Effects of fire regimes on terrestrial biodiversity in Gippsland, Victoria: a retrospective approach

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Front cover photos: From top left clockwise: Brown Thornbill, *Acanthiza pusilla* (L. Bluff); A stand of Bottlebrush *Callistemon* sp. resprouting following a 2009 planned burn in Croajingolong National Park (L. Bluff); A site dominated by Austral Bracken *Pteridium esculentum* and Silvertop Ash *Eucalyptus sieberi* - this is one of the most frequently-burnt sites in the study, having experienced three bushfires followed by three prescribed burns since 1966. (L. Bluff); Spotted Quail-thrush*, Cinclosoma punctatum* (L. Bluff); Short-beaked Echidna, *Tachyglossus aculeatus* (automated camera).

Effects of fire regimes on terrestrial biodiversity in Gippsland, Victoria: a retrospective approach

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Summary

Achieving biodiversity objectives can be a challenging aspect of fire management because different flora and fauna species may require varied fire regimes in order to maintain viable populations, and trade-offs may be needed to satisfy other objectives. This report describes major findings of a project investigating the relationships between aspects of fire regimes on selected flora and fauna, using a space-for-time sampling approach. It was undertaken between 2010 and 2012 in two types of mixed-species forest common to East Gippsland in Victoria.

The Ecological Vegetation Divisions (EVDs) represented by these forest types are Grassy/Heathy Dry Forest (EVD 3) and Tall Mixed Forest Eastern (EVD 7). A total of 132 sites were selected in Gippsland, arranged in 21 landscapes each of 20 km^2. In each landscape, sites represented combinations of fire frequency (number of fires since 1970) and time since fire (from 0–5 years to 41+ years since fire). An additional 13 sites were sampled in north-eastern Victoria for a subset of taxa, to investigate the effects of regional variation and potentially as a pilot for any future work in that region.

All sites were assessed for vascular flora, and various subsets of fire regime combinations were assessed for diurnal birds, mammals, fuel hazard, lichens and microbats. Vascular flora species' and lichen groups' frequencies were derived from sampling species in 21 x 1 m^2 plots at each site. Fuel hazard was assessed from three plots at each site using a standardised rating system. The abundances of diurnal birds were recorded from 20 min / 2 ha timed area-searches at each site. The presence of ground-dwelling mammals at sites was detected by automated camera-traps. Microbats were detected by recording their echolocation calls on bat detector units. Data were entered into a Microsoft Access database.

These data were analysed using quasi-binomial and general linear mixed models and occupancy analysis. The analyses investigated the relationships between response variables (plant functional types, bird guilds, mammal species, overall fuel hazard, lichen groups and microbat species) and explanatory variables (years since last fire, number of fires since 1970, whether the last fire was a bushfire or planned burn, and fires at less than minimum Tolerable Fire Intervals).

The results offer insights into these relationships for two forest types in East Gippsland, and also about sampling design issues in studying these phenomena. They provided support for some of our initial predictions about the relationships between fire regimes and some functional types of flora, birds and lichens and some microbat species, but no clear effects of fire regime emerged for other groups including mammals.

The effects of time since fire were most pronounced for flora functional types and lichen groups (growth form combined with substrate). Shrubs which are killed by fire, that produce seed quickly and have soil-stored seed (e.g. many *Acacia* species), were most common at recently burnt sites in EVD 7. Obligate-seeder herbs were also more frequent at recently burnt sites for both EVDs. Shrubs which are killed by fire, and take long periods to produce seed which is then exhausted by fire (e.g. *Allocasuarina littoralis* Black She-oak), showed a weak trend to be more commonly recorded in EVD 7 as decades progressed after fire. The highest occurrence of lichens growing on dead fallen wood was at sites burnt more than 40 years before our surveys. There were no strong relationships between time since fire and any bird guild (in contrast with other studies). There was also no clear relationship detected between time since fire and mammal presence, but detectability of some mammal species varied with time since fire. The probability of higher overall fuel hazard ratings was higher with longer times since last fire.

Fire frequency effects were evident for some groups of plants and birds. Rhizomatous plants which resprout vigorously after fire (e.g. Austral Bracken and Forest Wire-grass) were more common at sites in EVD 3 where there had been high fire frequency (number of fires since 1970). There were no detectable differences in density of bird guilds (relative abundance of different nesting and feeding groups) where one or two fires in 40 years had occurred compared with no fires. However there was 43% lower density of honeyeaters and other nectar-feeding birds in sites with three or more fires over the same period. The Superb Lyrebird was less likely to occur (probability of occupancy declined) with increasing fire frequency in EVD 7. Two bird guilds (carnivores and insectivores that feed from open ground below trees) showed weaker evidence of the reverse trend, being favoured by frequent fire. Microbat activity was associated with the number of recorded fires at a

site. There was a significant negative relationship between the number of fires and the activity of Chocolate Wattled Bat and Little Forest Bat. This relationship was positive for White-striped Freetail Bat activity and positive in EVD 7 for Gould's Wattled Bat. No clear relationship was detected between fire frequency and mammal presence. Relationships between fire frequency and fuel hazard rating were not found.

Relationships with minimum Tolerable Fire Intervals (TFI) were only evident for two groups of flora and birds. There was a higher occurrence of the flora functional type dominated by Forest Wire-Grass and Austral Bracken in EVD 3 where fires occurred below the minimum TFI. Low densities of ground nesting birds were associated with sites where successive fires occurred below the minimum TFI. The effects of minimum TFI were not analysed for mammals, fuel hazard, lichens and microbats.

The effects of geographic and temporal variation were only tested for birds as resources were not available to extend this part of the research to other taxa. Bird guilds varied notably between East Gippsland and North East sites and according to vegetation type, potentially obscuring the signal from possible fire effects (e.g. time since fire). Differences in the bird density between years highlight the need for annual monitoring to get a clearer understanding of background climatic variation.

