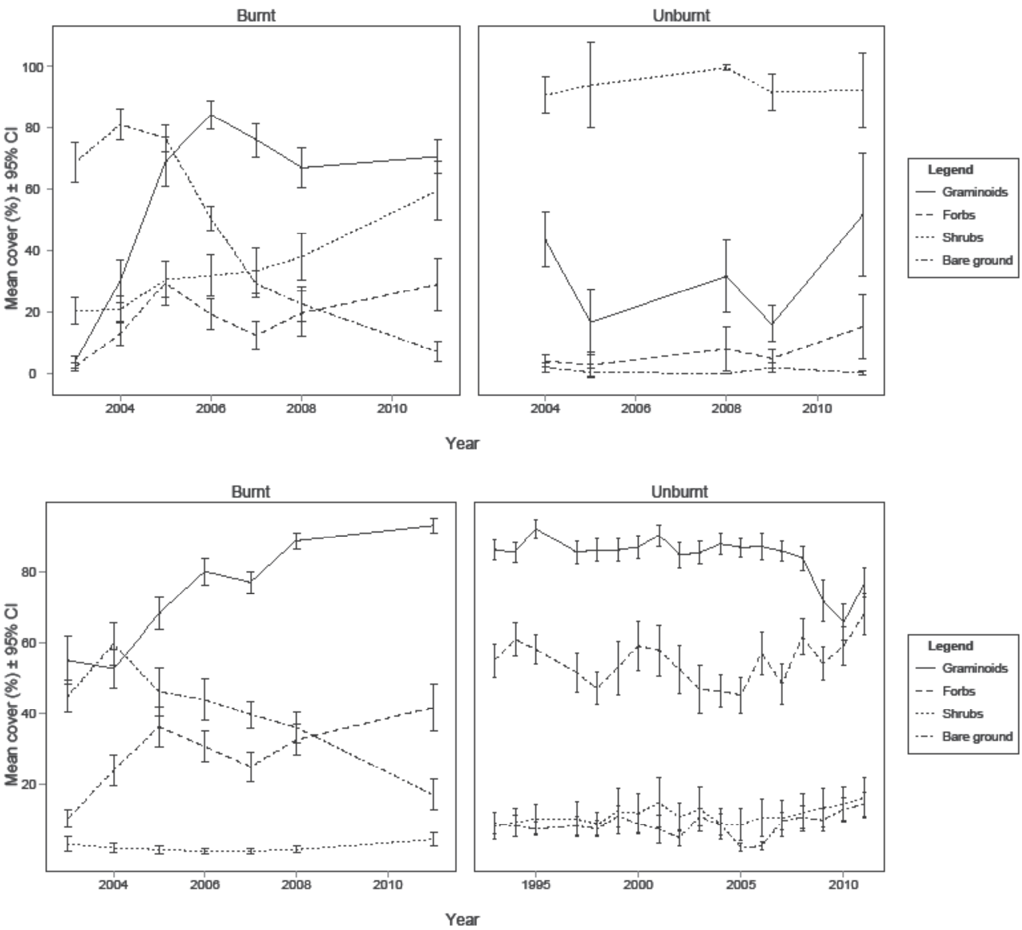

Fig. 1. Change in cover of major variables (graminoids, shrub, forbs, bare ground; mean + 95% CIs) in heathland (a, b) and grassland (c, d) on the Bogong High Plains following the 2003 fires. Data are for burnt (a,c) and unburnt (b,d) sample sites. Cover data collected from point quadrats along permanent transects according to methods in Wahren et al. (1994; 2001).

species composition were assessed using five 6 m2 plots along a 50 m transect at each of 40 sites (10 unburnt, 30 burnt to varying severity) per community; cover was estimated using standard Braun Blanquet methods (Camac et al. 2012). Data on wetlands were collected from 17 sites, based on contiguous 0.25m^2 quadrats along permanent 30m transects in each wetland. Primary attributes were the cover of dominant taxa: *Sphagnum cristatum*, ericaceous and myrtaceous shrubs, forbs and graminoids (Shannon 2012). Data on *Burramys* were based on 'capture-mark-recapture' protocols detailed in Heinze (2010). These techniques detect changes in populations over time, and determine survival, mortality and the structure of local populations, for males and females.

