Immediate and short-term responses of bird and mammal assemblages to a subalpine wildfire in the Snowy Mountains, Australia

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Abstract Over 35 days in January–February 2003, wildfires burnt across much of the subalpine/alpine landscape of south-eastern Australia, including about 70% of the land above 1500 m in the Snowy Mountains. At the time of the fire, studies of two subalpine faunal assemblages were being undertaken. The opportunity to resurvey the assemblages was taken in order to examine the immediate impact of fire in an environment where it is uncommon but predicted to occur increasingly with global warming. A study area in the Whites River Valley, where the number of bird species was counted monthly from 1996 to 2003, and weekly in late winter–spring from 2000 to 2003, was burnt in one fire. As well as the expected decrease in the number of individual birds, the fire resulted in an immediate decrease in the number of bird species, unlike in previously studied montane forest, with only the regularly wintering species plus the olive whistler and the ground-feeding flame robin remaining. During the post-winter avian immigration, few regular spring migrants appeared on burnt sites despite their nearby presence on the unburnt side of the valley. Five of six small mammal trapping grids were burnt. As with fires at lower altitudes, there was an immediate reduction in mammal numbers on burnt grids following the fire, but in addition, one species, Mastacomys fuscus, declined further in the ensuing 2 months both on burnt and unburnt sites. Numbers of Antechinus swainsonii and Rattus fuscipes stabilized until autumn/winter when there was a further decline due to the unavailability of subnivean space to allow winter foraging, allied with a concentration of fox predation on areas still carrying populations of small mammals.

Key words: alpine, bird migration, fox, small mammal, snow.

INTRODUCTION

Mountain areas may be among the most severely affected by predicted global warming (Hughes 2003), with the change in the bioclimatic envelope making areas unsuitable for some species (Brereton et al. 1995). However, threshold or stochastic events may be more important than just a general warming in terms of loss of biodiversity. An understanding of the initial impacts of such events is important in directing management responses, especially in relation to the protection of endangered species and communities.

One such stochastic event is fire. Predictions from Global Change scenarios in Australia include an increased fire frequency, with the average interfire interval halved for the Canberra region under a modelled moderate climate change scenario (Cary 2002). The primary factor in this increased frequency is a reduction of (natural) extinguishment (Cary 2002), an important factor in mountainous terrain where the rate of spread of a fire doubles for every 10° of upward slope (McArthur 1967). Periodic fire is considered to be a normal part of the ecology of southern hemisphere sclerophyllous woodlands (Good 1981; Rasolonandrasana & Goodman 2005). Most Australian eucalypt species respond to loss of foliage following fire with the growth of epicormic shoots, specialized regenerative buds along the trunk and branches (Good 1992a). The dominant subalpine species, snowgum (Eucalyptus niphophila), however, is sensitive to fire and all of the above-ground biomass generally dies and the tree responds with basal shooting from a specialized root system – the lignotuber (Good 1992a,b). Frequent fires can ‘exhaust’ the lignotubers leading to death of the trees (Good 1981). Alpine and subalpine heathlands can be effectively extirpated by fire, particularly if it burns through the peaty soil beneath, reducing water-holding capacity and hence the conditions necessary for such a heath to survive (Costin 1954). While many data exist in Australia for fires in lowland woodlands (Hobbs 2002) and heath

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Accepted for publication November 2005.

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(Keith et al. 2002) there are few data on the impacts of high altitude fires because of their low natural frequency. Banks (1989), for example, recorded a fire frequency in the Australian Alps of about 50 years (at Thredbo) and a mean fire-free interval of at least 140 years at Schlinks Pass, near to where Barker (1989) estimated the age of old fire-sensitive trees at about 500 years.