The broad spectrum of responses to fire regime found in this study indicates that species have different growth stage preferences, and thus confirms the benefits of managing the landscape as a mosaic of fire age classes. Increased planned burning and wildfires below minimum TFI may benefit some vigorous rhizomatous herbs and have adverse effects on ground nesting birds. Higher fire frequency was also associated with lower density of nectar-feeding birds and lower activity of two species of microbats. There was evidence for the value of sites unburnt for several decades, through the greater occurrence of some lichen groups. But overall there were few strong responses to fire regimes, suggesting many species inhabiting the drier forests in our study area are probably quite resilient to fire.

However the muted responses might also stem from limitations associated with the study design. This included: environmental variation across the study area; low numbers of fire sensitive species due to past disturbance; choice of survey methods for mammals; exclusion of some taxonomic groups such as arboreal mammals, non-vascular plants and invertebrates; and lack of sampling of gullies and riparian areas which act as fauna refuges.

The outputs of the project will continue to have value into the future. Datasets developed for this project can help inform ecosystem resilience metrics for use in growth stage optimisation. The data is already being used in broader analyses in the Foothills Fire and Biota project. The project identified some fire sensitive taxonomic groups and species (e.g. serotinous obligate seeder shrubs with long reproductive maturity periods, nectivorous birds, Lyrebirds, lichens, microbats). Research resources can be used more efficiently by focusing on these groups as part of an adaptive management framework.

1. Introduction

1.1 Fire management and biodiversity

Fire is a vital component of many Victorian ecosystems, influencing the abundance and distribution of flora and fauna species, and the structure and composition of vegetation (Cheal 2010). However, fire can be a serious threat to human life and property, and hence the necessity for government agencies to manage fire in ways which integrate social, economic and biodiversity needs (DSE 2012). Evidence is needed to inform public policy, ecological fire planning decisions and community discussion of trade-offs between competing values.

Public land management decisions need to be based on sound understanding of how forests change over time in response to particular fire regimes. The consequences for plant diversity (species composition and relative abundance), animal diversity (species composition, occupancy and relative abundance), fuel loads (vegetation quantity, structure and flammability) and animal habitat (influenced by vegetation diversity and structure) should be investigated. This information will inform ecological fire planning decisions, such as the merits of short or long fire return times between particular types of fire, and the proportion of forest stands representing long, short or intermediate periods of time since the last fire. We know little of the consequences for biodiversity if the proportions or patterns of forest age-classes change beyond certain thresholds.

There have been a number of Australian studies of flora and fauna responses to fire regimes over decadal time-spans. Flora research in Victoria, New South Wales, Queensland and south-western Australia (e.g. Bradstock *et al.* 1997, Watson and Wardell-Johnson 2004, Watson *et al.* 2009, Wittkuhn *et al.* 2011, Duff *et al.* 2013) has measured changes in abundance of groups of species in relation to time since fire, fire frequency and inter-fire intervals. These relationships have not been investigated in the foothill forests of eastern Victoria. Research on fauna has predominantly focused on short-term (< 5 years post fire) responses but there is evidence, particularly for small mammals and birds, that fauna assemblages post-fire can be closely tied to vegetation succession (Coops and Catling 2000, Bradshaw *et al.* 2013). However there are fewer studies on the longer-term effects of fire regimes on fauna, and uncertainty with the application of these results to Victorian foothill forests (Clarke 2008, De Cáceres *et al.* 2013).

Current practices for ecological fire management planning on Victorian public land are based on a framework of Tolerable Fire Intervals (TFI) and Vegetation Growth Stages (VGS) (Platt *et al.* 2012). Minimum and maximum TFIs for a vegetation type reflect the upper and lower desirable limits of fire frequency to maintain plant diversity (Cheal 2010). They are based on knowledge of plant 'vital attributes', indicating time-frames for plant reproduction and survival (Noble and Slatyer 1980, Fire Ecology Working Group 2004), of the most fire sensitive flora species (Cheal 2010). VGSs, also known as seral stages, represent variation in fauna habitat attributes with time since fire, such as changes in vegetation density or formation of nest hollows, and are used as a surrogate for fauna requirements. Fauna abundance is envisaged to change in response to variations in the availability of VGSs in the landscape (MacHunter *et al.* 2009). Some species (termed Key Fire Response Species) or groups of species with similar life history attributes (plant functional types or bird guilds) are considered to be sensitive to fire intervals (Coops and Catling 2000, Gill and Catling 2002, Whelan *et al.* 2002, Cheal 2010). This knowledge is far from complete, and need to be informed by more detailed and broad-based empirical data from different vegetation age-classes and fire regimes. Predictions about the relationships between fire regimes and Key Fire Response Species, plant functional types and bird guilds should be tested.

Time since fire was predicted to have the strongest influence on plant responses (Cheal 2012) and faunal responses (Loyn 2012), though plants could be expected to be more sensitive to fire frequency than mobile animals, because they are more dependent on in situ regeneration whereas animals may rely more on recolonisation from elsewhere in the landscape (Cheal 2012, Loyn 2012). Fire frequency and time since fire are clearly related variables. In general we might expect that plants or animals showing a preference for longer times since fire would be disadvantaged by frequent fire and those with a preference for shorter time since fire might be advantaged by more frequent fire. This study makes a contribution to information on the differential effects of these two key variables.