Statistical analyses were based on 95% confidence intervals, where the transect or trapping grid was the experimental unit. Where 95% confidence intervals of sample means did not overlap we inferred a significant difference (Cumming and Finch 2005).

RESULTS

Post-fire regeneration in heathland and grassland

The cover of the dominant life forms (shrubs, graminoids and forbs) and the amount of bare ground in heathland and grassland following the 2003 fires

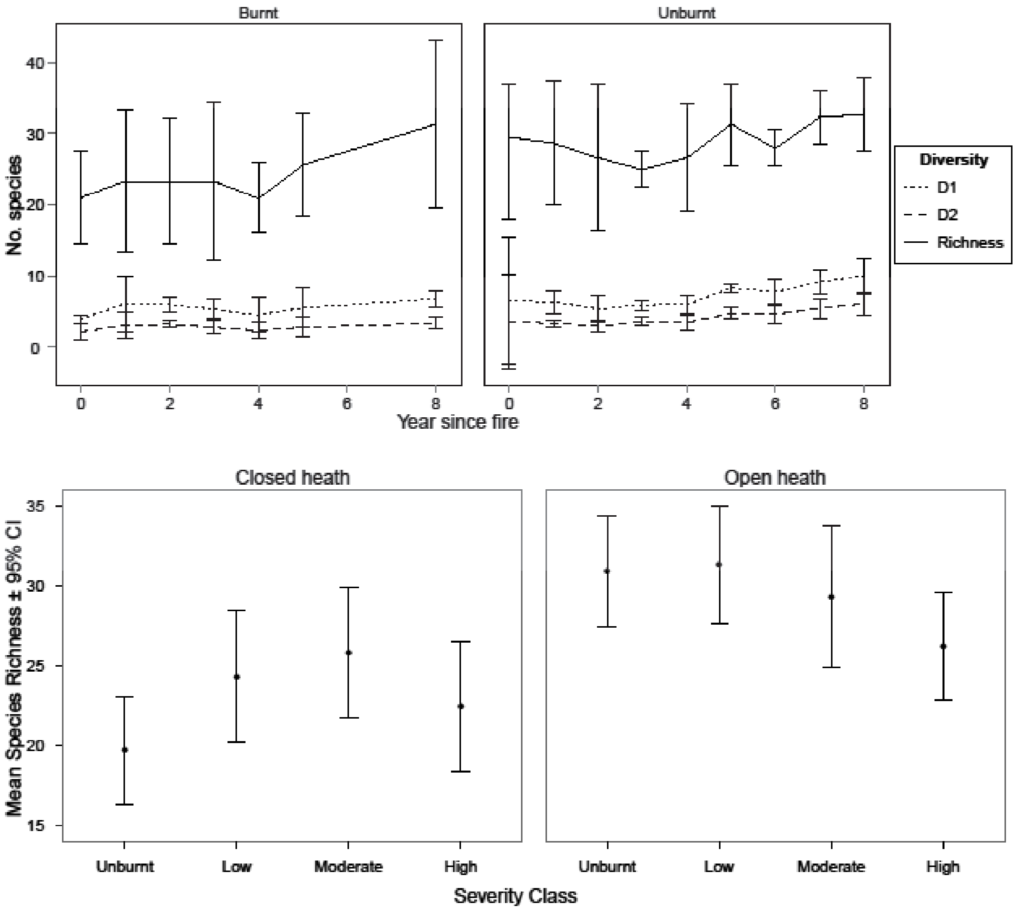

Fig. 2. Plant species diversity (mean + 95% CIs) as a function of time since the 2003 fires in grassland (a,b) and as a function of fire severity in heathland (c, closed heathland; d, open heathland) five years after the 2003 fires. Diversity measures in (a,b) are plant species richness ('Richness') and two measures of evenness (D1, D2; see Jost et al. 2010) per 10m transect. Data from Bogong High Plains. (Note that x-axis of both (a) and (b) represents time since the 2003 fires). In Fig 2c,d fire severity classes (unburnt, low severity, moderate severity and high severity) were measured in permanent reference sites in 2003-04 (Williams et al. 2006a) and diversity (plant species richness per 50 m transect) was recorded in December 2007 - January 2008 (Fig. 2c, d redrawn from data in Camac et al. 2012).

on the Bogong High are shown in Fig. 1. In heathland, regeneration commenced within days of burning. The cover of graminoids (mainly snowgrass, *Poa* spp) and forbs increased relative to that of the unburnt sites, especially in the initial 2-3 years post-fire. By 2011, shrub cover was about 60% of its pre-fire level of ca. 85-95%. Despite fire causing substantial increases in the amount of bare ground (from <5% to >80%), bare ground was about 10% by 2011 (Figs 1a,b).

