Department of Sustainability and Environment

Assessing the impact of the 2009 Kilmore East-Murrindindi Complex fire on microbats

Black Saturday Victoria 2009 – Natural values fire recovery program

Micaela Jemison, Lindy Lumsden, Jenny Nelson, Michael Scroggie, Ryan Chick

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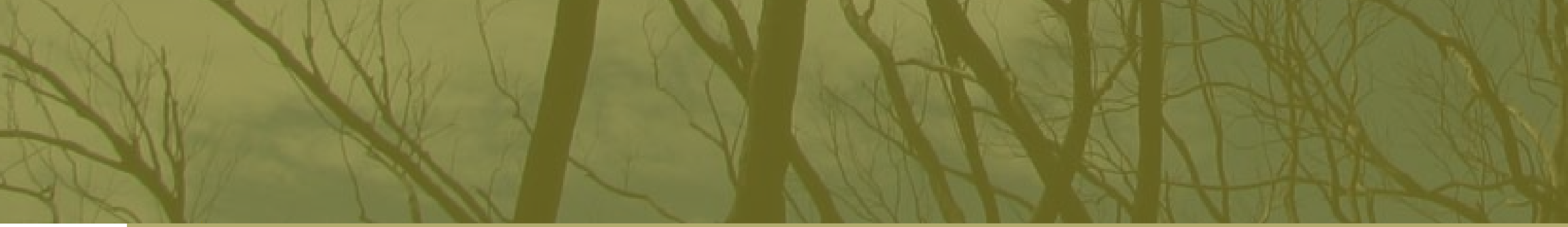

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Front cover photo: A severely burnt area near Kinglake, two years after the 2009 fires, sampled for microbat activity (Micaela Jemison) and the Lesser Long-eared Bat (*Nyctophilus geoffroyi*) which appears more susceptible to the impact of fire than other bat species (Lindy Lumsden).

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Acknowledgements

This project is No. 29 of the program 'Rebuilding Together' funded by the Victorian and Commonwealth governments' State-wide Bushfire Recovery Plan, launched October 2009. We thank Stephen Platt (Department of Sustainability and Environment [DSE], Biodiversity and Ecosystem Services) and Steve Smith (DSE, Regional Services) for facilitating and managing this funding.

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Summary

Fire is a prominent component of the Australian landscape, particularly in the south-east of the continent. While many species of flora and fauna have adapted to fire, there are varying levels of knowledge of how species survive and recover after a fire event. Microbat species are one group that is poorly understood in relation to fire. This project was instigated to increase knowledge of the response by microbats to the bushfires in February 2009 (the 'Black Saturday' fires), that burnt approximately 430,000 ha of Victoria.

The aim of this study was to assess the impact of fire on threatened and non-threatened microbat species in areas burnt by the Kilmore East-Murrindindi Complex fire, the largest (330,000 ha) of the 2009 'Black Saturday' bushfires. The impact of these fires on populations of bats and the availability of foraging habitat was inferred by comparing activity levels of bats between sites with different fire histories. Dry forest habitats of similar age and structure within public land in the Eildon, Kinglake and Tallarook regions were sampled. A total of 68 sites were surveyed using Anabat ultrasonic detectors, that were evenly distributed across three fire history categories. The fire categories were defined by whether the area was burnt during the 2009 fires and the previous fire regime based on the number of fires occurring in the last 41 years (since 1970). The fire histories targeted were: burnt in 2009 but unburnt in the previous 41 years; burnt in 2009 and also burnt one or more times prior to this within the last 41 years; and unburnt in 2009 and not burnt for at least 41 years. This design enabled an examination of the impact of different fire regimes, not just the most recent fire.

Sites were sampled from January to March 2011, two years after the Black Saturday fires. At each site microbats were surveyed using a single Anabat detector, set for six nights. Habitat assessments were made at each site to investigate factors that may influence activity levels, such as fire severity and tree size. Fourteen taxa of microbats were recorded. The three most commonly recorded species (comprising 60.1% of the overall activity of identified species) were the White-striped Freetail Bat *Tadarida australis*, Little Forest Bat *Vespadelus vulturnus* and Large Forest Bat *Vespadelus darlingtoni*. Whilst microbat activity was recorded at every site, a significantly greater index of activity was recorded in unburnt habitats compared to burnt habitats. Fire severity was found to be a strong influence on the total bat activity, with greater activity recorded at less severely burnt sites. Similar relationships were found for several individual species in their responses to fire. Species that had higher activity levels at less-severely burnt sites included the Chocolate Wattled Bat *Chalinolobus morio*, Eastern Bent-wing Bat *Miniopterus schreibersii oceanensis*, Large Forest Bat, Southern Forest Bat *Vespadelus regulus* and long-eared bats *Nyctophilus* sp. The Eastern Bent-wing Bat, which is listed under the Victorian *Flora and Fauna Guarantee Act 1988*, demonstrated a clear negative relationship with fire severity, showing higher activity levels in unburnt habitats compared to burnt habitats. The other nine species recorded in this study, including the only other threatened species recorded (Yellow-bellied Sheathtail Bat *Saccolaimus flaviventris*), did not show any significant relationship between activity levels and burn intensity. No species showed a positive relationship with higher fire intensities. In this study, the past fire regime did not influence bat activity, with no statistical difference found in the activity levels in areas burnt in 2009 that had also burnt one or more times in the previous 41 years compared to those that had remained unburnt prior to 2009.

Fire can reduce the amount of clutter in a habitat and thus reduce physical obstacles that impede microbat flight, thereby allowing greater ease of flight for less clutter-tolerant species. This, however, was not observed in this study, with microbat species composition found to be the same in burnt and unburnt areas, and no species demonstrating higher levels of activity in less cluttered, burnt areas.

The factors influencing the observed responses are not fully understood, but are likely to be related to both direct and indirect impacts of fire on microbat populations and habitat features. The extent of mortality resulting from the fire is unknown. However, the high intensity and rapid movement of the 2009 bushfires is likely to have led to a high mortality of microbats. Species may have been impacted differently based on their roosting habits and behavioural response to the threat of bushfire. The fire may have led to indirect effects on microbats through changes to roosting habitat, foraging habitat and insect prey availability. Greater knowledge is required on all these aspects to improve our understanding of the impact of fire on microbat populations.

1 Introduction

During February 2009, a number of intense bushfires swept across the Victorian landscape. These 'Black Saturday' fires severely burnt a number of areas including a large area (330,000 ha) to the north and north-east of Melbourne where two large fires combined to form the Kilmore East–Murrindindi Complex fire (Teague *et al.* 2010). While fire is a key component of the Australian landscape, there is limited knowledge of the impact of fire on flora and fauna (Clarke 2008). Insectivorous bats (or microbats, Microchiroptera) play a key ecological role in ecosystem health by consuming large quantities of insects (Kunz *et al.* 2011). Despite their ecological importance, little is known of the impact of fire on microbats, with very few studies addressing the impact of fire on bat abundance or diversity in Australian environments (Humann 2009). There have been few international studies on bats in relation to prescribed fire regimes (Boyles and Aubrey 2006, Loeb and Waldrop 2008, Layne 2009). A study in North America suggested that fire may have potential positive impacts on habitat for bats through a reduction in vegetation clutter in burnt areas allowing greater ease of flight, and a higher proportion of dead trees available for roosting (Boyles and Aubrey 2006). Behavioural responses of Northern American bats to fire have also been investigated (Layne 2009) revealing that bats respond to the threat of an approaching fire by using both the sound and smell of the fire as cues for arousal.

Fire has long been recognised as an important part of Australian landscape ecology, particularly in the south-east of the continent. While many species have adapted to fire, the effect of fire on flora and fauna depends largely on the fire's intensity, how widespread the fire is, the time between burns and the patchiness of the burnt and unburnt mosaic (Gill 1975, Whelan 1995, Friend 2004). Low-intensity fires tend to move slowly, with impacts largely restricted to the ground-layer and understorey plant species (Gill and Catling 2002). In contrast, high intensity fires move rapidly and defoliate the canopy as well as removing the understorey (Gill and Catling 2002). The effects of heat, smoke and oxygen depletion generated by both low and high intensity fires can cause mortality or injury to wildlife (Whelan *et al.* 2002). These effects, combined with the ignition of entire trees, we suggest are likely to have resulted in the death of many thousands of bats during the high intensity Black Saturday bushfires. However, the proportion of the pre-fire population that was killed is unknown. Several features of microbats make them susceptible to a high mortality rate: most bats in the fire-affected area roost in tree hollows or under bark (Menkhorst 1995); they are nocturnal and reluctant to fly during the day; and even if they did attempt to out-fly the fire front they are likely to be severely affected by radiant heat due to their small body size.

In addition to direct mortality, fire can also indirectly affect bats post-fire through changes to the forest environment. The ability of bats to effectively fly and echolocate is influenced by the amount of clutter found in their habitat (Fenton 1990). Law and Chidel (2002) broadly define clutter as background objects, including vegetation, branches and rocks that impede flight and echolocation. Variation in wing shape and echolocation calls between different species allow them to make varying use of environments with different amounts of clutter (Findley *et al.* 1972, Aldridge and Rautenbach 1987, Law and Chidel 2002). For instance, smaller bats with broader wings and higher frequency echolocation calls are more tolerant of clutter than less manoeuvrable species with long, narrow wings and low frequency echolocation calls (Aldridge and Rautenbach 1987, Crome and Richards 1988, Law and Chidel 2002). As such, individual species may respond differently to changes in clutter resulting from fire.

Changes in forest structure may also alter prey availability for microbats. Microbats eat large amounts of insects (Saikia 2007), and the impact of fire on prey availability is poorly understood (Carter *et al.* 2002). Fire can directly and indirectly influence insect populations (Lacki *et al.* 2007). Changes in insect abundance can result directly from fire through initial mortality (McCullough *et al.* 1998) and the removal of vegetation (Webala *et al.* 2011), as well as indirectly, as burnt forests regenerate with a different structure from the previous unburnt forest (Webala *et al.* 2011). Very few studies have examined the effects of fire on insect diversity and abundance, and further research is needed to gain a greater understanding of its subsequent influence on bat populations.

The impact of fire on the availability of tree hollows will also influence microbat populations. Many Australian microbat species use tree hollows and cavities formed under bark as diurnal roost sites (e.g. Lumsden *et al.* 2002a, Goldingay 2009). The role of fire in the development or destruction of these tree cavities is complex. Fire can assist in the development of tree hollows by directly burning out cavities (Inions *et al.* 1989) or by creating points of entry for microbes and insects, which can assist in hollow formation (McCaw 1983, Perry *et al.* 1985). However, depending on intensity, fire may also kill or severely damage trees (Inions *et al.* 1989). Intense fires reduce the number of hollow-bearing trees due to the increased susceptibility of dead trees to collapse (Lindenmayer *et al*. 1990, Lindenmayer *et al.* 1993). Due to this reduction in roosting habitat, microbat species which preferentially roost in dead, hollow-bearing trees, such as the Lesser Long-eared Bat *Nyctophilus geoffroyi* (Lumsden *et al.* 2002a), are more likely to be affected than those species that roost in hollows of live trees.

The two key habitat requirements for bats are roost sites and foraging resources. Whilst knowledge of the impact of fire on roosting requirements is important to fully consider the impact of fire on bat populations, this study takes the first step in improving our understanding by focusing on the impact of fire on foraging habitat.