A number of studies in south-eastern Australia have used groupings of plants according to their vital attributes to predict and test responses to time since fire (e.g. Keith *et al.* 2007, Duff *et al.* 2013). Generally obligate seeders have the strongest responses to time since fire (Gill 1981), because their persistence is reliant on replacement of seed-banks (Keith *et al.* 2007). Responses of plants to fire frequency were also expected to differ according to differences in seed-bank type and maturation times (Keith 2012). For example, obligate seeding shrubs with seed-banks exhausted by disturbance and long juvenile periods were expected to be less abundant at sites with short fire intervals (Bradstock and Kenny 2003). Resprouting shrubs were expected to be less sensitive to fire intervals, but high-intensity fires can reduce survival rates (Knox and Clarke 2005). Resprouting herbs were expected to increase with short inter-fire intervals (Cary and Morrison 1995).

We predicted bird community changes in response to time since fire, particularly for hollow nesting birds, since research in central Victoria found these species were more common in older forests (Loyn 1985). Populations of ground dwelling birds such as the Eastern Bristlebird (*Dasyornis brachypteris*) have also been shown to decline in response to fire (Campbell *et al.* 2011), hence we expected similar patterns in our study. Repeated fires were expected to disadvantage hollow nesting birds, frugivores and nectarivores due to their direct dependence on plant resources that are combusted during fire (Loyn 1997, Barrett and Silcocks 2002, Bradshaw *et al.* 2013).

Many mammals common to the forest types surveyed in this study were predicted by expert elicitation to show an increase in occupancy with time since fire (MacHunter *et al.* 2009) . Mammals in this category include Black Wallaby (Wallabia bicolor), Agile Antechinus (*Antechinus agilis*), Long-nosed Bandicoot (*Perameles nasuta*), Long-nosed Potoroo (*Potorous tridactylus*) and Common and Mountain Brustail Possums (*Trichosurus* spp.) (MacHunter *et al.* 2009). Another possible response is an initial spike in occupancy followed by a rapid decline with increasing time since fire (e. g. Eastern Grey Kangaroo *Macropus giganteus*) (MacHunter *et al.* 2009). There is very little literature on the impact of fire frequency on mammals in the forest types surveyed in this study.

1.2 This project

In 2010, DSE funded a 'Landscape Fire Ecology – Biodiversity Research' program including a project titled 'Retrospective Approach to Identify the Value of Different Fire Mosaics' (Friend 2010, Loyn 2011). This is referred to subsequently as the 'Retrospective Project'. The impetus for this project arose from the limited information in Victoria on responses of flora and fauna to fire regimes and mosaics over different time scales.

Subsequently, the Gippsland HawkEye project was established and provided supplementary funding to extend the range of sites and depth of data collected in the Retrospective Project (DSE 2012). HawkEye was established in response to the recommendations of the (Victorian Bushfires Royal Commission 2009) to significantly upgrade DSE's long term data collection to monitor and model the effects of increased planned burning on biodiversity in Victoria.

The Retrospective Project investigated the responses of flora and fauna to some key fire regime variables, using a space-for-time substitution (retrospective) approach. That is, instead of monitoring baseline condition, waiting for fires to occur, and monitoring their outcomes, the history of the site was used to represent time. The Gippsland study region was well provided with a complex fire history from which a wide range of suitable sites with various fire histories could be selected. Vascular flora, diurnal birds and ground-dwelling mammals were selected for study. This was in part driven by the availability of cost-effective research techniques and available budget.

1.2.1 Objectives

The project was designed to examine relationships between some key elements of fire regimes (principally time since fire and fire frequency) and flora and fauna (species and groups of species), using a space-for-time substitution approach. This sampling approach enabled inferences about changes in flora and fauna over decadal time-spans, by sampling many sites with different fire histories at one period in time. This approach permitted seasonal differences to be accommodated within the analyses, because all sites were subject to the same local climate variation. The data collected and analysed from these sites were used to test predictions about the response of flora and fauna to fire regimes. Identification of these relationships can

facilitate improved policy and planning of where and when to apply planned burns in the landscape to improve biodiversity outcomes.

1.2.2 Location and scope

The project was undertaken in East Gippsland (Figure 1), in foothill mixed-species forests with complex fire regimes and histories of fire management. Surveys were conducted at 132 sites, representing nine different fire regimes (varying in time since fire and fire frequency) within two Ecological Vegetation Divisions (EVDs, sensu Cheal 2010). The data collected were: vascular flora frequency; fuel hazard rating; diurnal bird abundance; and ground-dwelling mammal occupancy. An additional 13 sites were sampled for flora, birds and mammals in north-eastern Victoria (with analysis of bird data only). Field work was conducted between 2010 and 2012, under scientific permit number 10006167.
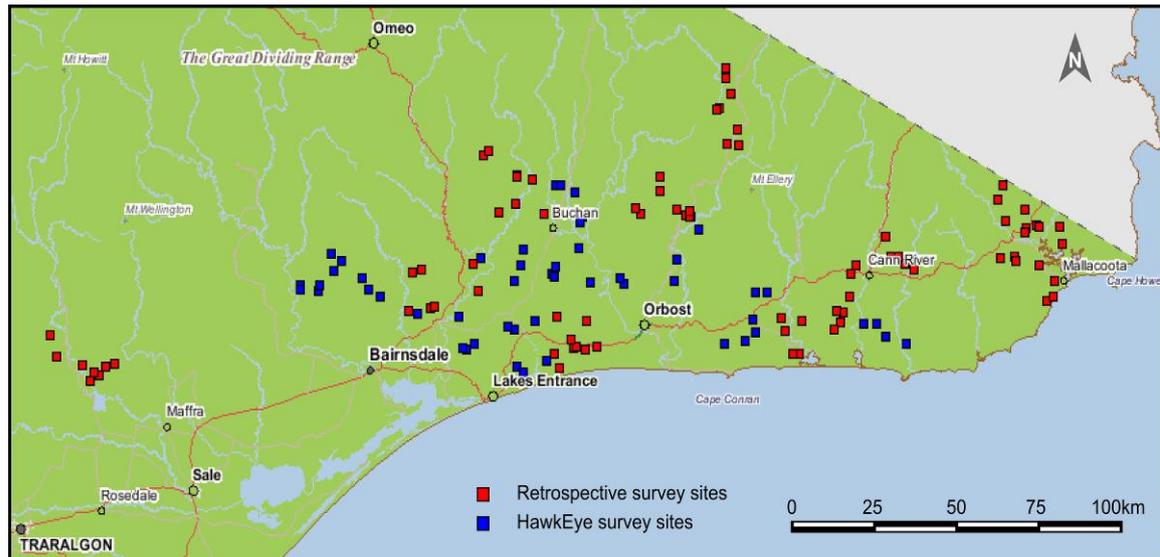
Figure 1: Location of survey sites for Retrospective and HawkEye projects 2010–2012 in East Gippsland