In grassland (Fig. 2 c,d), post-fire regeneration was rapid for the snow grasses and forbs; the cover of snowgrass had returned to pre-fire levels of cover (ca. 90%) within 5 years. On unburnt sites, the cover of snowgrass declined between 205 and 2011, as a consequence of drought – the driest period on record in south-eastern Australia (CSIRO, 2010; Timbal, 2009; Ummenhofer, 2009). Bare ground was initially 40-60% in the first two years post fire on burnt sites, declining to ca. 20% in 2011. On unburnt sites, the cover of bare ground was ca. 5-10% over most of the monitoring period, increasing to 15% post-2005, as a consequence of the drought-induced decline in the cover of snowgrass. Although there were some significant differences between burnt and unburnt

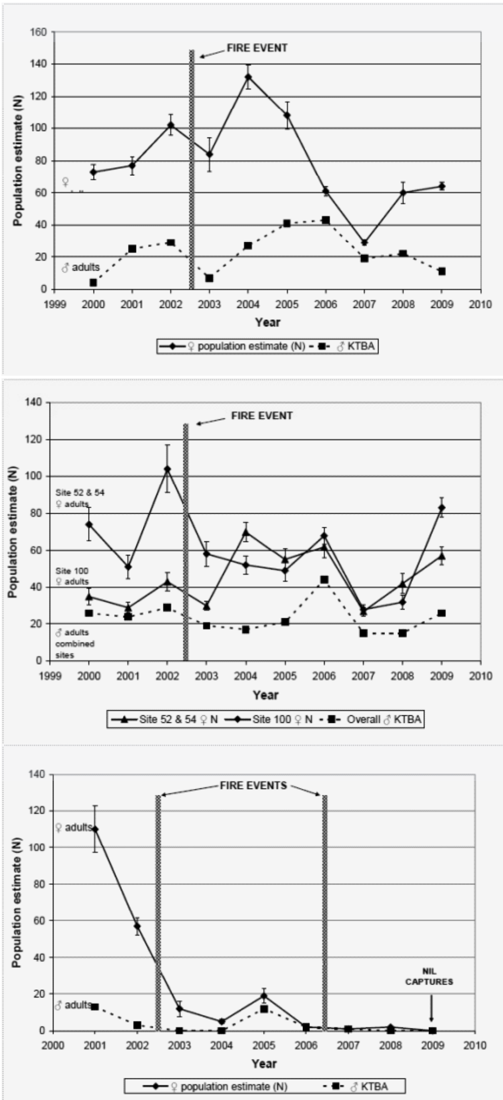

Fig. 3. Trends in the numbers of *Burramys parvus* males and females at three sites in Victoria, 1999/2000-2009. Adult female population (soild line) and 'known to be alive' male population. (a) Mt Loch; (b) Mt Highinbotham East and West (c) Mt McKay. (Source: Heinze 2010).

vegetation in the cover of some life forms in some years, after eight years the cover of shrubs, grasses and forbs in burnt grassland was similar to that of unburnt grassland. Bare ground, however, was significantly higher at burnt sites than unburnt sites, 8 years post-fire.