The Snowy Mountains in New South Wales contain the largest contiguous areas of subalpine and alpine environments in Australia (Costin 1989). In January 2003, 98% of New South Wales was declared in drought. (NSW Agriculture 2003). In the nine preceding months (April 1 to December 31) most of New South Wales had serious to severe rainfall deficiencies (lowest 5–10% of totals dating back to 1900) (Bureau of Meteorology (BOM) 2003). For 2003, the average temperature over Australia was the sixth highest on record since 1910 (BOM January 2004). The average temperature at the treeline in February (the warmest month and normally expected to be about 10°C) was 13.2°C (K. Green, unpubl. data 2003). Over about 35 days in January and February 2003, wildfires burnt through much of the Snowy Mountains including 69.3% of the 139 900 ha above 1500 m. These fires, which also burnt through high elevation areas of the Australian Capital Territory and Victoria, were the most extensive high altitude fires since 1939.

Even if fire does not kill snowgums or scorch the canopy, it can effectively ringbark the trees which then slowly lose their leaves as they are deprived of nutrient and moisture (D. Wimbush, pers. comm., 2002). This means that there is no immediate regrowth of canopy for birds, and little live material above ground for insects. The snowgum bark peels and, together with the loss of the shrub layer, the number of feeding niches is significantly reduced. In addition to this, within subalpine woodlands and heaths, seasonal snow cover acts as a major ecological selection pressure (Green & Osborne 1994, 1998). With the fires extinguishing in February, and snowfalls commencing in May, there was little time for recovery of the vegetation structure before the end of the growing season. However, good rains in the 2 months from the end of March to the end of May 2003 (148 mm at Wragges Creek at 1580 m and 190 mm at Pengilleys Bog at 1660 m) (K. Green, unpubl. data 2003) allowed for strong regrowth of grass at many sites (K. Green & G. Sanecki, pers. obs. 2003). Establishment of the permanent winter snowpack commenced by 12 June at sites above 1600 m, halting any further vegetative growth.

At different times over the past 8 years, two faunal assemblages have been studied intensively at subalpine altitudes of the Snowy Mountains, the migratory bird species, mainly in woodland (Green & Pickering 2002; K. Green 2006) and the introduced fox and its prey species, particularly the broad-toothed rat Mastacomys fuscus (Green 2002, 2003; Green & Osborne 2003; Sanecki & Green 2005). Mastacomys fuscus is generally restricted to patches of optimal habitat in alpine, subalpine and montane heathlands and open eucalypt woodland (Happold 1995). It is a species identified as most at risk due to habitat changes resulting from global warming (Brereton et al. 1995). It experienced an approximate 80% decrease in numbers in 1999 (K. Green unpubl. data 2000) and numbers had not recovered by late 2002. Major portions of the study sites for these assemblages burnt during the fires of early 2003. The present study examined these two assemblages, drawing on pre-fire data and immediate and short-term (<1 year) post-fire data to examine the impacts of fire on the native fauna, on the activity of foxes, and the effect of fire on vegetation and consequently on the subnivean space.

METHODS

Birds

The number of bird species was recorded each month from summer 1995/96 to spring 2003 in Whites River Valley above 1500 m a.s.l., while walking or skiing a 4.5-km transect along a four-wheel drive access track up Disappointment Spur and along an aqueduct bench to the junction with the Guthega Power Station-Geehi Dam road (see Osborne & Green 1992). For a study of migratory birds, the transect was skied weekly from the beginning of July each winter from 2000. The vegetation was essentially woodland, consisting mainly of snowgum with thick heath understory (Osborne & Green 1992). The fire in January–February 2003 removed virtually all of the understory and most of the tree canopy along the transect.

On each visit, the bird species present were identified by sight or by call, and in the rare occurrences of superb lyrebird Menura novaehollandiae by tracks in snow. The two raven species Corvus mellori and Corvus coronoides, frequently seen without positive identification to species, were treated as one species for the purposes of analysis although the former was more commonly identified (Osborne & Green 1992). The number of resident and migratory bird species occurring on the transect was compared pre- and post fire using the χ² statistic.