1.2.3 Lichen morphogroups, insectivorous bats, fuel hazard, vegetation structure

A number of other variables were measured as part of this project (lichen morphogroups, insectivorous bats and fuel hazard). However, due to limitations in the resources available, this work was analysed at a later stage of the project, and is described in the Appendices.

The presence of lichen morphogroups (flat and projecting growth forms on either live or dead wood) were recorded at 48 sites, as a trial to inform the direction of further data collection and sampling design. Results of the analysis of these data are presented in Appendix 5.

Insectivorous bats were surveyed at 26 sites using ultrasonic detectors, as a trial. The results of the data analyses are presented in Appendix 6.

Fuel hazard assessments were conducted at 123 sites, and the results of the data analyses are presented in Appendix 7.

Vegetation structure is affected by fire and is an important component of habitat for some fauna species (MacHunter *et al.* 2009). Data were collected on tree diameters and shrub cover (via the fuel assessments) at the flora sites. However, analysis of these data and more detailed structural measurements were beyond the scope of the project. More comprehensive data analyses on growth stages and habitat features are being conducted by the Foothills Fire and Biota project (ARI, La Trobe University, University of Melbourne, Deakin University) which will provide insights into relationships between vegetation structure and fire regimes.

1.2.4 This report

This is the final report for the Gippsland HawkEye Project and the Retrospective Project. It provides results from analyses of data for the combined projects. It describes the experimental design, including selection of the study area, key response and predictor variables and survey methods. It also describes the structure of the database that was developed to store and manage the large volume of data from the project. The report explains the modelling analysis and presents models with the most evidence for relationships between fire variables and taxonomic groups. Results are discussed in relation to initial hypotheses about flora and fauna responses to fire regimes. Implications of these results are discussed for current fire planning and future study design.

2. Methods

2.1 Study area stratification

2.1.1 Selection of study area

The study took a retrospective or space-for-time substitution approach to investigate the effects of fire regimes on flora and fauna. We note that retrospective studies are constrained by correlative evidence to infer possible relationships, as is the case for most ecological studies (Johnson 2002). However, through replication across variables of interest, in combination with evidence from other studies, this method is reasonable to gain credible insights about fire effects on biodiversity.

This method required the selection of sites which have varying fire histories but collectively similar environmental conditions, to enable inferences to be made about changes in flora and fauna due to fire. In selecting a study area, the foothill forests of eastern Victoria were initially stratified by key fire variables of interest. Large parts of this region were found to be unsuitable because recent extensive bushfires have simplified the fire history. The second consideration was to limit the effects of environmental variation masking the signal of fire regimes. The East Gippsland area provided the greatest variation in fire variables, and reduced the environmental variability while still representing forest types which have a broad applicability to fire management planning. The research sites selected represent a range of different times since fire and different fire frequencies, within two of the most extensive forest types in the foothills of eastern Victoria.

2.1.2 Forest types and environmental attributes

Environmental attributes (elevation, annual rainfall, mean temperature etc.) are influential in determining patterns of species occurrences across the landscape. Combining the array of environmental attributes in the stratification process proved difficult, and so Ecological Vegetation Divisions (EVDs) were used as surrogates. EVDs are aggregations of DSE's statewide Ecological Vegetation Classes (EVCs), and are based on shared ecological characteristics and fire responses (Cheal 2010).

We selected forest types (EVDs) that were considered most likely to be targeted for planned burning. Five EVDs were considered: Grassy / Heathy Dry Forest (EVD 3); Tall Mixed Forest (eastern) (EVD 7); Foothills Forest (EVD 8), Forby Forest (EVD 9); and Moist Forest (EVD 10). Pilot analyses were undertaken, using existing floristic data from the Victorian Flora Information System (Viridans Biological Databases 2012). Two EVDs, EVD 3 and EVD7, were identified in regression models (GLMs) as providing the strongest signal of fire effects compared with other EVDs with the same number of available sites. These forest types also had the greatest variation in fire histories, and a decision was made to focus on these two EVDs.