Plant diversity in burnt grasslands (both richness and evenness) was not significantly different from that in unburnt grasslands over the monitoring period. Average total species richness per transect in burnt grassland two months post-fire was ca. 20, increasing to ca. 30 in 2010, compared with ca. 30 in unburnt grassland over the same period (Fig 2 a,b). There was no effect of variation in fire severity on plant diversity in heathlands on the Bogong High Plains (Fig. 2 c,d). Ordination of the sites over time also demonstrated convergence in floristic composition of burnt grassland and heathland towards the respective unburnt state within 3-5 years (Camac et al. 2012).

Post-fire regeneration in wetlands

The average cover of the major wetland species in 2006 (pooling sites) prior to the fires of 2006-07, and in 2007 and 2009 is given in Table 1. Sites are divided into 'bog' sites, where the pre-fire cover of the dominant mound-building moss, *Sphagnum cristatum*, is relatively high (>60%) and 'wet heathland' sites, where the pre-fire cover of *S. cristatum* is relatively low (<25%) but other typical wetland species, especially myrtaceous shrubs, are common. Both vegetation types are underlain by peat soils. Several post-fire responses are apparent. First, *Sphagnum* can regenerate post-fire; *Sphagnum* had reached ca. 80% and 70% of its pre-fire cover in bogs and wet heaths respectively. Second, the cover of the dominant graminoids, *Empodisma minus* and *Carex* spp., may increase in the short-term, post-fire. Third, the major ericaceous shrubs, *Richea continentis* and *Epacris* spp. and the major myrtaceous shrub *Baeckea gunniana*, were also regenerating. Importantly, regeneration of the ericaceous shrubs, which are obligate seeders, was substantially higher in the bogs, where the cover of *Sphagnum* is higher, than in the wet heaths. The cover of ericaceous shrubs pre-fire was similar in both bog and wet heath sites (ca. 33%) but was ca. 25% in the bogs in 2009, compared with ca. 7% in the wet heaths.

Post-fire rends in Burramys parvus *populations*

Burramys persisted in areas that were burnt in the 2003 fires at both Mt Loch and Mt Higginbotham, despite substantial population fluctuations (Fig. 3a,b). The situation was similar at other long-term monitoring sites such as Timms Lookout. However, the situation at Mt McKay was different (Fig. 3c). Following the 2003 fires, there was limited recovery

Table 1. Mean (+/- SD) cover values of six dominant and/or common taxa in the subalpine wetlands of the Bennison-Moroka-Snowy Range region of Victoria. The wetlands were burnt in January 2007. Data were collected in April 2006; April 2007 (3 months post-fire) and April 2009. (Source: Shannon 2012).

Species	**Bog**			**Wet heath**		
	2006	2007	2009	2006	2007	2009
Sphagnum cristatum	62.8 (± 9.0)	42.1 (± 6.6)	51.4 (± 5.7)	23.3 (± 5.0)	7.9 (± 3.0)	15.5 (± 4.1)
Empodisma minus	17.3 (± 7.1)	6.3 (± 2.3)	22.9 (± 8.7)	12.4 (± 5.1)	0.8 (± 0.2)	9.2 (± 2.8)
Carex gaudichaudiana	0.8 (± 0.1)	1.4 (± 0.3)	2.7 (± 0.3)	2.9 (± 1.9)	3.8 (± 1.7)	7.2 (± 3.4)
Baeckea gunniana	9.6 (± 2.8)	2.9 (± 1.8)	5.4 (± 1.7)	12.3 (± 2.0)	1.5 (± 0.3)	5.9 (± 1.7)
Epacris spp.	18.0 (± 3.0)	8.0 (± 3.9)	15.7 (± 6.2)	12.8 (± 2.4)	1.1 (± 0.4)	4.4 (± 0.8)
Richea continentis	15.4 (± 8.5)	5.9 (± 4.2)	8.6 (± 5.2)	20.9 (± 9.7)	2.1 (± 1.6)	2.9 (± 1.9)