Mammals

Trapping

In the region of the Snowy Mountains running north and east of the long-term monitoring site at Smiggin
Holes (36°23′S, 148°25′E), six trapping grids of 50–80 traps at 10–15 m spacing, depending on the area of habitat, and located 1.5–15 km apart were established between 1978 and 2002 for long-term monitoring of the broad-toothed rat. Trapping was undertaken three times a year as close as possible to the first week of December, February and April. In 2003, because fires in the region were still burning early in the month, trapping was conducted in the third and fourth week of February. At each grid, Elliott traps were baited with a mixture of peanut butter, rolled oats and honey and were left open for three nights. All *M. fuscus* were individually marked with microchips inserted beneath the skin. Other species were only characterized by age and sex (*Antechinus swainsonii* and occasional *Antechinus agilis* and *Burramys parvus*) or just age (*Rattus fuscipes*). Consequently, the minimum numbers of *M. fuscus* known to be alive on the grids could be calculated, whereas for *A. swainsonii* and *R. fuscipes*, only the minimum numbers of individuals at each trapping session could be given. This number for these two species was the sum of the numbers of any given age and/or sex caught on the day of their maximum occurrence over the 3 days. Because small mammal numbers vary widely but relatively predictably between seasons, numbers of the three species on four burnt grids were compared with the same period in the previous year using analysis of variance.

In January–February 2003, fire burnt through five of the six trapping grids. Because of the extent of the fire, the actual date of each grid burning could not be determined. Because of the subsequent period of snow cover, there was little vegetative growth before spring/summer 2003. To determine vegetation cover and area burnt, at each trapping grid in spring, a 2-m ranging pole marked with 10-cm intervals was used to provide a measure of vegetation structure (Carron 1985; G. Sanecki & K. Green, unpubl. 2003). At each grid point, the ranging pole was placed vertically through the vegetation to the ground at the centre of the grid point and at a distance of 3 m uphill, downhill and to the left and right of the grid point centre. Any vegetation contact within a 20-cm interval was scored, the sum of the five scores providing a total vegetation structure score for each grid point. At each point location, vegetation was classified as burnt or unburnt and an estimate of area burnt was calculated for the grids. The distance from each burnt grid to the nearest location where *M. fuscus* appeared to be extant from evidence of fresh scats, was measured using a hand-held Global Positioning System (Garmin Ltd, Kansas City, USA).

**Subnivean space**

In winter 2003, to assess the effect of fire on the development of the subnivean space (the space between the base of the snowpack and the ground surface), we sampled sites at elevations between 1600 m and 1800 m a.s.l. that had been established for a previous study of small mammal distribution during winter (Sanecki et al. 2006). We selected five burnt and five unburnt replicates of each of the four major habitat types present in the subalpine zone of the Snowy Mountains (wet heath, dry heath, seral woodland, grassland). At each site, the subnivean space was measured at two random points within a 3-m radius of each of three permanently marked sampling points. The size of the subnivean space was determined during late August and September once snow cover was established and had attained a relatively homogenous structure. A Federal Snow Sampler (Carpenter Machine Works, Seattle, WA, USA) was used to drill through the snow to ground level to measure snow depth. The subnivean space was calculated as the difference between the snow depth and the core length. Data on burnt and unburnt subnivean space were averaged for each site, log + 1 transformed and compared using analysis of variance.

**Foxes**

Fox scats were collected from a transect two to three m wide, along the bird survey transect monthly during a 3-year study of fox diet (1996–1998). After the commencement of a fox control program in 1998, scats were removed from the transect at the end of February each year from 1999 to 2004. New fox scats were then collected at the beginning of April, were counted and an assessment of their content was made (see Green 2003). The proportions by volume of individual scats occupied by small mammal remains before and after the fire were compared using the $\chi^2$ statistic.