The main objective of this study was to assess the impact of the 2009 fires by comparing the relative levels of activity of bats in areas burnt in these fires with nearby unburnt areas. This project was undertaken two years after the fire and so represents the situation after some regeneration and recovery, rather than immediately post-fire. A secondary objective was to assess if the previous fire regime influenced bat activity. Our results will provide a greater understanding of the impact of fire on the foraging requirements of microbats, which may be useful in informing future management.

2 Methods

2.1 Study Area

This study focused on areas burnt by the 2009 Kilmore East–Murrindindi Complex fire and adjacent unburnt areas. Three areas were selected for study, based broadly around the townships of Eildon (-37°14'S, 145°55'E), Kinglake (-37°31'S, 145°21'E) and Tallarook (-37°06'S, 145°46'E) (Figure 1). Sites were selected on public land encompassing a range of fire histories (described in Section 2.2). Spatial data layers were used to identify Ecological Vegetation Classes (EVC) ('NV_EVCBCS', August 2010 © The State of Victoria, Department of Sustainability and Environment) and fire history ('LASTBURNT100', August 2010 © The State of Victoria, Department of Sustainability and Environment).

2.1.1 Lake Eildon National Park and adjoining state forest

Lake Eildon National Park (27,750 ha) is in the northern foothills of the Victorian Central Highlands, close to the township of Eildon. The Park is characterised by strongly dissected mountainous terrain with habitats ranging from open woodlands to areas of dense forest (Parks Victoria 1997). The dominant Ecological Vegetation Classes (EVCs) in the Park include: Herb-rich Foothill Forest, Shrubby Dry Forest and Grassy Dry Forest. Herb-rich Foothill Forest, Shrubby Dry Forest and Damp Forest are the most common EVCs in the state forest adjoining the Park to the south.

Lake Eildon National Park remained largely unburnt in February 2009, with the fire mostly contained along the Park's south-western boundary. However, large areas of state forest directly south of the Park were burnt by the Kilmore East–Murrindindi Complex fire (Figure 1).

2.1.2 Kinglake National Park, Yan Yean Reservoir and southern nature conservation reserves

Sites were selected within Kinglake National Park, forested areas surrounding Yan Yean Reservoir and several nature conservation reserves (NCR) south of the Park: Warrandyte-Kinglake NCR, Boomers NCR, St. Andrews NCR and Yering Gorge Bushland Reserve.

Kinglake National Park (22,360 ha) is located near the township of Kinglake. The Park landscape is characterised by the Kinglake plateau and its southern escarpment. The plateau consists of undulating terrain with steeper slopes confined to stream valleys. This contrasts with the escarpment, which is characterised by a series of steep-sided ridges and valleys where slopes of up to 30° are common (National Parks Service 1996). The vegetation of the Park is mostly comprised of dry forest EVCs including Herb-rich Foothill Forest, Shrubby Foothill Forest, Heathy Dry Forest, Valley Grassy Forest and Grassy Dry Forest.

The forested area surrounding Yan Yean Reservoir and the nature conservation reserves south of the Park are characterised by relatively flat terrain. Yan Yean Reservoir is located south east of the township of Whittlesea (-37°10'S, 145°56'E) and the surrounding forest is most commonly characterised by Grassy Dry Forest, Valley Grassy Forest and Plains Grassy Woodland EVCs. Herb-rich Foothill Forest and Grassy Dry Forest are the most common EVCs in the nature conservation reserves.

Approximately 90% of Kinglake National Park was burnt by the Kilmore East–Murrindindi Complex fire on Black Saturday in February 2009 (ABZECO *et al.* 2010). Areas south of the Park, including Yan Yean Reservoir and the nature conservation reserves, were not burnt by the Black Saturday bushfires (Figure 1).

2.1.3 Tallarook State Forest and Clonbinane State Forest

The third cluster of sites was in the Clonbinane State Forest and Tallarook State Forest. The Clonbinane State Forest lies adjacent to the northern boundaries of Kinglake National Park, near Flowerdale (-37°10'S, 145°56'E). The terrain of the Clonbinane State Forest is similar to that of the undulating plateau and escarpments of Kinglake National Park. The vegetation of the state forest is mostly comprised of dry forest EVCs including Herb-rich Foothill Forest and Grassy Dry Forest. The Kilmore East–Murrindindi Complex fire burnt all of the Clonbinane State Forest in 2009 (Figure 1).

Tallarook State Forest is directly north of the Clonbinane State Forest and lies east of the Hume Highway between the townships of Tallarook and Broadford (-37°10'S, 145°56'E). It encompasses mountainous terrain. The most common EVC in the State Forest is Herb-rich Foothill Forest with small patches of Grassy Dry Forest. Tallarook State Forest was unburnt in 2009, with the fire mostly contained along the northern boundary of Clonbinane State Forest (Figure 1).

2.2 Sampling Design

Sites were selected based on fire history, vegetation type and forest age structure. The primary aim of the study was to investigate the impact of the 2009 fires on bat activity and so sites were broadly categorised as being burnt or unburnt in those fires. A secondary aim was to investigate if previous fire regimes influenced bat activity. Therefore, the burnt category was divided further based on the number of fires in the previous 41 years (since 1970): burnt in 2009 but unburnt in the previous 41 years; and burnt in 2009 and also burnt one or more times prior to this within the last 41 years. The unburnt category represented areas not burnt in 2009 or during the previous 41 years (Figure 2, Table 1). A fourth fire category was also present in the landscape, consisting of areas that had experienced at least one fire since 1970 but had not burnt in the 2009 bushfires. This category was not sampled because the emphasis of this study was on comparing areas burnt in 2009 with those with no recent fire history.

Figure 1. The study area used to examine the impact of fire on microbats, showing the three areas that were sampled and the extent of the Kilmore East–Murrindindi Complex fire in this area.

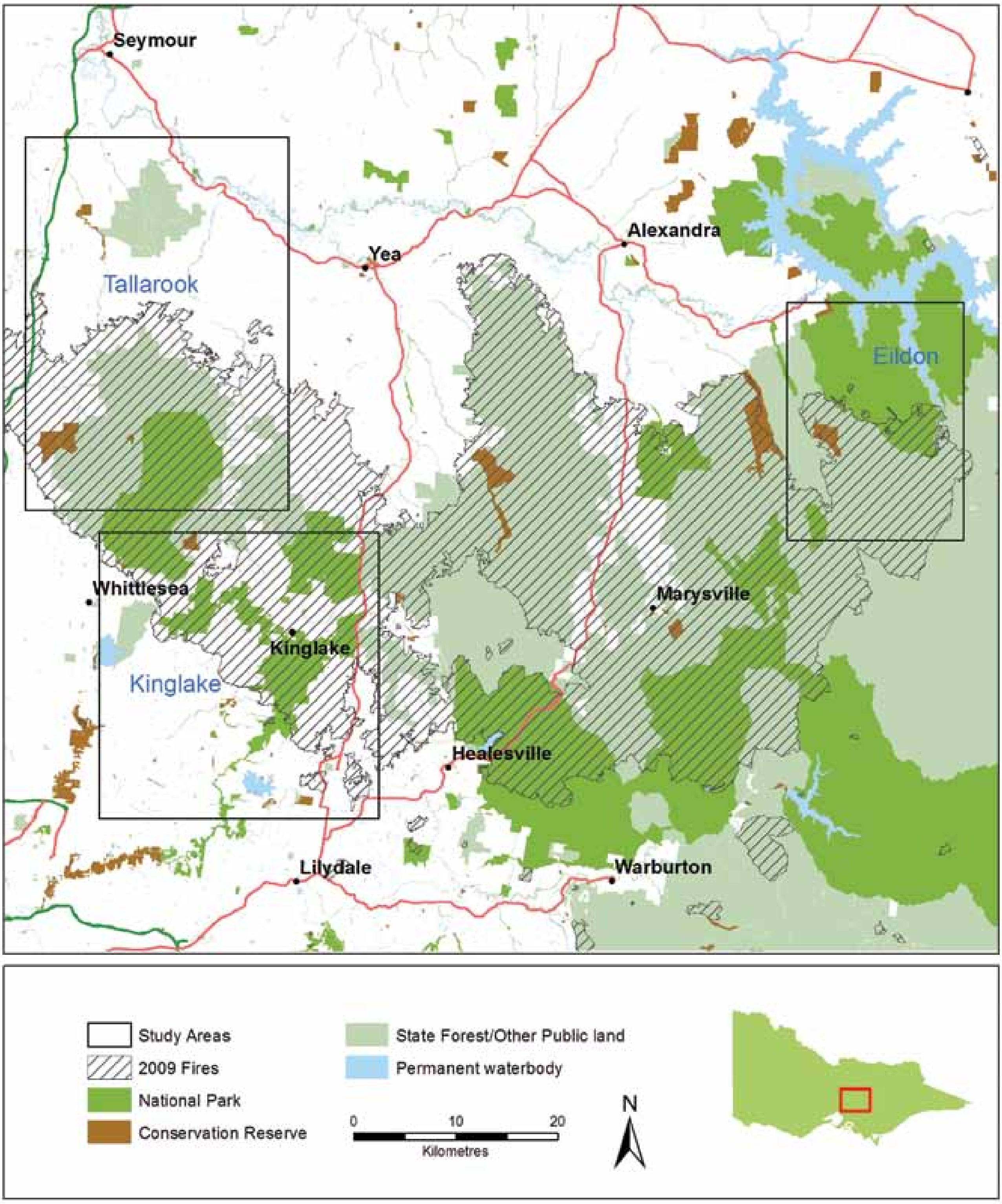
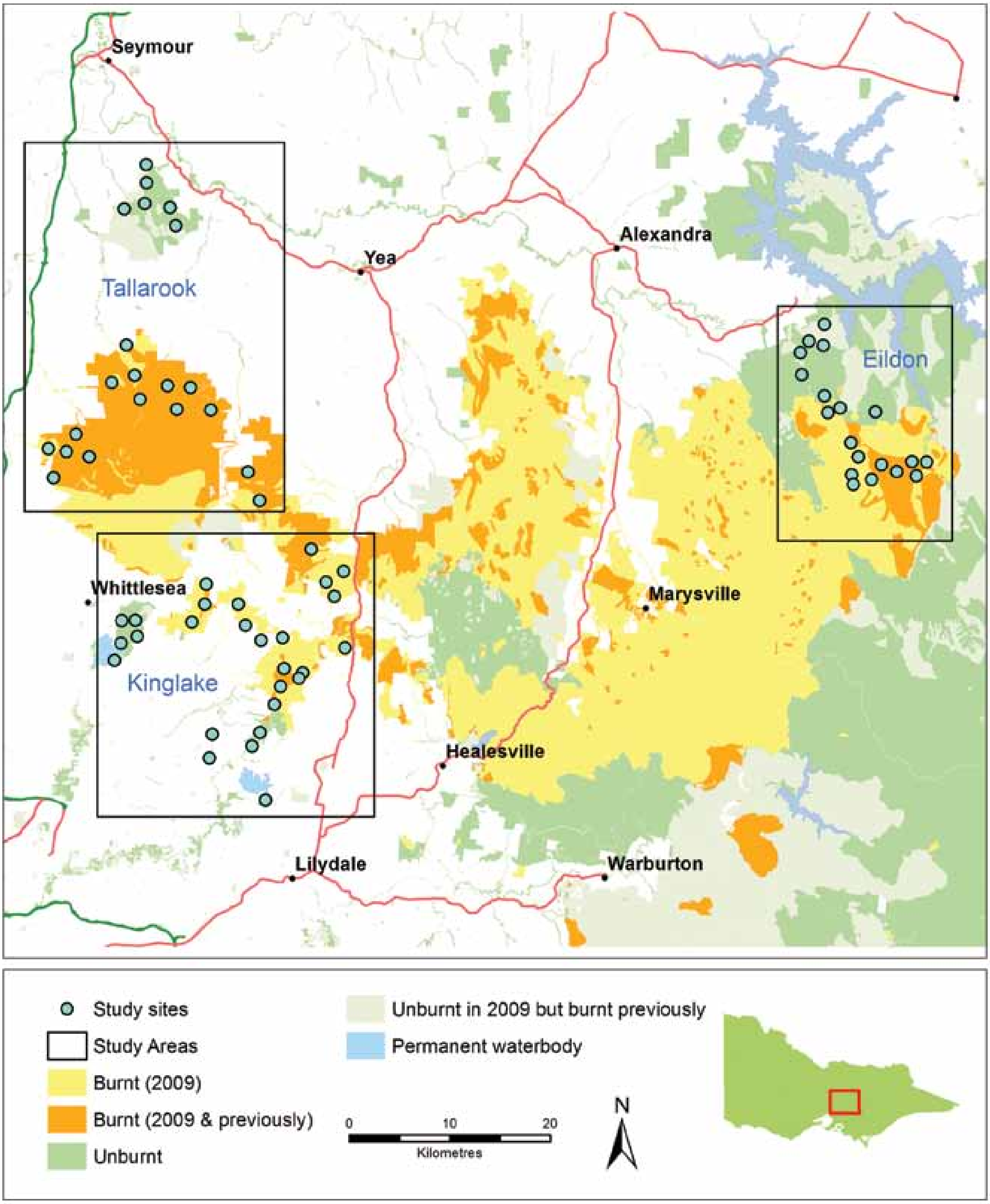