of the numbers of both males and females. The rate of recovery at Mt McKay was slower than at other sites such as Mt Loch and Mt Higginbotham, because the habitat at the McKay site is poorer than that at the other sites (closed heath with no nearby boulderfields; Heinze 2010). At Mt McKay the population was further affected by fires in 2007, which burnt heathland habitat that was also burnt in 2003. No animals were recorded at the McKay site in 2008 and 2009.

DISCUSSION

Vegetation

Alpine vegetation in Victoria has a strong capacity to regenerate after fire, including high severity fire. Our data show that there is clear evidence of convergence in floristic composition, diversity and some measures of ecosystem structure towards the long unburnt state (i.e. unburnt for > 50 years) within 5-10 years. This is especially apparent in the grasslands and heathlands, but may also occur in wetlands, especially where pre-fire cover of *Sphagnum* is high (>50%). This rapid recovery of diversity and composition occurs because most species of the alpine vascular flora can resprout from subterranean organs such as rhizomes, rootstocks and tubers, with many species also able to regenerate by seed (Williams et al. 2006a). Regeneration of the dominant life forms in heathland appears to be largely unaffected by variation in fire severity (Camac et al. 2012). Although diversity and composition show convergence to the unburnt state in 5-8 years in grasslands and heathlands, bare ground and shrub cover are likely to take more than a decade to return to unburnt/pre-fire levels. Importantly, we found no evidence that any species failed to regenerate after fire. Our data are consistent with other studies of post-fire regeneration of alpine heathland and grassland on mainland Australia (Wahren et al. 2001; Walsh and McDougall 2005; Williams et al. 2008).

The data from wetlands indicate clearly the capacity of *Sphagnum cristatum* and other dominant species to regenerate post-fire, despite some wetlands having been moderately-severely burnt and that *Sphagnum* is relatively slow growing (Shannon 2012). Whether post-fire regeneration in *Sphagnum* is from shoots that have survived at or near the surface of the peat column, or from deeper-seated shoots, is unclear. However, *Sphagnum* spp in the UK can regenerate from decaying material 30 cm below the surface of the peat (Clymo and Duckert 1986). *Sphagnum* is an important mound-building species in Australian alpine wetlands (Williams et al. 2006a; Shannon 2012) and other species of Sphagnum are well-known as a mound-builders in the northern hemisphere (Clymo and Hayward 1982). Our data also highlight the importance of *Sphagnum* as an ecological engineer (sensu Jones et al. 1994) in Australian alpine environments – the cover of obligate seeding ericaceous shrubs two years post-fire was significantly higher in bogs, with a relatively high cover of *Sphagnum*, than in wet heaths with relatively low *Sphagnum* cover.

Burramys parvus

Burramys parvus is a small, rare mammal that only occurs in restricted habitat in the Australian Alps (Mansergh and Broom 1994). On this basis, it may be expected to be highly vulnerable across its range to large severe fires. However, monitoring of *Burramys* populations before and after the 2003 and

2006 bushfires on the Bogong High Plains has shown that populations can persist in the landscape despite widespread fire. This is potentially because its core habitat (boulder fields) offers refuge from fire, and a major food source over summer, the Bogong Moth (*Agrotis infusa*), is migratory, aestivates among rocks in large numbers over summer, and is thus essentially independent of fire in the alpine zone. Moreover, because the fires on the Bogong High Plains in 2003 and 2006 were patchy (Williams et al. 2006b) unburnt patches of heathland could also have served as refugia. Nevertheless, numbers plummeted at Mt McKay after both the 2003 fires and 2006 fires extensively burnt habitat, such that no *Burramys* were trapped in 2009. The habitat at Mt McKay was heathland as opposed to boulderfields, hence it is not surprising that the loss of this vegetation cover coincided with a dramatic decline in *Burramys* numbers at this site. The *Burramys* population at Mt McKay may now be functionally extinct. Thus, although *Burramys* can persist post fire, it is at risk from subsequent disturbances (e.g two fires < 5 years apart in closed heathlands). It is also at risk, post-fire, from predation by foxes, and drought (Green and Sanecki 2006).