Throughout winter from 1992 to 2003, after a fresh fall of snow, fox tracks were counted on a transect from Perisher Valley to near Wheatley Gap (1.7 km) and from Wheatley Gap to Betts Creek (2.6 km). These transects were burnt in February 2003. Opportunistic counts of tracks after fresh snowfall were also conducted in Whites River Valley on the bird transect up Disappointment Spur from 1500 m to the aqueduct (1.5 km), from the commencement of the aqueduct to the edge of the unburnt area (2.75 km), in unburnt vegetation from the aqueduct to the Whites River Hut (1.5 km), from Whites River Hut to Schlunks Pass (1.25 km) and from Schlunks Pass to the Schlunks Hilton Hut (1.5 km). All tracks crossing the transects were counted. Where a fox track ran along the transect it was counted as 0.5 where it joined the transect and 0.5 where it left the transect.
RESULTS

Birds

Over the years before the fire, the number of bird species >1500 m altitude showed a decline from December through to May as first non-breeding honeyeaters and then summer breeding residents left, until by May only winter resident species were present (Fig. 1). The species composition has been described previously (Osborne & Green 1992). On the day the bushfires commenced in the Snowy Mountains in January 2003, there were 12 species of bird recorded on the aqueduct component of the transect (3.0 of 4.5 km). There was a sharp decline by the end of February before numbers of species returned to within the normal range in March and May (Fig. 1).

In the 3 years before the fire, between July and October, there were 11–12 resident bird species (see Osborne & Green 1992) on the transect and 10–12 migrant species. In the year after the fire there were 8 resident and 3 migrant bird species recorded in the same months, a significant difference ($\chi^2 = 19.59$, 1 d.f. $P<0.0001$). The numbers of species in burnt areas did not rise above the normal wintering numbers and the only immigrant species were flame robins ($Petroica phoenica$), pink robins ($Petroica rodinogaster$) and striated pardalotes ($Pardalotus striatus$). By contrast, on the unburnt sites the full suite of expected immigrants arrived for a 3-week period before unseasonable weather reduced the number (Fig. 2).

Mammals

Trapping

The average area of vegetation burnt on five trapping grids was $87.5 \pm 9.8\%$. Except in one grid, the unburnt areas tended to be small, providing no relatively large patches that could act as refugia for small mammals. One grid was completely unburnt. There was an immediate significant reduction ($F_{1,22} 17.59$, $P < 0.001$) in small mammal numbers on burnt trapping grids after the fire relative to February in the previous year. Similarly, April 2003 had significantly fewer ($F_{1,22} 14.05$, $P < 0.001$) mammals than April 2002, however, there was no significant change in populations between February and April 2003 (Fig. 3). On the burnt grids in December 2003, the numbers of the three species had virtually declined to zero. On the unburnt grid, there were slight rises in numbers in February and April 2003.

After the fire, four of the six grids (one unburnt) contained $M. fuscus$ in February, but only one (burnt) still had $M. fuscus$ in April. After the fires, the distance from burnt grids to the nearest location where fresh droppings indicated that $M. fuscus$ appeared to be extant averaged 235 m.

![Fig. 1. The number of bird species on the transect as the mean ($\pm$SD) from 7 years of pre-fire data (●), and single-month censuses (■) for December and January, immediately before the fire and February March and May post fire. There was no post-fire census for April.](image1)

![Fig. 2. The number of birds on the winter–spring transect for quarter months from the last quarter of July: (●)average values for three seasons before the fire ($\pm$SD) (■) burnt areas and (●) unburnt areas in the season post fire.](image2)
**Subnivean space**

The subnivean space in four habitats was significantly less in burnt than unburnt habitats (Table 1). The unburnt habitat least used by small mammals (grassland) had a larger subnivean space and was not significantly different to the burnt wet heath (Fig. 4) which, when unburnt, was the habitat most used of the four by small mammals during the nival period (Sanecki et al. 2006).