Figure 2. The location of study sites on public land in the Eildon, Kinglake and Tallarook areas, in relation to the fire categories (refer Table 1) used in this study to examine the impact of fire on microbats.



Two dry forest Ecological Vegetation Divisions (EVDs: an aggregation of several similar EVCs into larger, ecologically based groupings; Cheal 2010), were surveyed. These were Forby Forest (including the EVCs Herb-rich Foothill Forest and Grassy Woodland) and Grassy/Heathy Dry Forest (including the EVCs Shrubby Dry Forest, Valley Grassy Forest and Grassy Dry Forest). Sites were selected with a similar pre-2009 fire age structure, to reduce any confounding effects of forest age. This was subsequently tested in the field by measuring the diameter at breast height (DBH) of ten live trees (greater than 10 cm DBH) closest to the sampling point at each site. No significant difference was found in the DBH of live trees between sites of the three fire categories, indicating a similar pre-fire age structure.

Spatial data containing information on fire history, EVD, land tenure and proximity to vehicle tracks were used to select the sites. Information on these factors was accessed from numerous spatial data layers held in the Department of Sustainability and Environment's (DSE) corporate geospatial data library and site selection was made using mapping software (ArcGIS and ArcView and Biodiversity Interactive Mapping, DSE).

Sites were located at least 2 km apart. Sites were also selected at least 2 km from the burnt/unburnt interface. Although microbats can fly considerable distances from their roost to foraging areas (up to 12 km for the Lesser Long-eared Bat and Gould's Wattled Bat *Chalinolobus gouldii*; Lumsden *et al.* 2002b), 2 km was considered far enough into the burnt or unburnt habitat that any animals present were there intentionally. To reduce biases in bat activity levels due to the availability or otherwise of obvious flight paths, all sites were positioned at least 80 m from vehicle tracks.

Sites were sampled from January to March 2011, two years after the 2009 fires. A total of 68 sites were sampled in the study, with 19 sites in the Eildon area (Figure 3), 27 sites in the Kinglake area (Figure 4) and 22 sites in the Tallarook area (Figure 5). Sites were evenly distributed between the three fire categories. Overall, there were 21 sites in the Burnt (2009) category; 23 sites were sampled in the Burnt (2009 & previously) category and 24 sites were in the Unburnt category.

Table 1. Fire categories sampled in this study.

Fire Category	Explanation
Burnt (2009)	The area was burnt in 2009, with this the only fire since 1970.
Burnt (2009 & previously)	The area was burnt in 2009, with at least one previous fire since 1970.
Unburnt	The area has remained unburnt since at least 1970 (41 years).
Unburnt in 2009 but burnt previously	The area has burnt at least once since 1970, but not in 2009.

Figure 3. The fire history and location of the sites sampled in the Eildon area. Fire history categories that were sampled are: Burnt (2009) – burnt in 2009 but not in the previous 41 years; Burnt (2009 & previously) – burnt in 2009 and at least once in the previous 41 years; Unburnt – not burnt in 2009 or in the previous 41 years.

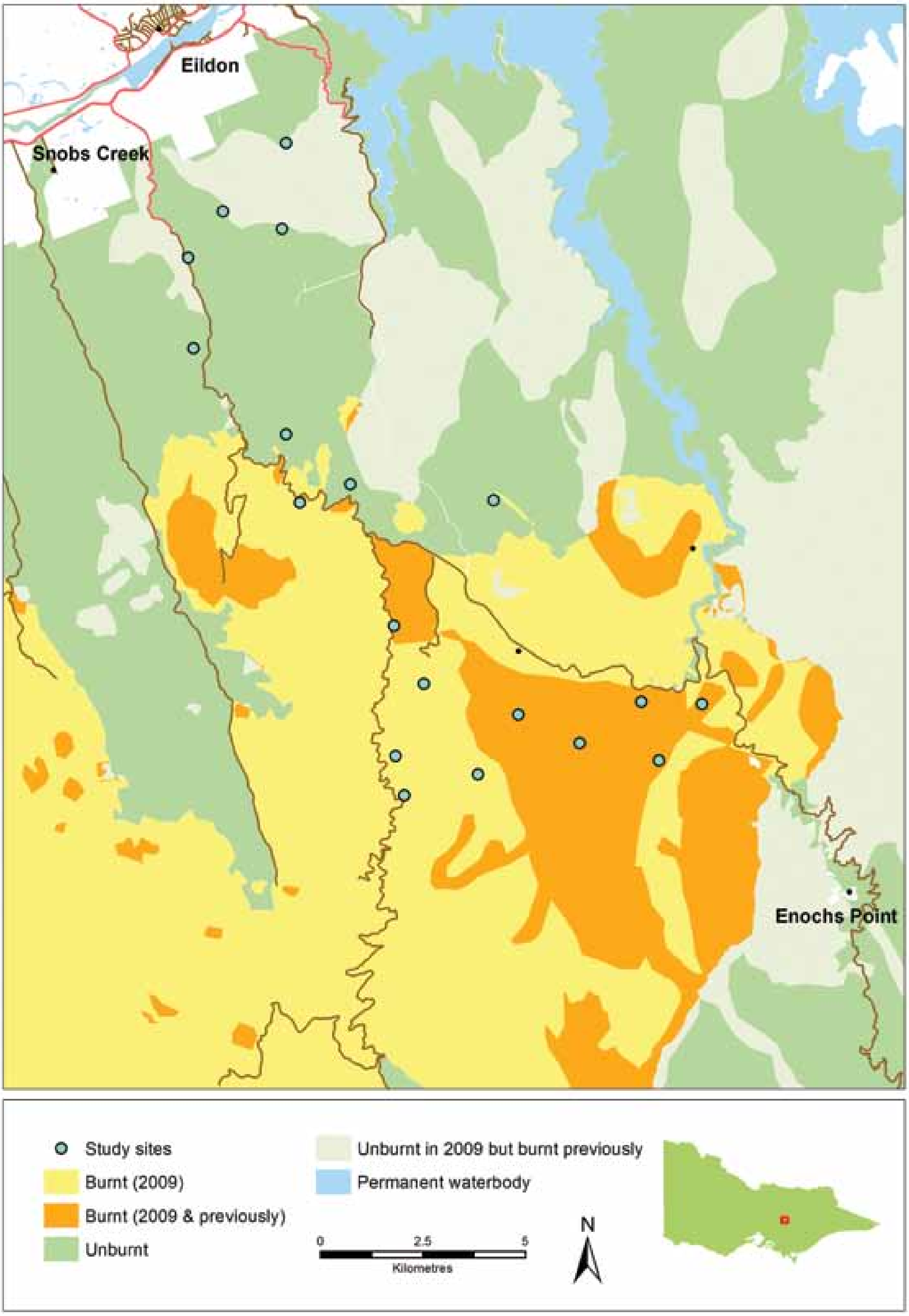


Figure 4. The fire history and location of the sites sampled in the Kinglake area. Fire history categories that were sampled are: Burnt (2009) – burnt in 2009 but not in the previous 41 years; Burnt (2009 & previously) – burnt in 2009 and at least once in the previous 41 years; Unburnt – not burnt in 2009 or in the previous 41 years.