EVD 3 was characterised by low open mixed-species forests with lower strata of sclerophyllous shrubs and sparse ground layers (Cheal 2010), and was largely represented by Shrubby Dry Forest EVC. EVD 7 was characterised by tall open mixed-species forests with multiple layers and species rich lower strata (Cheal 2010), and largely comprised Lowland Forest EVC. Figure 2 shows the distribution of these two EVDs in the study area. The component EVCs are fully described by (Cheal *et al.* 2011).
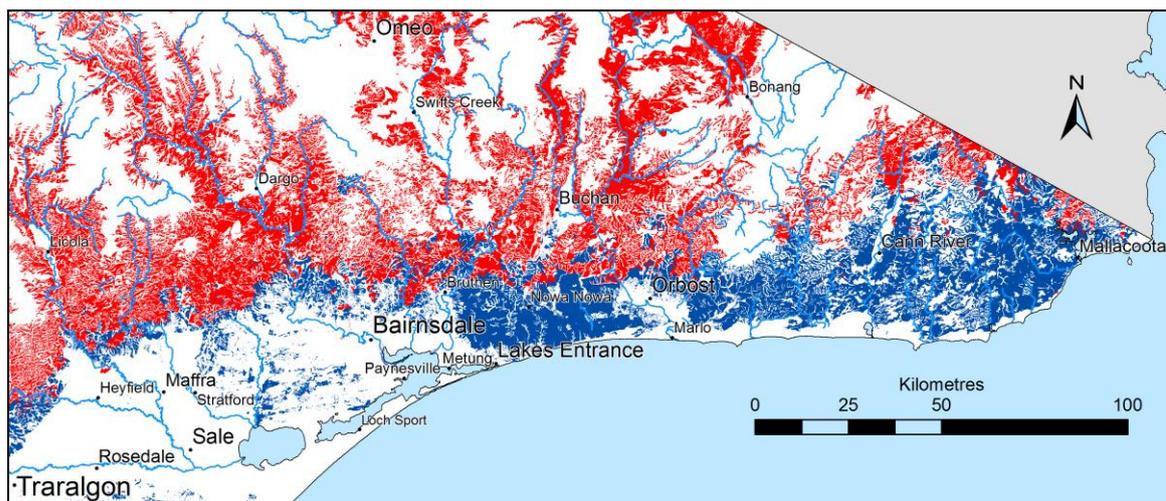
Figure 2: Distribution of EVD 3 (red) and EVD 7 (blue) in the study region

2.1.3 Fire regimes

Fire regimes describe the patterns of fire in ecosystems over space and time, and comprise a number of components (e.g. frequency, intensity, season and patchiness). In this study, we focussed on two aspects of fire: time since fire and fire interval. In order to capture relevant ecological data for flora and fauna, fire parameters were selected that reflect the time to reproductive maturity for flora species, and the time to develop critical habitat attributes of relevance to faunal occupancy and abundance. Combinations of times since fire and fire frequencies likely to be present in the landscape also informed the choice of site locations. Fire parameter time-frames were restricted by fire history records in DSE's spatial databases, which were only reliable from the 1970s onwards. These databases do not contain data on fire severity, but sites were differentiated on the basis of whether the last fires were planned burns or bushfires.

A power analysis was undertaken to provide an indication of the number of fire regime categories that could be sufficiently replicated within budgetary constraints. This procedure indicated an optimum number of nine fire regime categories (Table 1). A subset of five of these categories was used for the HawkEye component of the study, to provide stronger contrasts in the fire variables.

Table 1: Fire regime categories used in the stratification of sites

Ticks indicate sites to be used for ongoing monitoring in the Hawkeye progam, with variations included in brackets

Years since last fire	Number of fires since 1970	HawkEye monitoring sites
0–5 years	1 fire	✓
0–5 years	2 fires	
0–5 years	3+ fires	✓
6–20 years	1 fire	✓ (11–20yrs)
6–20 years	2 fires	
6–20 years	3+ fires	✓ (11–20yrs)
21–40 years	1 fire	
21–40 years	2+ fires	
41+ years	0+ fires	✓

2.2 Site selection

2.2.1 Site selection procedures

Sites were clustered in defined areas each 20km square (referred to in this report as 'landscapes'). This approach reduced costs associated with travel between sites, as would arise from a random distribution of sites across the extensive study area. Possible effects of using landscape clusters can be considered in statistical modelling through the inclusion of landscape as a random factor.

The study area was limited to the following bioregions: Highlands Northern Fall, Highlands Southern Fall, Central Victorian Uplands, East Gippsland Lowlands and East Gippsland Highlands (DSE 2011). Landscapes chosen were required to contain Grassy/Heathy Dry Forest and/or Tall Mixed Forest (eastern) EVDs, with adequate representation of all nine fire categories derived from the time since fire and fire frequency combinations in Table 1. To ensure enough potential sites for selection in the field, ten replicates in each landscape were required of all fire regime categories. Each site was required to occur within 500 m of an access track, be further than 200 m from a private land boundary, not have been logged since 1990, be more than 200 m from another fire combination and be more than 2 km from any other selected site.

Due to the size of the potential case study region the site selection process used Geographic Information Systems (GIS) and a spatial database known as Fire History Analysis Tool or FireHAT (DSE 2010). Within FireHAT a grid of 20 km x 20 km cells (landscapes) was established across the study region. Those landscapes that contained more than 20 ha of each of the fires combinations in Table 1 were selected and used to clip a shapefile of the nine fire combinations, creating a landscape fire shapefile. A selection criteria shapefile was then created that represented the above criteria. This was achieved by intersecting a 500 m externally buffered road network with a 200 m internally buffered public land shapefile, merging this with a logging shapefile and removing all polygons that included land logged since 1990. The selection criteria shapefile was merged with the landscape fire shapefile to create a survey shapefile that represented all the vegetation suitable for survey for this project. The survey shapefile was used to create three spatially random points within each of the nine fire categories within each landscape. These points were then selected haphazardly for the field survey.

Potential sites were checked in the field and assessed as to whether forest type and fire regime accorded with the mapping. This was necessary because of the limitations of fire mapping in the FireHat database, whereby the perimeter of a polygon does not reflect the potential patchiness of burns within that polygon. In addition some fires may not have been captured by mapping. Fifty sites in ten landscapes were marked with steel posts, to be used for ongoing monitoring.