**Foxes**

The number of fox scats on the transect ranged between 74 and 124 during the 3-year study of fox diet (1996–1998). These numbers fell after the commencement of a fox control program. However, the number of fox scats collected in 2003 was similar to that in other years after the commencement of fox control (Fig. 5). Similarly, there was a decline in fox tracks on the transect from Perisher Valley after the commencement of fox control but not further from the ski resort. The figures for winter 2003, however, were similar to all years after the commencement of fox control (Fig. 6).

On the scat transect, a significantly lower proportion of the contents of scats, 38.4 ± 19.8%, was mammal hair in the 6 years sampled before the fire compared with the 2 years after the fire when the figure was 77.5 ± 3.5% ($\chi^2 = 162.74$, 1 d.f. $P < 0.0001$). On the ski transect through burnt and unburnt areas, six burnt transects averaged 0.90 ± 0.90 tracks km$^{-1}$, whereas two unburnt transects averaged 7.33 ± 0.47 tracks km$^{-1}$ ($t = 9.37$ 7 d.f. $P < 0.0001$).

**DISCUSSION**

**Birds**

After the fire, there was an immediate reduction in numbers of bird species and individuals in burnt

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**Fig. 3.** The minimum numbers alive (MNA) of three species of small mammals on trapping grids in February and April 2002 and 2003. (○) Rattus fuscipes (■) Antechinus swainsonii and (●) Mastacomys fuscus.

**Fig. 4.** Depth of subnivean space in burnt and unburnt habitat in winter 2003. (□) SD, (■) SE, and (○) mean.
woodland. The birds present in late February constituted only the regular winter species plus two migrants, the olive whistler (Pachycephala olivacea) and the flame robin. The number of species returned to the ‘normal’ range by the end of March (Fig. 1); there was no survey in April. Although four species were recorded in May, a figure within the expected range, this constituted only seven individuals. Although individuals were not normally counted in the present study, a count along both arms of the aqueduct (about twice the distance as in the present study) in May 1983 detected about 60 individuals (Osborne & Green 1992). Numbers of individual birds also declined after a coastal wildfire at Nadgee in 1972 but only three species present before the fire disappeared, while one new species appeared (Catling & Newsome 1981). The only species commonly recorded on the present transect after the fire but not before it was the little raven (C. mellori), probably due to the foraging opportunities presented by the opening up of the woodland shrub layer.

In a mist netting program conducted from nine to 19 times a year in montane forest of Eucalyptus dalrympleana on the Brindabella Range to the north of the study area, there were changes in abundance of birds after a wildfire in 1972 although there was no loss or gain of species (Catling & Newsome 1981). However, in the present study in winter–spring, the numbers of species in weekly counts never rose above two to five on the burnt side of the valley and these were mainly the normal winter species, indicating that conditions 8 months after the fire were still not suitable for most bird species. All immigrant species that were expected to occur appeared on the unburnt side of the valley. The birds that spend the winter in the area feed in a number of different locations, such as under the bark of trees, in the bushes, or on the snow surface (Osborne & Green 1992) and those species persisted through the winter, although with a reduced number of individuals. However, some of the migrant species (such as honeyeaters) are dependent on flowering shrubs which were absent after the fire, others feed on shrubs, tree trunks and in the tree canopy; all these feeding locations were very much reduced in the fires.