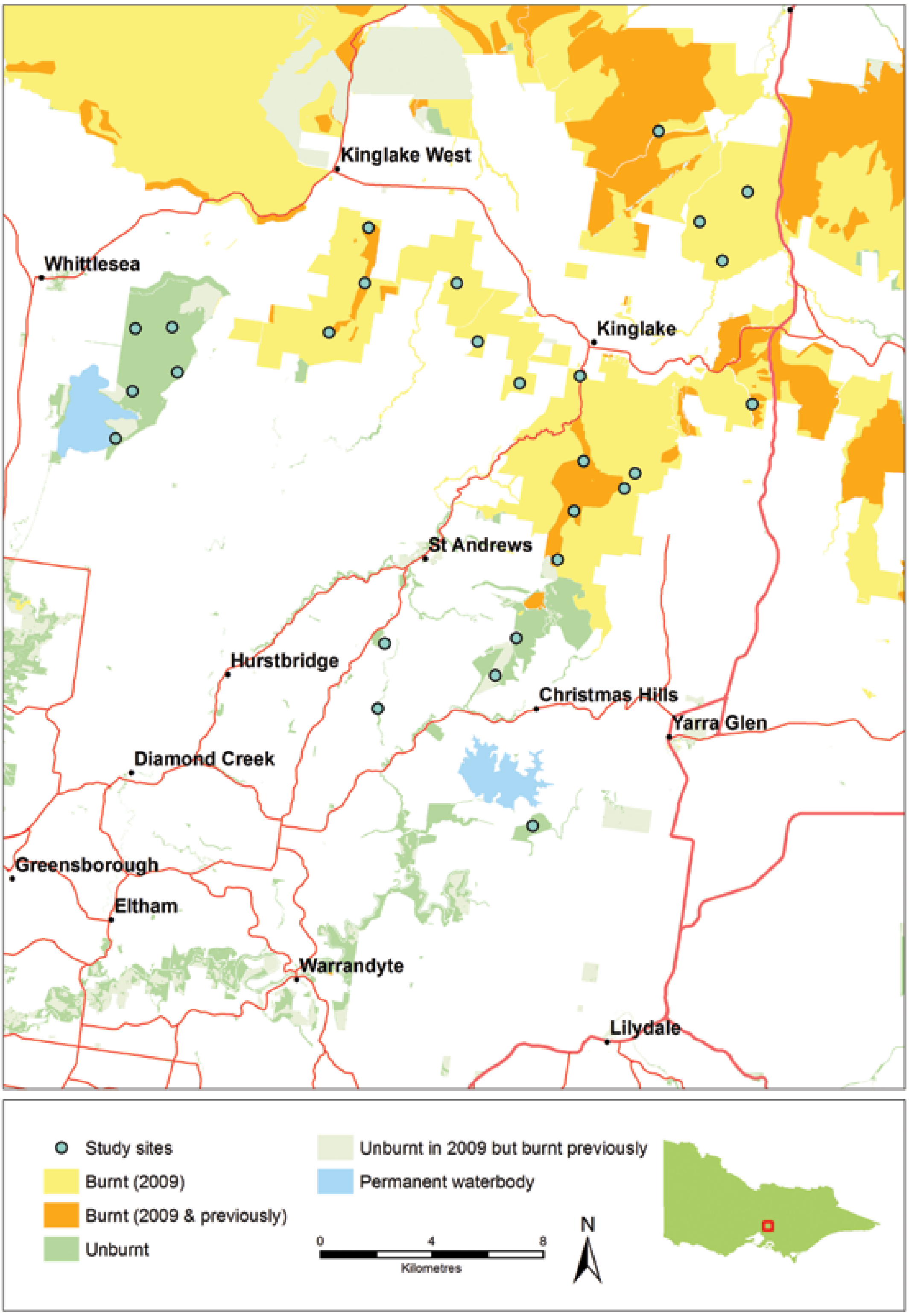
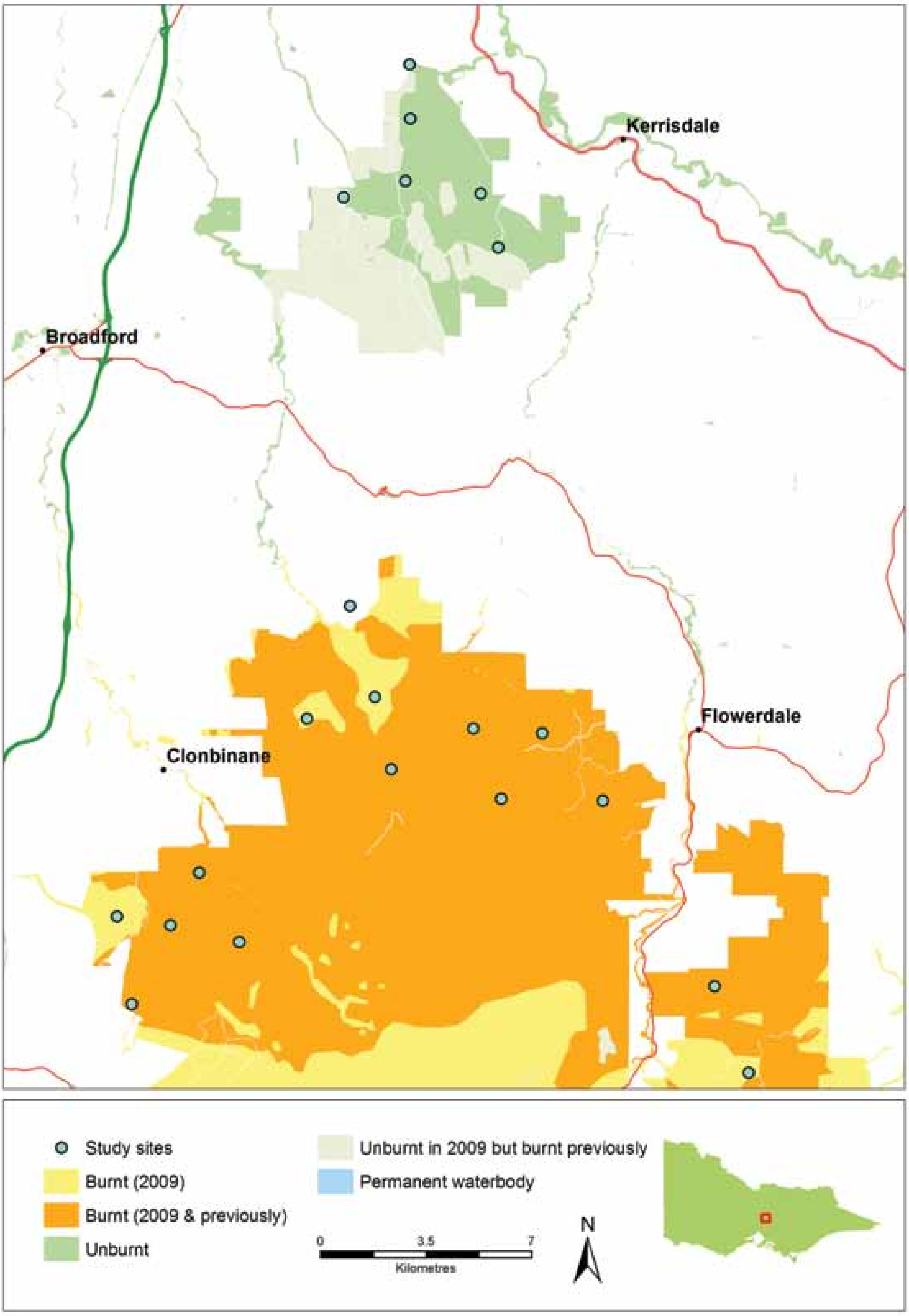


Figure 5. The fire history and location of the sites sampled in the Tallarook area. Fire history categories that were sampled are: Burnt (2009) – burnt in 2009 but not in the previous 41 years; Burnt (2009 & previously) – burnt in 2009 and at least once in the previous 41 years; Unburnt – not burnt in 2009 or in the previous 41 years.



2.3 Bat Survey Techniques

Ultrasonic echolocation calls were recorded using Anabat bat detector units (a mixture of Anabat SD1 and Anabat SD2 detectors along with AnabatII detectors connected to an Anabat ZCAIM [Zero Crossings Analysis Interface Module]; Titley Electronics, Ballina, Australia). All detectors produce the same output and no distinction is made between the different units. One Anabat detector unit was placed at each site. Each unit was set on the ground, with the microphone encased in a weather proof housing and positioned at a height of 1 m facing upwards at an angle of 45 degrees from horizontal. The microphone was positioned to point into a small vegetation gap within the site (Figure 6).

Each detector unit was set to begin recording 30 minutes before dusk and switch off 30 minutes after sunrise. The frequency-division ratio was set at 8. The sensitivity was set to a level just below the audible static of the detector. This varied between detectors with the sensitivity level chosen to maximise the range of echolocation calls recorded while avoiding recording unwanted environmental noise, such as from wind and insect calls. Each time a bat flew past the detector (defined here as a 'pass'), a recording of its call was saved as a digital file on the detector's compact flash sound card (Lumsden and Bennett 2005). This system enables high quality recordings of calls and multiple, complete nights of data to be collected.

Figure 6. Bat detector microphone (encased in weather proof housing), set towards an opening in the canopy. The arrow represents the direction the microphone is angled (Micaela Jemison).

The initial study design was to sample each site for six nights. However, due to unseasonable weather during the sampling periods, detectors were left in place for an average of 11 nights, so that six nights with the most favourable conditions could be selected for inclusion in the analyses. Nights following days with higher maximum temperatures (22°C and above), low wind and no rain were considered most suitable for bat activity. Weather condition data were accessed from the Bureau of Meteorology website (www.bom.gov.au).

Ultrasonic detector data provides an index of relative activity, rather than a direct measure of abundance, as it is not possible to determine the number of individuals producing the echolocation calls. Due to differing levels of detectability and identifiability, comparisons cannot validly be made between species. The detectability of each species varies depending on the height at which individuals fly and the strength of their calls, and hence the distance over which the bat can be detected. Detectability is also affected by the amount of vegetation clutter in the environment with higher frequency calls being more easily attenuated (and therefore less likely to be detected) than lower frequency calls. In addition, not all species are equally identifiable due to overlap of call parameters; for example the calls of the three species of forest bats (genus *Vespadelus* spp.) overlap considerably. Despite these limitations, bat detectors provide a useful comparison of the levels of activity of species between areas, and are not biased by the availability of suitable fight paths required for trapping bats.

2.4 Activity Analysis

Calls were extracted using CFCread software (C. Corben/Titley Electronics). Calls were pre-screened for extraneous noise using AnalookW software before analysis. During this process, files containing echolocation calls were manually separated from files that only contained insect or environmental noise. Echolocation calls were identified by using AnaScheme software (Gibson and Lumsden 2003) which automatically analyses Anabat files in a consistent, quantifiable way (Lumsden and Bennett 2005, Adams *et al.* 2010). The software compares call variables (e.g. frequency, shape, pulse duration) to those from reference calls of known species in regional call libraries. An identification key specifically developed for the southern central region of Victoria was used to analyse the calls from the three study areas. The calls of two species, Gould's Long-eared Bat *Nyctophilus gouldi* and Lesser Long-eared Bat are indistinguishable, and so were classified together as long-eared bats *Nyctophilus* sp. by the identification key. Calls from the Large-footed Myotis *Myotis macropus* could not be reliably distinguished from those of the long-eared bat species. However, as none of the sites surveyed in this study were near waterbodies, which are the preferred foraging habitat of the Large-footed Myotis (Thompson and Fenton 1982), all these similar types of calls have been attributed to long-eared bats.

The number of passes of each species was averaged over the six nights selected for analysis at each site. In addition, the total number of passes, irrespective of whether they could be identified, have been averaged per site.

Activity data were analysed using R (version 2.13.0). The relationship between the mean number of passes (bat activity) and fire severity (see below) and fire category (i.e. unburnt and the two categories of burnt) was assessed using analysis of variance (for fire category) and linear regression analysis (for fire severity). The raw activity data was log(x+1) transformed prior to analysis, to reduce skewness and to ensure homogeneity of variances.

The influence of fire was assessed by comparing (using a one-way ANOVA) the mean bat activity (log transformed) between sites drawn from each of three fire categories. A series of planned contrast tests were used to test the significance of differences in activity levels between unburnt sites and the burnt sites, considering each burn category both separately and together in the analysis. This analytical approach was carried out both for overall bat activity levels, and separately for the activity data for each species detected during the surveys.

The responses of microbats to fire severity was assessed by using linear regression to model the relationship between the mean bat activity for each site, and the site's ordinal fire severity score. As with the fire category analysis, analyses were conducted for overall bat activity and for each species separately.

2.5 Habitat Assessment

A habitat assessment was made at each site to record fire severity. The severity of the fire was assessed using DSE's 'Spot 5 Satellite Image Fire Severity Classification' (DSE 2007). This classification describes fire severity classes for vegetation burnt or scorched by fire. Both tree crowns and understorey vegetation contribute to the percentage of affected vegetation. Fire severity classes were assigned based on the criteria outlined in Table 2. As the site assessments were undertaken two years after the fire, the fire severity at each site was scored based on interpreting what these categories would look like two years post-fire.