2.2.2 Fire history verification

Prior to this study, there was no quantitative information available regarding the on-ground accuracy of the DSE's fire mapping in Gippsland. Accordingly, survey teams attempted to ground-truth mapped fire history in the process of establishing sites. Although numbers of potential sites were rejected as having obviously incorrect fire history (e.g. absence of charring where mapping indicated a 2010 burn), this was a novel task and more subtle assessments could not be made with confidence (e.g. whether a mapped 1996 burn had burnt a particular site).

Of the many potential floristic and structural clues to fire history, the charring retained on the lower trunks of some *Eucalyptus* species may provide the most easily quantified estimate of the time elapsed since the last fire. However, no previous work was found on the relationship between time since fire and retained charring of *Eucalyptus* in south-eastern Australia. In order to conduct a post hoc verification of fire history across all study locations, a secondary project was initiated to quantify trunk charring at a subset of sites.

Verification procedures

The bases of six trees were photographed at each of the 50 HawkEye sites. Trees were selected using the following protocols:

- Stringybark trees only were sampled (including *E. muelleriana* , *E. macrorhyncha*, *E. baxteri*, *E. globoidea*, *E. consideniana* and *E. obliqua*), as this bark type is readily scorched and retained on the trunk after fire.

- Three trees less than 20 cm diameter at breast height (DBH), and three trees greater than 20 cm DBH, were selected on the basis of their close proximity to the plot centre.

- The lowest 1.2 m of the eastern face of each tree was photographed.

- Trees with silvicultural defects were avoided where possible (i.e. trees with multiple trunks or structural defects that would affect trunk expansion).

The photographs were scored using the following procedures:

- From the sample of 300 photographs, representative photos were selected to define a series of 10 evenly-gradated char levels ranging from 1 (charring negligible) to 10 (entire surface charred).

- To determine the repeatability of char assessment from photographs, four observers each allocated scores to all 300 photos. Photos were scored in random order and observers were blind to site identity and fire history. A high degree of inter-observer correlation ($r > 0.95$) demonstrated that subjectiveness in trunk assessment contributes only a small fraction of total variation in trunk scores.

- Char scores for each size class of tree at each site were then compiled across all observers.

- A basic logarithmic regression model of time since fire versus mean tree char per site was then fitted in Microsoft Excel. Graphs of the fitted line, including raw data points, were subsequently used in fire history verification.

The *post hoc* verification of fire history information was then undertaken in a two-step process:

- Desktop assessment (all sites). All visible clues to time since fire (flora, fuel, coarse woody debris and charring of stringybark trees) in site photographs were compared with available spatial data on all fires near individual sites. The likelihood of the fire history being correct was assessed as: correct, likely, plausible or doubtful. This assessment was then used to prioritise a subset of sites for field visits. It was not possible to visit all doubtful sites, i.e. those that had already experienced fire after the surveys had been carried out.

- Field assessment (subset of sites; n = 41). Comparison was made between mapped fire history and fire history clues (flora, fuel, coarse woody debris and charring of stringybark trees) over two hectares at each study site. Further trunk photographs were taken using the method described above. This process was repeated at nearby locations, if these appeared to match the mapped fire history more closely than the survey site. A final categorisation of the fire history was made on-site (correct, likely, plausible, probably incorrect, definitely incorrect) and an alternative fire history was supplied in the case of incorrectly attributed sites.

Revised fire histories

The combined desktop and field fire history verification process resulted in updated fire histories at 25 sites. It is important to note that (i) only the time since the most recent fire was considered because it was not possible to verify preceding fires, and (ii) further work is required before a standard method of fire history verification can be adopted.

During desktop assessment, 11 sites were identified where the mapped fire history included duplicate fires; (i.e. fires of the same type, same or very similar footprint, and in successive years). In most cases, this was due to repeat treatment of a burn, and it is likely that fire was indeed applied twice. However, as the second treatment would have been targeted at patches not burnt in the initial fire, it is very unlikely that the site was burnt twice within two years. As these 'dual fires' would otherwise confound some predictor variables (i.e. count of fires), versions of the dataset were produced that excluded the first year of a dual fire sequence. Combining the corrected fire histories and corrections for dual fires, a total of 32 sites had a modified total fire count.

Following the revision of fire history, site replication according to fire regime was reassessed to evaluate if the study design was balanced among categories (Table 2).

Table 2: Site replication according to revised fire regime

Values denote the number of site replicates in each fire regime derived from the verification process, and values in brackets are those from the FireHAT database. Inclusive of both Retrospective and HawkEye Gippsland sites.

Number of fires since 1970	0	1	2	3+	All sites
Time since fire class					
0–5		12 (12)	8 (11)	13 (18)	33 (41)
6–10		4 (2)	7 (5)	4 (5)	15 (12)
11–20		14 (18)	5 (5)	13 (14)	32 (37)
21–40		21 (10)	7 (7)	2 (2)	30 (19)
41+	24 (20)	(4)		(2)	24 (26)
All sites	24 (20)	51 (46)	27 (28)	32 (41)	134 (135)

2.3 Database

2.3.1 Database design and structure

A *Microsoft Access* database was established to manage and integrate the large amount of data from the Gippsland HawkEye and Retrospective Project. Control measures (e.g. simple auditing queries and setting of indexes) were used to eliminate storage of duplicate data within tables and to check for inconsistencies within the data. The database can be easily interrogated and summarised in various formats and scales and a number of queries have been created, including those to output data for analysis and for import to the Victorian Biodiversity Atlas (VBA) (DEPI 2013). *Microsoft Excel* data entry templates were designed for all surveys, which were later used to import the data directly into the database. The use of templates ensured standardisation of data collection and ease of import to the database.