Catling and Newsome (1981) examined 18 bird species after a fire in montane forest and categorized them by three feeding locations: forest floor, shrub layer and canopy. Of the species recorded by Catling and Newsome (1981), 11 were also common in the present study area before the fire (Osborne & Green 1992). The one ‘forest floor’ species, the flame robin, was found to increase significantly in total numbers in mountain gum forest after fire in 1972 (Catling & Newsome 1981). The one ‘forest floor’ species, the flame robin, was found to increase significantly in total numbers in mountain gum forest after fire in 1972 (Catling & Newsome 1981). This was also the only regular migrant that was common in the burnt areas of the present study after winter 2003 although it is not normally present in winter due to the cover of snow (Osborne & Green 1992). Four species of the shrub layer of both montane forest (Catling & Newsome 1981) and subalpine woodland (Osborne & Green 1992) were still absent from the burnt woodland in...
the present study 1 year after the fire, as were four of the five ‘canopy’ species with only the brown thornbill (*Acanthiza pusilla*) remaining. By contrast, in the 5 years post fire in montane forest, Catling and Newsome (1981) only recorded a significant decrease in the numbers of eastern spinebill (*Acanthorhynchus tenuirostris*) and crescent honeyeaters (*Phylidonyris pyrrhoptera*). This highlights the differences in the fire adaptedness of the two forest types. Montane wet forest of *E. dalrympleana* regenerates from epicormic shoots and the loss of canopy from above-ground structures such as stems and larger branches is therefore a very temporary affair unlike the permanent loss in snowgum (until shoots from ground level grow to form a canopy). Additionally, other lower feeding areas are still available in montane wet forest because the area is not subjected to winter cover of snow.

**Mammals**

The requirements for a species to inhabit a given area are the critical resources usually identified as food and cover (Whelan et al. 2002). Both of these may be lost in a fire and the responses of small mammals vary with their resource requirements, with some species such as feral house mice (*Mus domesticus*) being favoured by fire (Newsome et al. 1975; Fox 1982; Rasolondrasana & Goodman 2005) and others such as swamp rat (*Rattus lutreolus*), which requires thick, cover being disadvantaged (Fox 1982). The immediate post-fire response of a suite of small mammals is therefore quite complex with possibly only the effects of competition and predation adding markedly to resource implications in the complexities of recolonization in other studies (reviewed by Sutherland & Dickman 1999). The present study differed from these in that, following the fires in February, two further periods characterized by strong selective forces on the small mammals followed in quick succession, the autumnal cold period before the onset of winter snow (Green 2001) and the period of the winter snowpack (Green & Osborne 1994, 1998).

While the immediate impact of fire on mammal numbers in the burnt grids was a reduction in numbers, there was still some food available in the form of insects and regrowth of grasses (K. Green & G. Saneecki, pers. obs. 2003). There was no discernible further decrease in numbers of *A. swainsonii* and *R. fuscipes* to April. However, *M. fuscus* was found on four grids (one unburnt) in the immediate aftermath of the fire but 2 months later it was only found on one burnt grid and was absent from the unburnt grid. Green (2003) found that mammals were least common in the diet of foxes in the snow-free months when foxes fed predominantly on insects. However, many insect groups such as grasshoppers were absent from burnt areas after the fire (K. Green, pers. obs. 2003), and there was an immediate significant increase in the proportion of fox scats containing mammal hair. Mammals that survived the fire were therefore probably at greater risk of predation immediately after the fire. However, there are few direct studies of post-fire impacts of predation (Keith et al. 2002), and mortality cannot be quantified using pre and post-fire numbers because mortality cannot be distinguished from emigration (Whelan 1995). In the present study, fox numbers appeared unchanged after the fire, whereas after fire at Nadgee in 1972 there was an initial decline, possibly due to the extreme scarcity of small mammals (Newsome et al. 1975). Although the number of fox scats collected on the transect in the present study was the same in 2003 as in previous years, more were found towards the unburnt end of the transect (K. Green, pers. obs. 2003). Despite an extra fox baiting effort in unburnt areas, these areas may have been targeted by foxes in the months after the fire (as they were later in winter), reducing the numbers of the preferred mammalian prey, *M. fuscus* (Green 2002).