Table 2. Fire severity classes used to score the intensity of the fire, based on the 'Spot 5 Satellite Image Fire Severity Classification' (DSE 2007).

Severity class	Severity type	Spot description
1	Burnt	100% of vegetation is burnt. An intense fire with complete vegetation burn (e.g. Figure 7).
2	Severe scorch	60 – 100% of vegetation is scorched, some vegetation is burnt. An intense understorey fire with widespread vegetation scorch (e.g. Figure 8).
3	Moderate scorch	30 – 65% of vegetation is scorched. A variable intensity of fire ranging from a light ground burn with minimal vegetation scorch to an intense understorey fire with widespread vegetation scorch (e.g. Figure 9).
4	Light scorch	0 – 35% of vegetation is scorched. A light ground burn with isolated patches of intense understorey fire and unburnt areas (e.g. Figure 10).
5	Unburnt	Not burnt (e.g. Figure 11).

Figure 7. A burnt site (Fire Severity Class 1), two years after the fires in the Kinglake area (Micaela Jemison).

Figure 8. A severely scorched site (Fire Severity Class 2), two years after the fires in the Kinglake area (Micaela Jemison).

Figure 9. A moderately scorched site (Fire Severity Class 3), two years after the fires in the Eildon area (Micaela Jemison).

Figure 10. A lightly scorched site (Fire Severity Class 4), two years after the fires in the Eildon area (Micaela Jemison).

Figure 11. An unburnt site (Fire Severity Class 5) in the Tallarook area (Micaela Jemison).

3 Results

A total of 50,257 bat passes were recorded during the 389 nights of detector recordings from the selected sampling nights. Bat activity was highly variable, both between sites and between nights at the same site. The highest activity in a night was 1,074 passes at a severely burnt site (fire category – Burnt [2009], Fire Severity Class 1) in the Kinglake area, and the lowest was 22 passes at a lightly scorched site (fire category – Burnt [2009], Fire Severity Class 4) in the Eildon area.

Using the AnaScheme program, 23,203 (46.2%) passes were identified to species level (or to genus for long-eared bats). The remainder could not be identified either because the sequence was too short with insufficient good quality pulses to meet the minimum criteria to attempt species identification, or the majority of pulses contained parameters that did not allow species with similar calls to be distinguished.

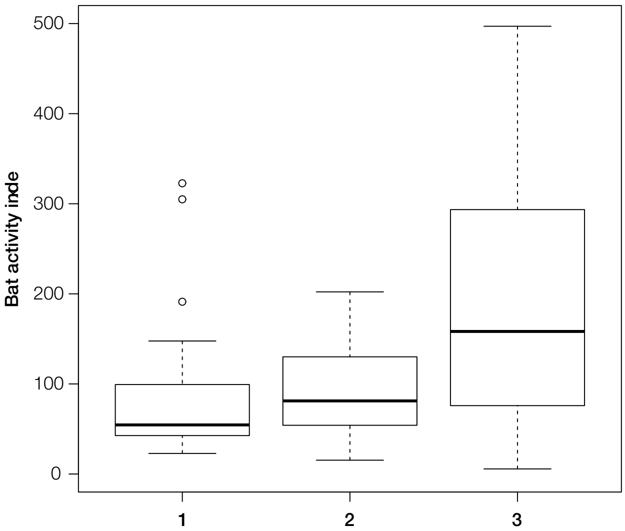
Fourteen taxa were identified (13 species and one genus; Table 3). Three species were most commonly recorded, together comprising 60% of the overall activity of identified species: White-striped Freetail Bat *Tadarida australis*, Little Forest Bat *Vespadelus vulturnus* and Large Forest Bat *Vespadelus darlingtoni*.

All 14 taxa were identified in each of the three fire categories. The overall level of bat activity differed significantly between the three fire categories (ANOVA, $F=732.94$, $df = 65$, $P < 0.001$). The mean index of all bat activity across the three fire categories is presented graphically in Figure 12. Analysis of variance, together with a series of planned contrast tests, demonstrated that the mean overall activity of bats at unburnt sites was significantly higher than at burnt sites (either of the two burnt categories separately or combined; Table 4). There was no significant difference in the mean bat activity between the two categories of burnt sites (i.e. whether or not they had been burnt prior to the 2009 fires).

Table 3. Mean (± standard error) number of bat passes per night for each species recorded in this study, across the three fire categories. Total bat activity includes all bat passes, irrespective of whether they could be identified to species.

Common name	Scientific name	Burnt (2009)	Burnt (2009 & previously)	Unburnt
Gould's Wattled Bat	*Chalinolobus gouldii*	1.88 ± 1.47	2.17 ± 1.93	4.39 ± 2.39
Chocolate Wattled Bat	*Chalinolobus morio*	3.99 ± 4.69	1.74 ± 1.32	8.27 ± 3.09
Eastern Falsistrelle	*Falsistrellus tasmaniensis*	0.22 ± 1.11	0.12 ± 0.66	0.26 ± 1.64
Southern Freetail Bat	*Mormopterus* sp. 4	2.36 ± 2.93	1.51 ± 1.17	3.77 ± 2.93
Eastern Freetail Bat	*Mormopterus* sp. 2	0.03 ± 0.48	0.13 ± 0.82	0.10 ± 0.64
Eastern Bent-wing Bat	*Miniopterus schreibersii oceanensis*	1.30 ± 1.89	1.62 ± 2.21	4.21 ± 3.99
Long-eared bats	*Nyctophilus* sp.	4.96 ± 3.85	5.36 ± 1.87	13.21 ± 3.57
Yellow-bellied Sheathtail Bat	*Saccolaimus flaviventris*	0.02 ± 0.71	0.01 ± 0.40	0.01 ± 0.40
Inland Broad-nosed Bat	*Scotorepens balstoni*	0.24 ± 0.83	0.24 ± 0.62	0.59 ± 1.24
Eastern Broad-nosed Bat	*Scotorepens orion*	0.24 ± 0.98	0.11 ± 0.47	0.34 ± 2.49
White-striped Freetail Bat	*Tadarida australis*	7.47 ± 2.12	16.52 ± 3.21	13.74 ± 4.54
Large Forest Bat	*Vespadelus darlingtoni*	9.38 ± 7.14	6.30 ± 3.37	21.82 ± 7.89
Southern Forest Bat	*Vespadelus regulus*	1.61 ± 1.94	1.09 ± 1.52	2.99 ± 2.69
Little Forest Bat	*Vespadelus vulturnus*	4.90 ± 3.09	4.23 ± 2.65	19.38 ± 7.78
Total bat activity		91.21 ± 8.87	92.26 ± 5.37	192.00 ± 9.67

Figure 12. Median values of microbat activity (number of bat passes per night ± quartiles) for the three fire categories. Fire categories 1, 2 and 3 refer to 'Burnt (2009)' (n = 21), 'Burnt (2009 & previously)' (n = 23) and Unburnt (n = 24) respectively.



All 14 taxa were identified in each of the five fire severity classes. The mean activity of bats (all species combined) is plotted against fire severity in Figure 13 (five point ordinal scale with severely burnt at one extreme and unburnt at the other). Linear regression analysis revealed a significant relationship between overall bat activity and fire severity, with higher activity at less-severely burnt sites (Figure 13). A similar significant relationship between activity and fire severity was found for several individual species (Figure 14). Species that demonstrated higher activity levels at less-severely burnt sites included the Chocolate Wattled Bat *Chalinolobus morio*, Eastern Bent-wing Bat *Miniopterus schreibersii oceanensis*, Large Forest Bat, Southern Forest Bat *Vespadelus regulus* and the long-eared bats. The other nine species of microbats detected in this study did not demonstrate a significant relationship between activity levels and fire severity. No species demonstrated a positive relationship with fire severity.

Table 4. ANOVA planned contrasts between the three fire categories.

Planned contrast	t	df	P
Unburnt vs. Burnt (2009) vs. Burnt (2009 & previously)	732.94	65	< 0.001
Unburnt vs. combined burnt categories	3.183	65	0.002
Unburnt vs. Burnt (2009)	2.957	65	0.004
Unburnt vs. Burnt (2009 & previously)	2.510	65	0.015
Burnt (2009) vs. Burnt (2009 & previously)	0.501	65	0.618

Figure 13. Overall bat activity (mean number of bat passes per site per night) plotted against the fire severity score (described in Table 2) for each site. The fitted regression line and 95% confidence intervals are superimposed for reference. Note that the scale of the y-axis is logarithmic.

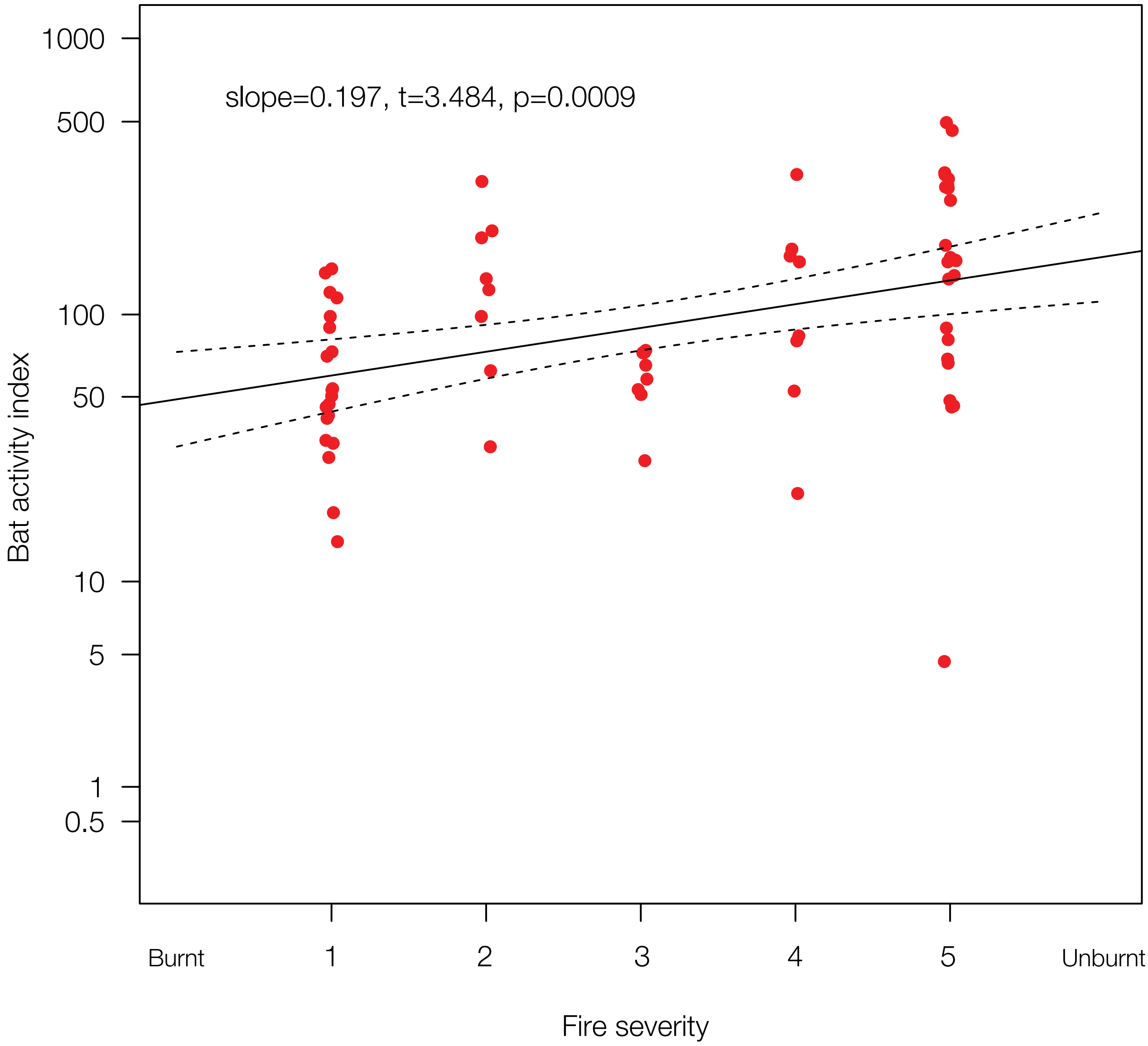


Figure 14. Mean number of bat passes (y-axis) of each species of bat, plotted against the fire severity score (see Table 2) for each site (x-axis). Linear regression lines and 95% confidence intervals are superimposed for reference. Note that the scale of the y-axis is logarithmic.