Management implications

The primary management implication of our findings is that the alpine and high subalpine treeless vegetation of Victoria is resilient to the effects of occasional, large scale fires. This is clearly the case with respect to plant species composition and diversity in grasslands and heathlands, which together account for about 90% of the area of treeless vegetation. Importantly, our data also show that species that may be hypothesised to be vulnerable to large, severe fires – slow-growing plants such as *Sphagnum cristatum*, and rare and endangered mammals, such as *Burramys parvus* - can persist in the landscape following such fires. Although large fires undoubtedly have widespread and immediate effects on alpine landscapes, and may result in dramatic reductions in vegetation cover and faunal population numbers, we found no evidence, across a range of taxa, that the large, severe fires we studied were of themselves 'ecologically disastrous'. Indeed, other ecological evidence suggests that this is the case for the fire regimes and associated biota of the widespread forests in the lowlands of south-eastern Australia in general (Bradstock 2008).

One major management concern in burnt grasslands and heathlands is the level of bare ground, which remained well above unburnt/pre-fire levels even 8 years post-fire. Minimising the amount of bare ground in alpine ecosystems is a primary objective for soil, water and nature conservation (Williams et al. 2006a). Thus, alpine vegetation that has been burnt needs to be protected from other, subsequent disturbances (prescribed fire, trampling, grazing by domestic livestock and feral animals; weed invasion) while it is regenerating, so that the rate of development of native vegetation cover over bare ground is maximised. Effective control of predators and exotic plants in the post-fire environment is very important. Although exhibiting broad resilience to large fires, *Burramys* is vulnerable to predation by foxes in the post-fire environment (Green and Sanecki 2006).

Management of fire regimes in alpine ecosystems also depends on effective long-term monitoring. We are able to make inferences about the nature and ecological effects of the recent large fires because of the array of monitoring sites first established in the 1940s. While grassland, heathland and even wetlands appear resilient to the effects of one-off large fires, and that regeneration in heathlands is independent of fire severity, we know little about ecosystem resilience in relation to intervals between fires. Parts of the Mt Buffalo Plateau (e.g. Five Acre Plain) have been burnt four times in the past four decades. Evidence from such sites indicates that short intervals between fires (<20 years) are likely to have detrimental effects on a range of species and ecosystem functions in alpine ecosystems (Coates and Walsh 2010). Monitoring of areas burnt in 2003 and 2006-07 that may be burnt again in the next 5-20 years will therefore provide important information on the responses of alpine ecosystems to variation in the intervals between fires, which will complement our developing understanding of how alpine ecosystems are affected by variation in fire intensity/severity.

Change in the biota in of the Australian Alps will be influenced by many factors, such as warming climate, changing fire regimes (Williams et al. 2009), a greater abundance of alien species (McDougall et al. 2005) and increasing human pressure. Burgman et al. (2007) have termed these interacting forces 'threat syndromes'. It is these that are likely to emerge as the main threats to biodiversity and the capacity of protected areas to conserve biodiversity. Because such threats interact at different spatial and temporal scales, it is essential to monitor changes in ecosystems, to determine whether such threats are emerging, how the biota is responding to them, and what level of change is acceptable (Bond and Archibald 2003). The alpine ecosystems of Victoria have a long-history of ecological monitoring. These monitoring sites and methods can be adapted readily to meet the emerging needs of understanding and managing fire regimes in Australia's alpine ecosystems in the coming century.

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