The generally higher numbers of small mammals on the unburnt grid in February and April 2003 than the same times in 2002 may have stemmed from immigration from nearby burnt areas, but are within the expected interannual variation. However, the falls in numbers from April to December 2003 are outside interannual variation, except for *Antechinus* spp. which undergo total post-mating mortality of males in the Snowy Mountains in late September (Green & Crowley 1989). Whelan et al. (2002) referred to ‘interval related processes’, those processes such as starvation and predation that affect a population in the weeks or months after a fire. There was no apparent fall in total small mammal numbers from February to April (Fig. 3) but the fall to December may have begun in April. The impacts of autumnal cold on *A. swainsonii* are a loss of body mass from April to May and lighter animals dying and being replaced by heavier animals (Green 2001). Within small unburnt areas, there might be little opportunity for immigration of heavier animals onto the one unburnt grid. The largest impacts, however, probably occurred during winter. Small mammals active through the winter are dependent upon the formation of the subnivean space (Green 1998). While the lowered availability of food from between the fire to the establishment of the winter snowpack could have been utilized by a lowered density of small mammals foraging widely, the opportunity for foraging widely, if at all, was prohibited in winter 2003 by the lack of subnivean space (Fig. 4). This in itself would have been sufficient to cause high mortality in wintering non-hibernating species. Additionally, however, the snow cover was not deep in 2003. The ‘standard’ snow cover location for the Snowy Mountains, the snowcourse at Spencers Creek...
(1830 m), had a mid range of snow for the 50 years data (ranked 25th of 50 years in terms of metre-days – Snowy Hydro 2003). However, at lower altitudes where all the trapping grids occurred, snow was patchy and at one grid at Whites River the nearby snowcourse at 1680 m had only 1 cm of snow at points as late as late July and points clear of snow only 8 weeks later (K. Green unpubl. data 2003). Foxes may concentrate their foraging efforts in areas of shallow snow where excavating prey is energetically less expensive. The shallow snow, combined with the need for animals to move over the snow surface in the absence of a sub-nivean space would have predisposed them to increased predation by foxes (Green 2000).

There is still the question of the decline of *M. fuscus* in the unburnt grid. The grid was well clear of any fire damage and therefore no edge effect is implicated. Halpin and Bisonette (1988) found that red foxes concentrated their foraging in preferred areas in winter snow. Although Green (2002) did not find any concentration of foraging effort in the present study area before the fire, this concentration was evident in the small amount of unburnt habitat post fire from two indices, fox scats in summer/autumn and fox tracks on winter snow. The one unburnt grid was on a north-facing slope at 1520 m where snow cover was not reliable, and in fact was absent for much of August 2003. Given the shallow winter snow and concentration of fox foraging, this area would have been a likely preferred feeding location. This might help to explain the sharp decline in numbers of *M. fuscus* at this location despite the intact vegetation.

Whelan et al. (2002) concluded that, except at a very general level, responses to fires will be site specific. The data from the present study show how winter-active small mammals above the level of the winter snowline, are totally dependent on the balance of the suite of edaphic and biological components in their habitat for continued existence. The interaction of snow cover, as insulation and in restricting foraging, shrub cover which allows for the formation of greater subnivean space (Green & Osborne 1994; Sanecki et al. 2006), and the presence of an introduced predator can only work in relative equilibrium in the absence of, or long time interval between, fires. Fires in other Australian ecosystems have a varying impact on small mammal populations. In sympathy with swamp rats, *R. lutreolus*, and with no pre-fire population crash in *M. fuscus*, Driessen (pers. comm. 2004) found *M. fuscus* returning to burnt areas earlier than *R. lutreolus*. In one mainland coastal heathland, *R. lutreolus* were slow to recolonize after a major fire, not returning until 4 years and not breeding until 5 years post fire (Fox 1982), whereas after another fire, recolonization was within 4 months, and breeding occurred in the first year (Monamy & Fox 2000). Swamp rats are a late-seral stage specialist and only recolonize an area when vegetation close to the ground attains near maximal density, independent of time since fire (Monamy & Fox 2000), However, recovery in the present study area is complicated by the need, not only for shrubs to provide cover for summer foraging, but also to provide sufficient structural strength to support the weight of winter snow before the burnt areas become habitable again on a year-round basis.

**ACKNOWLEDGEMENTS**

We thank Snowy Hydro for funding post-fire monitoring of small mammals. Chris Dickman, Michael Driessen and Ian Mansergh commented on the manuscript.

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