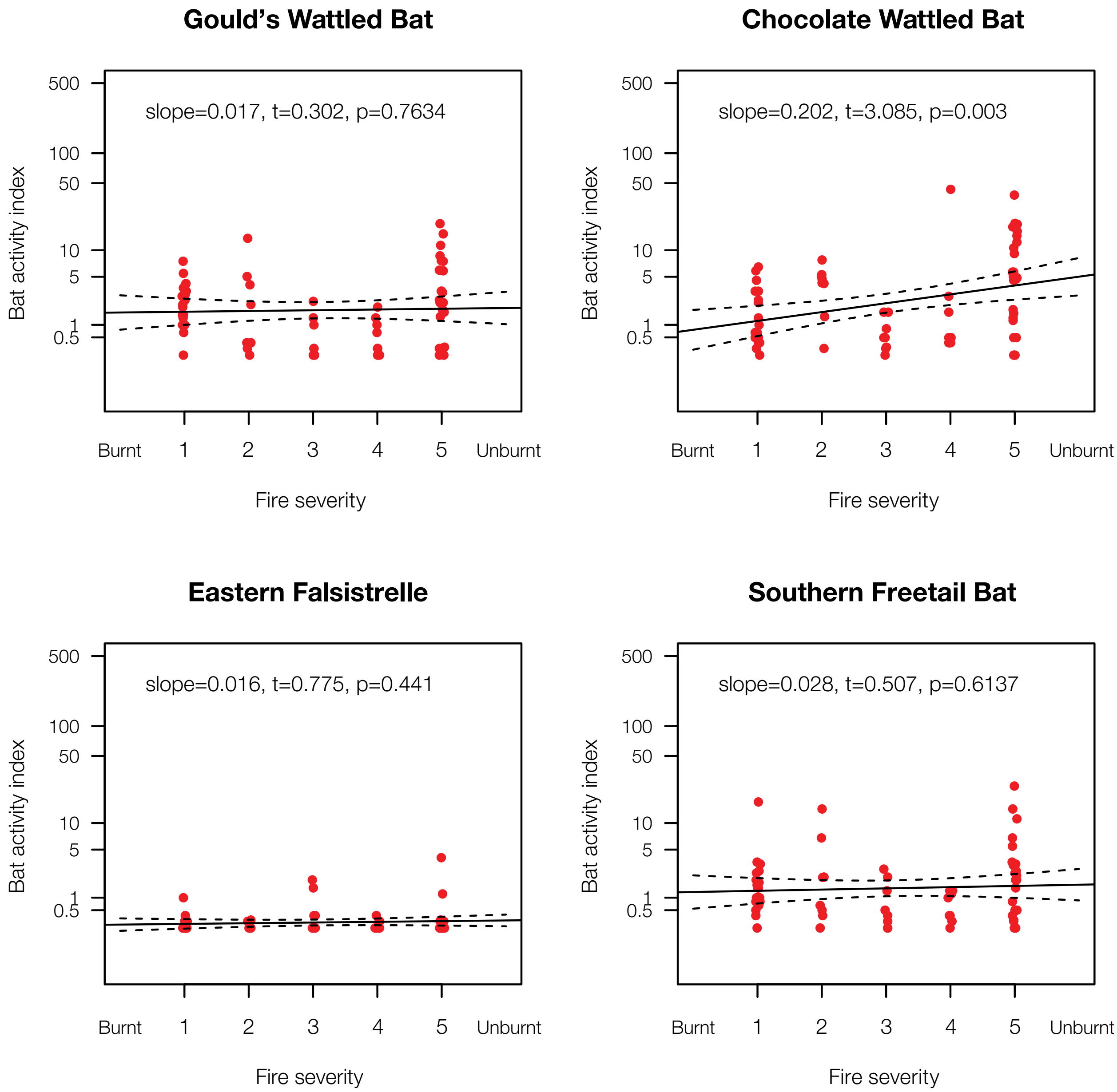


Figure 14 (cont'd). Mean number of bat passes (y-axis) of each species of bat, plotted against the fire severity score (see Table 2) for each site (x-axis). Linear regression lines and 95% confidence intervals are superimposed for reference. Note that the scale of the y-axis is logarithmic.

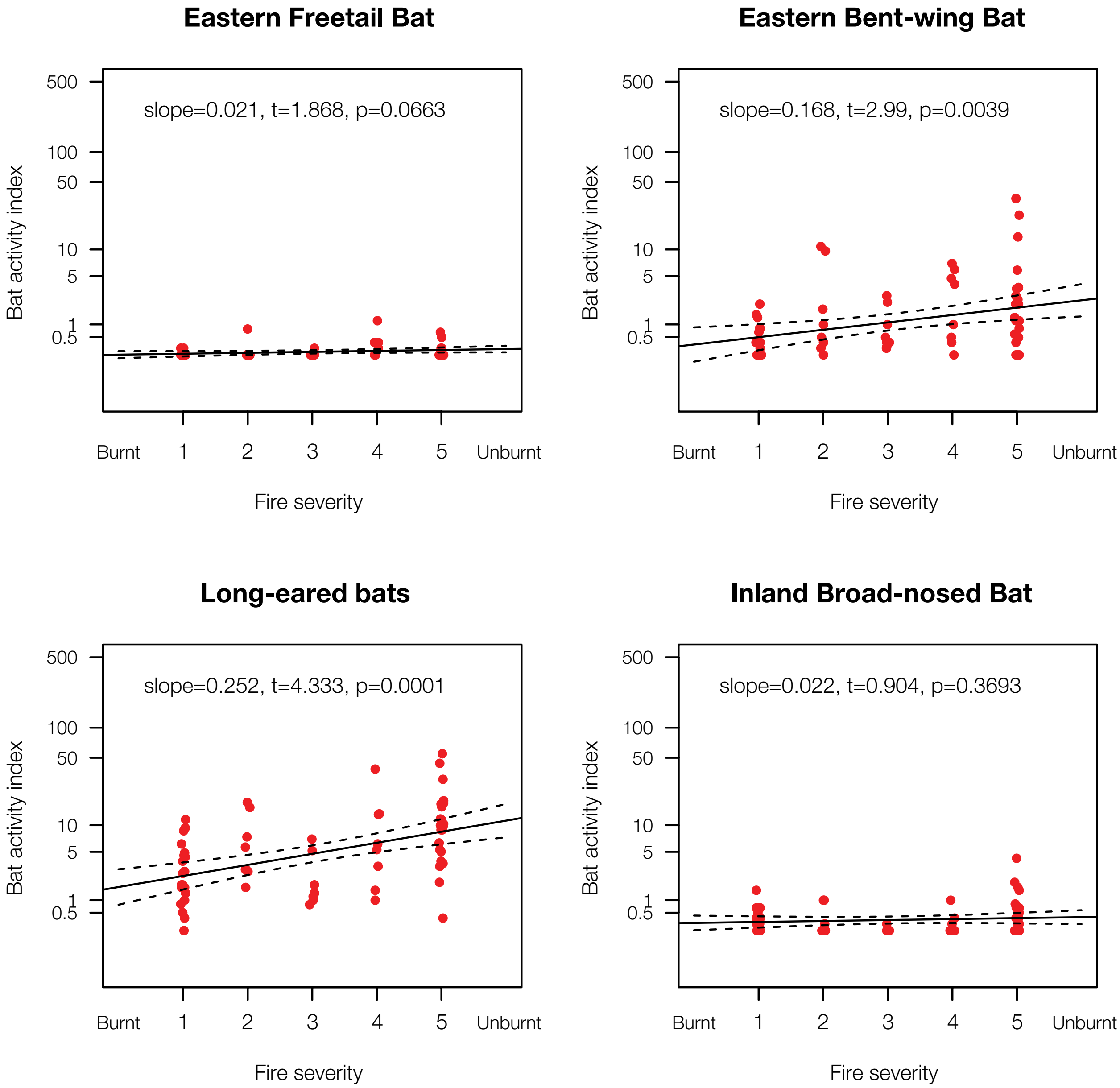


Figure 14 (cont'd). Mean number of bat passes (y-axis) of each species of bat, plotted against the fire severity score (see Table 2) for each site (x-axis). Linear regression lines and 95% confidence intervals are superimposed for reference. Note that the scale of the y-axis is logarithmic.