The database structure consists of 19 main data tables and 17 look-up tables, linked by a unique identifier. A number of look-up tables were incorporated into the database design to ensure consistency within the datasets (e.g. standardisation of species nomenclature) and to add additional variables for analyses (e.g. flora life form attributes and bird guild information). For the purposes of illustrating the database structure in this report, the design has been segregated into several groupings of common tables (shared by all surveys) and tables specific for each survey. Diagrams showing the database structure are shown in Appendix 1.

2.3.2 Database tables

There are five common tables (Figure 16, Appendix 1) which are shared by each survey type and are linked via 'Site ID' (a unique identifier). The 'Site Info' table includes site location details and is linked by 'Site ID' to four additional tables which include survey design, fire and environmental variables for each site.

The habitat assessment data are stored in three tables (Figure 17, Appendix 1): DBH, Vegetation Structure, and Fuel Assessment. These tables are linked to the 'Site Info' table via 'Site ID.

The Flora assessment tables (Figure 17, Appendix 1) consist of three main data tables which are linked to the 'Site Info' table via 'Site ID': i) Flora_Survey Info (includes on ground site information as well as individual survey information); ii) Flora_Freq Flora (presence/absence data); iii) Flora Comments (layer height and cover information as well as additional habitat comments). In addition there are five look-up tables linked to these tables including FIS and VBA species codes, flora functional groups and traits, and flora methods.

There is one main bird survey table Bird Survey (Figure 18, Appendix 1) which is linked to seven look-up tables to include information on bird guilds, fauna methods and VBA taxon ID.

There are two main data tables for both small mammal and predator mammal surveys (Figure 19, Appendix 1): i) _Camera Info (data on individual surveys); ii) _Photo Info (data on individual photos). Two look-up tables are linked to these tables and include fauna methods and VBA taxon ID.

2.4 Vascular flora surveys

2.4.1 Flora survey site stratification and replication

Flora surveys were conducted at 132 sites in Gippsland, between November 2010 and April 2011, and between October 2011 and February 2012. The number of sites in each time since fire class ranged from 24 to 33, with the exception of the 6–10 year class which was represented at 15 sites. This extra class was a subset of the original stratification and was included because this period is a critical time for maturation and changes in reproductive status for many plant species (Cheal 2010). EVD 3 and EVD 7 had reasonably matched numbers of sites. Table 3 & Table 4 summarise the sites by fire history and EVD.

Table 3: Number of sites surveyed for flora, by time since last fire

Time Since Last Fire (years)	EVD 3	EVD 7	Total
0–5	16	17	33
6–10	7	8	15
11–20	17	14	31
21–40	15	14	29
41+	14	10	24
Total	69	63	132

Table 4: Number of sites surveyed for flora, by fire frequency since 1970

Fires Since 1970 (number)	EVD 3	EVD 7	Total
0	14	10	24
1	27	22	49
2	10	17	27
3+	18	14	32
Total	69	63	132

2.4.2 Measurement variables and sampling design

All vascular plant species were targeted for survey. Vascular plant species are important to sample because they comprise a large proportion of the biodiversity and much of the biomass on which other organisms depend (Kent and Koker 1992) and provide fuel for bushfires. In addition, vascular plants are readily detectable in surveys and are commonly used in monitoring by DSE (e.g. Cawson and Muir 2008, Tolsma *et al.* 2010, Treloar *et al.* 2012).

A frequency metric was used, based on recording the presence of species in a number of plots at a site and then calculating a percentage occurrence. Comparisons of measurement techniques indicated that a frequency method was most suitable for the objective of the study because it maximises detection of differences in occurrence of species between sites (Godínez-Alvarez *et al.* 2009), and is repeatable by different observers (Elzinga *et al.* 2001). This approach is particularly suitable for broad-scale studies of species' responses to disturbance (Penman *et al.* 2008, Wilson 2012).

The allocation of 21 plots per site was deemed the acceptable trade-off between cost and sample completeness. This was based on information from pilot studies carried out for the Forest Monitoring and Reporting Information System and the Landscape Fire and Environmental Monitoring Program (Tolsma 2010, University of Melbourne unpublished data, Tolsma *et al.* 2010). The plots were located along three transects in a Y configuration to match an approach used for the Landscape Fire and Environmental Monitoring Program (Treloar *et al.* 2012).

2.4.3 Field procedures and plant identifications

Twenty-one 1 m² sub-plots were sampled at each site, seven along each of three transects (Figure 3). The following procedures were followed in sampling vascular flora at each site:

- From the centre point of the site, a 50 m transect was laid out on a bearing of 0° (magnetic), using a compass and 50 m tape measure.

- Starting from the 15 m mark, a 1 m x 1 m quadrat frame was placed at 5 metre intervals along the right side of the transect, finishing at the 45 m mark.

- The presence of each species of vascular plant growing within, or projecting over, each quadrat was recorded.

- This procedure was repeated for the angles of 120⁰ and 240⁰, so that three 50 m transects were created in a 'Y' shape.
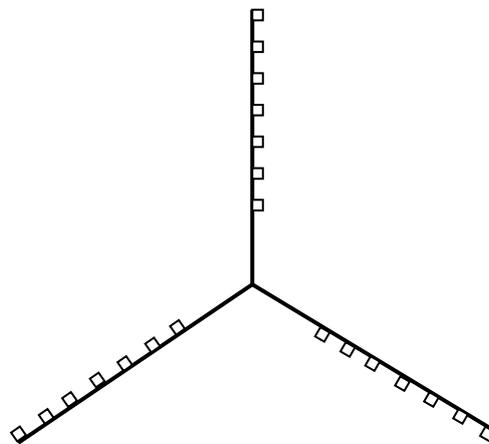
Figure 3: Layout of flora plots

The following additional information was recorded:

- From the centre point of the site, two photographs of each transect were taken, in portrait and landscape orientation.

- Comments on the datasheets included notes on aspect, slope, soil texture, evidence of fire, evidence of logging, and projective cover of major vegetation layers.