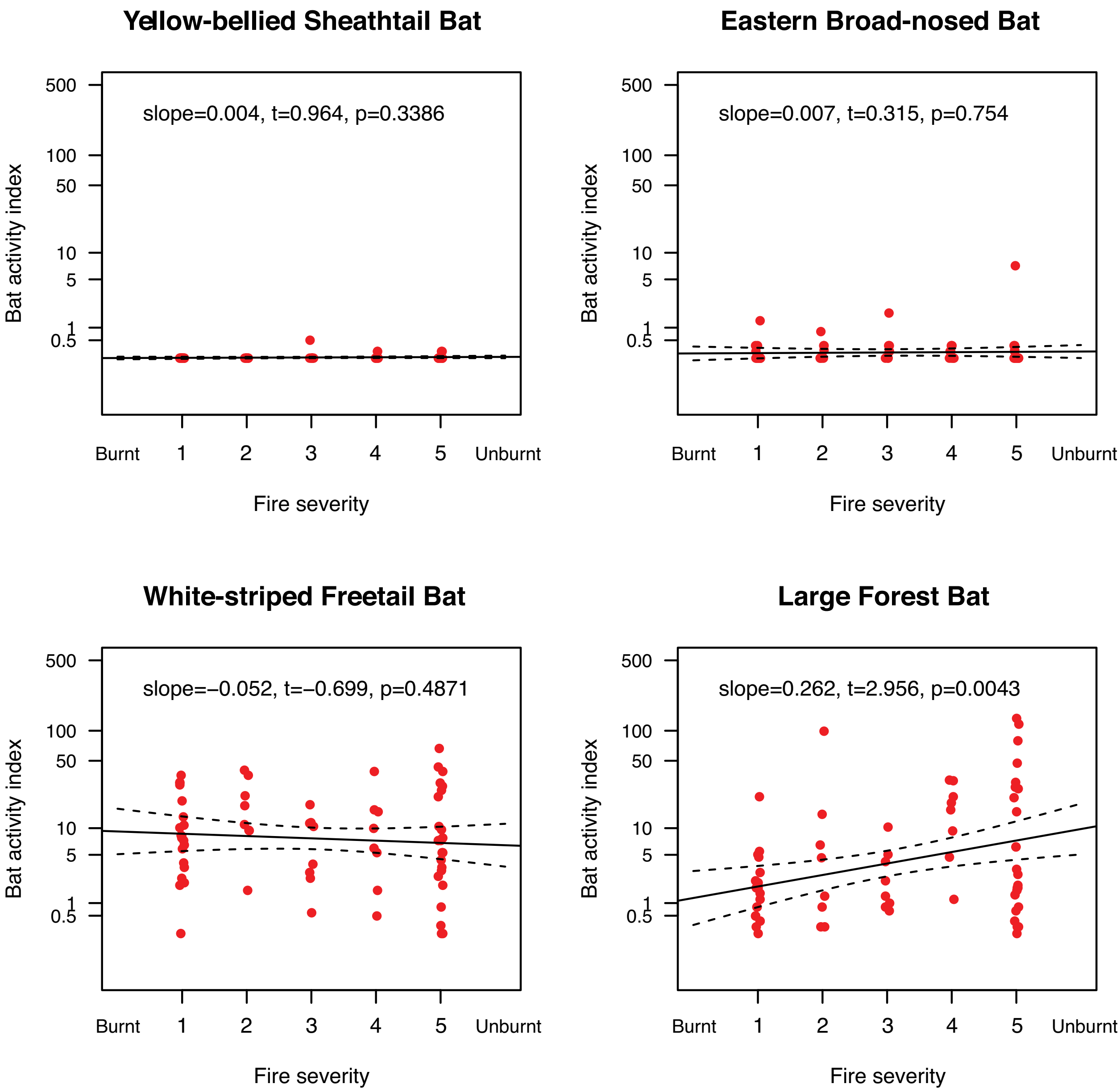
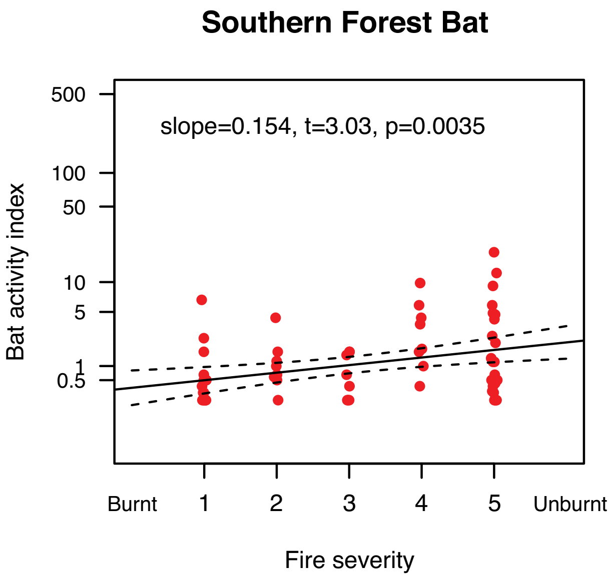
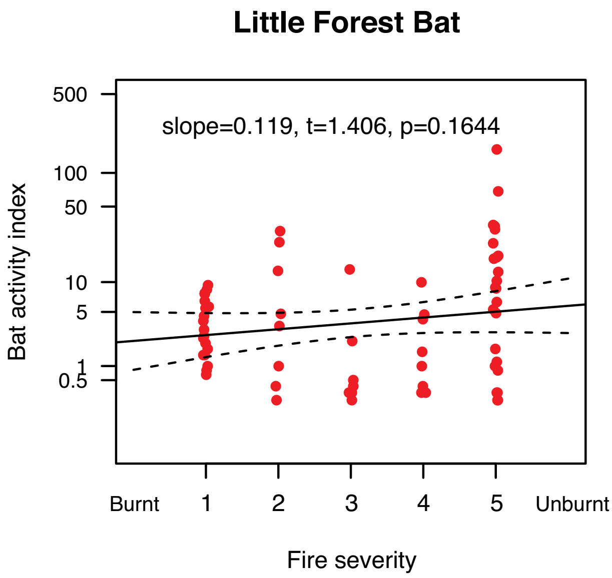


Figure 14 (cont'd). Mean number of bat passes (y-axis) of each species of bat, plotted against the fire severity score (see Table 2) for each site (x-axis). Linear regression lines and 95% confidence intervals are superimposed for reference. Note that the scale of the y-axis is logarithmic.





4 Discussion

4.1 The impact of fire on microbats

The fourteen taxa of microbats recorded during this study represent the majority of the species known from southern Victoria, with the Eastern Horseshoe Bat *Rhinolophus megaphyllus* the only species not recorded. While all categories of fire history were used by bats, a significantly greater level of activity was recorded in unburnt habitats compared to burnt habitats. Fire severity was also found to be a strong influence on both total species activity and the activity of five individual species: Chocolate Wattled Bat, Eastern Bent-wing Bat, Large Forest Bat, Southern Forest Bat and the long-eared bats.

The specific causes of these observed responses are yet to be determined, however, a number of potential mechanisms are proposed below. These mechanisms may result from direct impacts of the fire on bat populations or indirect impacts on critical habitat features and food availability.

4.2 Direct impacts of fire: Mortality during the fire event

Little is known of how bats respond to a fire front moving through the forest, or what proportion of the overall population is killed during different fire intensities. Tree-hole roosting bats are likely to be susceptible to intense crown fires that burn entire trees while bats are sheltering during the day in tree hollows or under bark. In normal situations, bats are reluctant to fly during the day due to the risk of predation by diurnal birds (Speakman 1991; Speakman *et al*. 1994). Fire severity is usually greater during the day than at night, due to higher temperatures and stronger winds, especially when associated with a temperature inversion. Temperature inversions are typically stable during the night but weaken during the day as the ground warms up, which can cause strong winds of hot, dry air close to the ground (Bureau of Meteorology 2009). Thus, fires are likely to have a greater impact on nocturnal species than for diurnal species. High temperatures, toxic smoke and oxygen depletion generated by bushfires are also likely to result in high levels of mortality (Whelan *et al*. 2002). The small body size and high surface area of bats makes them more susceptible to death from radiant heat than larger animals. In addition, the smoke-filled environment with strong, shifting thermal currents would make flight and orientation difficult. We suggest that the high intensity and rapid movement of the 2009 Kilmore East–Murrindindi Complex fire is likely to have led to a high mortality of bats, which is reflected in the lower levels of activity recorded at the burnt sites in this study, two years after the fires.

There may be some variation in the mortality risk between species due to different behavioural responses. One of the few studies on the behavioural response of bats to fire was undertaken in North American oak forests (Layne 2009). Eastern Red Bats *Lasiurus borealis* responded to the threat of an approaching fire by using both the sound and smell of the fire as cues for arousal from torpor (Layne 2009). Unlike bats in Australia, these bats hibernate in the ground leaf litter during cold periods (Layne 2009). Bats awoke from torpor in response to smoke exposure and, more rapidly, from the combination of smoke and the playing of sound recordings of fire. Given that most Australian microbat species roost within tree cavities or in underground caves or mines (Goldingay 2009), their perception and response to fire needed for exit and escape may be delayed due to the added insulation provided by these roosts (Carter *et al*. 2002).

Microbat susceptibility to the effects of heat exposure and toxic smoke may vary between species due to differences in roosting habitat. Bats that roost under bark or in cracks in timber, such as the Lesser Long-eared Bat (Lumsden *et al.* 2002a), may be more susceptible to the effects of heat and smoke than species that roost deep within tree cavities, such as the White-striped Freetail Bat (Rhodes and Wardell-Johnson 2006). Research into the gas and heat exchange of small-volume bark flap roosts revealed that such roosts offer little protection from exposure (Guelta and Balbach 2005, Dickinson *et al.* 2010). Thus, species residing in these types of roosts may be overcome by the effects of heat and smoke more rapidly than those in more sheltered cavities.

The effects of heat exposure may also be increased for species that primarily roost in dead trees. Dead trees are generally less well insulated than live trees as a result of the absence of, or a reduction in, the amount of bark and a lower water content in the wood (Maeda 1974). Species which primarily roost in dead trees, such as the Lesser Long-eared Bat (Lumsden *et al.* 2002a) and Little Forest Bat (Campbell *et al.* 2005), are therefore more likely to be susceptible to heat exposure due to this lack of insulation. We would expect this risk to be increased by the faster speed at which dead trees can catch alight and burn. These species showed the strongest differentiation in activity levels between burnt and unburnt habitats in this study, providing some support for this hypothesis.

The position of the roost within the tree may also provide varying degrees of shelter from the heat of a fire. During low intensity fires, species that roost higher in the tree are more likely to survive than those that roost closer to the ground. Low-intensity fires tend to move slowly, with impacts restricted to the ground-layer and understorey plant species, and do not typically reach the canopy (Gill and Catling 2002). As such, species that roost higher in the tree, such as the Gould's Wattled Bat, are more likely to survive than those roosting closer to the ground such as the Lesser Long-eared Bat (Lumsden *et al.* 2002a).

Species-specific flight characteristics, such as speed and manoeuvrability, are also factors that are likely to influence the ability of bats to escape a bushfire. Species which exhibit faster flight speeds may have a greater chance of out-flying an oncoming bushfire than slower flying species. Patterns between flight characteristics of species and their response to fire severity may support this hypothesis. Species such as the Southern Forest Bat, Chocolate Wattled Bat and long-eared bats exhibit slow to medium flight speeds (O'Neill and Taylor 1986). While the Southern Forest Bat and Chocolate Wattled Bat both fly faster than long-eared bats, all of these highly manoeuvrable species tend to fly at low to mid levels through the understorey and sub-canopy (O'Neill and Taylor 1986). Within our study, bats of this group showed significant negative relationships between fire severity and bat activity. These slower, lower flying species are less likely to be able to out-fly the fire, and may suffer greater mortality rates as a consequence. Conversely, species with relatively fast flight speeds and direct flight patterns, such as the White-striped Freetail Bat, Gould's Wattled Bat and Eastern Falsistrelle *Falsistrellus tasmaniensis* (O'Neill and Taylor 1986, Law and Chidel 2002) did not demonstrate such relationships in this study. These species prefer to fly above or high in the canopy and in open areas (O'Neill and Taylor 1986, Law and Chidel 2002) and may be better able to escape a fire due to their faster speed.

It is likely that the mortality rate of individual species due to fire is influenced by a combination of their behaviour and morphology. Their ability to recover from such mortality events is likely to be inhibited by their relatively low reproductive rate. The microbat species recorded in this study typically breed only once a year, producing one or two young each year (Menkhorst 1995). As such, the recovery of these populations is likely to be slow. As there had only been two breeding seasons between this study and the 2009 fires, differences in population levels between species should still have been evident in the comparative activity levels between burnt and unburnt habitats.

4.3 Indirect impacts of fire: Changes in the vegetation structure

In addition to direct mortality, fire can also have indirect effects on microbats through changes to the vegetation structure. The impacts of fire on vegetation structure, which for bats may be interpreted as clutter, and how this influences microbat activity levels, is a complex issue involving fire intensity, time-since-fire and regeneration factors.

Fire can change the amount of clutter in a number of ways. After a bushfire there is typically a reduction in the amount of clutter through a decrease in canopy, sub-canopy and shrub density (Boyles and Aubrey 2006). This reduction in physical obstacles such as branches, stems and foliage in some situations in the USA, has been found to lead to an increase in overall bat activity and the number of bat species in an area (Humes *et al.* 1999, Carter *et al.* 2002, Loeb and Waldrop 2008), by allowing greater ease of flight for less clutter-tolerant species (Boyles and Aubrey 2006). This pattern, however, was not observed in this study. The species composition was the same in burnt and unburnt areas and no species showed higher levels of activity in areas affected by fire. To the contrary, several species demonstrated significantly less activity in such areas, two years after the fire. While there has been some regeneration within the two years following the fire, the habitat is typically still more open than unburnt areas and so, had a preference for more open areas been a factor, it should still have been evident when the study was undertaken.

While clutter may be initially reduced in areas affected by fire, forest regeneration may result in increased levels of clutter in subsequent years (Eyre *et al.* 2010). When eucalypt and shrub regeneration is dense, increased clutter can exert a strong negative influence on total bat activity (Law and Chidel 2002, Lloyd *et al.* 2006, Eyre *et al.* 2010), likely due to a reduction in activity levels of clutter-sensitive species (Law and Chidel 2006). For example, lower activity levels of the Eastern Falsistrelle, which is a fast flying species with low manoeuvrability, have been recorded in areas of increased clutter and regrowth (Law and Chidel 2002). While clutter-sensitive species may avoid dense, regenerated areas, clutter-tolerant species such as the Chocolate Wattled Bat and the long-eared bats (Norberg and Rayner 1987, Fullard *et al.* 1991) may use both the denser regenerating habitats (Law and Chidel 2002) and the more open areas with lower clutter (Lloyd *et al.* 2006).

The degree to which regeneration following bushfires affects different microbat species is likely to be influenced by the height of the regrowth and the area within the vegetation strata that species typically forage. Bats that forage high in, or above, the canopy (Law *et al.* 1998, Law and Chidel 2002) are less likely to be affected by clutter generated by regrowth than species that forage closer to the understorey layer (O'Neill and Taylor 1986). This may have influenced the response to fire recorded for the long-eared bats in this study. Although species of this genus are typically clutter tolerant, demonstrating highly manoeuvrable flight patterns, the height range in which they typically fly is relatively low (Lumsden *et al.* 1994). The dense clutter generated by vigorous regeneration low to the ground in the areas long-eared bats typically forage may have been too dense even for these clutter-tolerant species. This may have contributed to the significantly larger negative responses to fire severity of these bats than other species.

4.4 Indirect impact of fire: Changes in prey availability

There is little knowledge on how fire affects insect abundance and diversity. Despite their importance in ecosystem function, very few studies have examined the effects of fire on insect populations and fewer still scrutinize the subsequent impacts on microbats. Some studies have examined the effects of prescribed burning on insects (e.g. Warren *et al.* 1987, Swengel 2001, Panzer 2002) but few focus on flying insects such as moths (order Lepidoptera) which make up the majority of the diet of many Victorian microbat species (Lumsden and Bennett 2005). While Moretti *et al.* (2006) found flying insects to be the group most resilient to fire due to their high mobility, the resilience of different orders varies considerably. For example, grasshoppers (order Orthoptera) can become more abundant after fire in the short and/or intermediate term (Warren *et al.* 1987, Samways 1996, Chambers and Samways 1998). While their numbers may initially increase after fire, the species richness of this order is often lower in more frequently burned areas compared to less frequently or unburnt areas (Evans 1984, 1988). In comparison to Orthoptera, insects of the order Lepidoptera appear to be more vulnerable to fire. Siemann *et al.* (1997) found that lepidopterans experienced a reduction in abundance, species richness and diversity after fire which further decreased with increased burning frequency. Lepidopterans are thought to be especially sensitive to burning if fires occur during the egg, larvae or pupae stages (Warren *et al.* 1987), which for many species typically occur over summer. Beyond fire frequency, the intensity of a fire may also have an impact on the ability of insect populations to recover after fire. For example, in north-west California, lepidopterans were found to recolonise habitats more rapidly in less intensely burnt areas (Powell 2005).

As fire appears to affect insect taxa in different ways, the impact of fire on microbat species is likely to vary due to the prey species they target. The Lesser Long-eared Bat and Gould's Wattled Bat, both common microbat species in south-eastern Australia, predominantly feed on lepidopterans (Lumsden and Bennett 2005, L. Lumsden unpublished data). Therefore, it is plausible that fire-induced changes in insect prey abundance, particularly of lepidopterans, may affect these bats more than those whose diet consists predominantly of insects of other orders. Further research is needed to determine the impact of fire on insect prey availability and its influence on microbat populations.

4.5 Species specific impacts of fire

The long-eared bats, which in this study area are a combination of Lesser Long-eared Bats (see front cover photo) and Gould's Long-eared Bat, was the group that showed the most negative relationship with fire severity and low levels of activity in burnt compared to unburnt habitat. The roosting requirements and foraging behaviour of this group of bats makes them particularly vulnerable to fire. As outlined above, long-eared bats roost low to the ground in dead timber, which is highly likely to burn, and are slow fliers and hence are less likely to be able to out-fly a fire. As a result, mortality levels for this group are likely to have been high during the 2009 fires. Changes to their foraging habitat (i.e. increased clutter) and lower prey availability (approximately 50% of Lesser Long-eared Bat diet is moths; L. Lumsden unpublished data) may also have influenced the lower activity levels in burnt habitats.

Three other species that showed a significant negative response to fire severity were the Chocolate Wattled Bat, Large Forest Bat and Southern Forest Bat. The Little Forest Bat, while not showing a significant relationship with fire severity, did have a considerably higher level of activity in unburnt areas compared to burnt habitats and so may also be considered in this category. These four species are all moderately slow-flying and likely to have had difficulty out-flying the fire front. In addition, their small body size (3–10 g in weight) would be likely to lead to severe impacts from radiant heat. The Chocolate Wattled Bat is a moth specialist, however the other three species take a wider range of prey (L. Lumsden, unpublished data).

The species that did not show a significant relationship with fire severity were all larger, faster-flying species that tend to forage higher in the vegetation strata. Two of these species (Eastern Freetail Bat *Mormopterus* sp. 2 and Yellow-bellied Sheathtail Bat *Saccolaimus flaviventris*) were recorded infrequently and so the statistical power to detect a response was limited. For the more commonly recorded species (Gould's Wattled Bat, Eastern Falsistrelle, Southern Freetail Bat *Mormopterus* sp. 4, Inland Broad-nosed Bat *Scotorepens balstoni,* Eastern Broad-nosed Bat *Scotorepens orion* and White-striped Freetail Bat – Figure 15), however, it suggests that these species were either better able to escape from the fire, resulting in a lower level of mortality, or the more open foraging space they use was less impacted by the fire. These species can fly up to 60 kmh^{-1} (Churchill 2008) and so would have a greater chance to out-fly the fire front than other species. The diet of this group of species is mixed, with moths an important component of the diet for some species (e.g. Gould's Wattled Bat and White-striped Freetail Bat), while others (e.g. Southern Freetail Bat and Inland Broad-nosed Bat) rarely consume moths (L. Lumsden, unpublished data).

One larger species that does not fit this pattern is the Eastern Bent-wing Bat. This species has a clear negative relationship with fire severity and higher activity levels in unburnt compared to burnt habitats. These findings are consistent with a study undertaken 10 months after the 2009 fires, which found markedly lower numbers and activity levels of Eastern Bent-wing Bats in the severely burnt area surrounding Toorourrong Reservoir (south-west of Kinglake) compared to pre-fire surveys (Gration 2010). The Eastern Bent-wing Bat has a foraging style more similar to the species which did not show a relationship with fire severity. As the only cave-dwelling species recorded during this study, it would have been more protected in its underground roosting habitat (which in this area are horizontal mine adits) when the fire front moved through. In addition, during the 2009 fires (in early February), the adult females would have been at the maternity roost in Gippsland (L. Lumsden unpublished data) and so any direct mortality would have affected only males and non-breeding females. Therefore, for this species, the lower activity levels are likely to be due to changes in foraging habitat or prey availability (predominantly moths).

Figure 15. The White-striped Freetail Bat *Tadarida australis*, one of the larger, faster-flying species which appears to have been less impacted by the 2009 fires (Lindy Lumsden).

Individual patterns may be masked by the two years that had elapsed between the fire event and the undertaking of this study. Had the study been conducted shortly after the fire, it may have been easier to separate the influences of the proposed mechanisms for species response to fire.

4.6 The influence of differing fire regimes

A secondary objective of this study was to investigate if the frequency of fire influenced bat activity by comparing bat activity at sites that had been long-unburnt prior to the 2009 fires, with sites that had been burnt multiple times during the previous 41 years and then again in 2009. Multiple fires may have changed forest structure or hollow availability. A response to fire frequency has been observed in the rare South-eastern Long-eared Bat *Nyctophilus corbeni* in north-western Victoria (Lumsden *et al.* 2008). This species roosts in long unburnt mallee, or in mallee that had not been burnt for a long time prior to the latest fire (i.e. a long inter-fire interval) which resulted in the trees developing to a size that enabled hollow formation in the dead stems. This pattern was not observed in the response to multiple fires in this study, with no difference in the activity levels between the areas burnt only in 2009 and those that had been burnt at least once prior to this in the previous 41 years. This finding, however, needs to be treated with caution, as this study was investigating the impact on foraging habitat and behaviour, not on roosting habitat, which may be more negatively influenced by multiple fires.

4.7 Key findings and recommendations

1. Fire was found to have a significant impact on activity levels of microbats with greater activity in unburnt compared to burnt habitats.
2. Individual species demonstrate a range of responses to fire, with five species displaying a significantly greater index of activity at less-severely burnt sites (including unburnt), while the remaining nine species showed no significant relationship between activity and fire severity.
3. The species most impacted by fire were smaller, slower-flying species that were likely to have suffered higher mortality rates and be influenced most by changes to the understorey vegetation. In contrast, species that did not show a significant response with fire severity were all larger, faster-flying species that may have been able to out-fly the fire front and thus may have suffered lower mortality rates. These species also tend to forage in more open environments and so post-fire habitat may not have been as unsuitable for them.
4. Our understanding of the impact of fire on microbats would be improved by further research into species-specific interactions with changes in forest clutter generated by fire; the effects of fire on insect abundance and diversity and its subsequent impact on microbats; and the behavioural response of bats to the threat of fire. A greater understanding of the response of individual species to fire and the risk of mortality to populations may inform management, including fuel reduction burning programs.
5. It is recommended that for future research on the impact of fire on microbats, sampling is undertaken soon after the fire event to improve the ability to distinguish between the possible mechanisms (such as direct mortality, or changes to prey availability and vegetation structure) that may explain the reduced activity in burnt areas observed in this study.
6. To gain a more complete understanding of the impact of fire on microbats, further investigations are required on how fire impacts the roosting requirements of tree-hole roosting bats.

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