All unknown plant specimens collected in the field were identified subsequently in the office. Taxonomy follows (Walsh and Entwisle 1994, 1996, 1999), with updates from the Flora Information System (Viridans Biological Databases 2012). Plants were determined to sub-species or variety level if possible. All data were entered into the *Microsoft* Access database created for the project.

2.4.4 Plant functional types and frequency calculation

Frequency values can be assigned to groups of related plants as well as individual species. Plant species can be grouped into functional types, based on common traits and responses (resprouting, seed banks, maturation and senescence) to fire (Keith *et al.* 2007). The 'plant vital attributes' scheme of Noble and Slatyer (1980) is a plant functional type scheme which forms the basis of ecological fire planning in DSE. Some plant functional types are sensitive to the intervals between fires, and therefore can help inform minimum and maximum Tolerable Fire Intervals for forest types (Fire Ecology Working Group 2004, Cheal 2010).

Plant functional types were characterised using a modified version of the approach in Keith et al. (2007). Table 5 shows how plant functional types were defined for our study. The vital attributes used (mortality of plants after fire and length of time to reproductive maturity) were considered critical for plants' responses to

fire and had accessible data. It should be noted that species' responses to individual fires are variable, and key attributes such as resprouting or seeding are influenced by fire severity (Bellingham and Sparrow 2000). Hence, allocation of taxa to plant functional types was based on the usual ecological behaviour of most individuals in most populations in the two forest types in the east Gippsland study area. The length of juvenile periods was generalised into broad categories. Taxa were assigned to the plant functional types using a draft DSE database of attributes for all Victorian vascular plant taxa (unpublished data - Matt White, ARI, April 2012), coupled with expert knowledge from David Cheal (Appendix 2). To minimise double-counting of taxa which were identified to different taxonomic levels (i.e. species or sub-species), some taxa were combined. This gives a fairer measure of relative occurrence at different sites.

Frequency values were calculated for each site by giving a score of '1' for the occurrence of one or more members of a plant functional type in a plot. These scores were summed for each site and then divided by the total number of plots (21) to give a percentage occurrence for each plant functional type. The rationale for this method of calculating frequency is that it scores the plant functional type's presence, regardless of how many species or how many individuals are in each 1 m^2 plot. The plots are not quantitative and so are best expressed as a proportion of the total plots for a site, and final frequency value is for the site.

Table 5: Plant functional types and their defining characteristics

Plant Functional Type	Regeneration after fire	Juvenile period	Life form
Canopy trees	not killed by fire		Tree
Serotinous obligate seeder shrubs	killed by fire	> 5 years	shrub, small tree
Obligate seeder shrubs – long juvenile	killed by fire	> 5 years	shrub, small tree
Obligate seeder shrubs – short juvenile	killed by fire	< 5 years	shrub, small tree
Resprouter shrubs – long juvenile	not killed by fire		shrub, small tree
Resprouter shrubs – short juvenile	not killed by fire		shrub, small tree
Obligate seeder herbs	killed by fire	< 5 years	forb, graminoid, climber
Resprouter herbs	not killed by fire		forb, graminoid, fern, climber
Rhizomatous herbs – vigorous	not killed by fire		forb, graminoid, fern
Ephemeral herbs	killed by fire	< 1 year	forb, graminoid
Introduced plants (to Australia)			mostly herbs

2.4.5 Data analyses

Analyses of the data from this project investigated the relationships between response variables (flora functional types and species) and explanatory variables (time since fire, number of fires since 1970, bushfire or planned burn, minimum Tolerable Fire Intervals (TFI).

Two analyses were carried out, using explanatory variables of EVD and several fire covariates (Table 6). In the first analysis, time since fire was treated as a continuous variable. A small number of sites had no recorded fire history and therefore could not be assigned a defensible numerical time since fire. Therefore, sites which had fire recorded as greater than 41 years or no fire recorded were excluded from these analyses. In the second analysis, the effects of fire intervals below minimum TFIs were tested.

Multiple quasi-binomial generalised linear models (GLM) were constructed relating to *a priori* hypotheses about the effect of fire on the presence of different flora groups. The hypotheses considered for each flora functional type are stated in Table 7. Quasi-binomial GLMs account for over- (and under-) dispersion by allowing for the standard deviation to vary by a constant from the usual standard deviation for a binomial GLM. As the models use a quasi-binomial distribution a Quasi-Akaike Information Criteria corrected for small sample size (QAICc) was used to select models with the best support (Burnham and Andersen 2010). The analysis was performed using the statistical program *R* version 2.15.1 (R Development Core Team 2013).

Table 6: Variables included in flora analyses

	Variable	Abbreviation	Possible values	Variable type
Analysis 1	EVD	EVD	3, 7	Categorical
	Time since fire	TSF	1 to 41 years	Numeric
	Fires since 1970	Fires	1 to 5 fires	Numeric
	Most recent fire type	LastFireType	planned, bushfire	Categorical
Analysis 2	EVD	EVD	3, 7	Categorical
	Minimum Tolerable Fire Interval	MinTFI	at least 1 fire interval less than minimum TFI	Categorical
	Minimum Tolerable Fire Interval count	MinTFIcount	count of fire intervals less than minimum TFI	Categorical
	Fire History	FireHist	Combination of time since fire (1-5, 6-10, 11-20, 21-40, 41+) & fires since 1970 (3+, 2, 1, 0)	Categorical

Table 7: Hypotheses/models considered to affect presence of each plant functional type

* indicates terms included both individually and their interaction.

	Hypothesis	Model
Analysis 1	Presence equal for all sites and histories	Null
	Presence is different between EVD 3 and EVD 7	EVD
	Presence is different between some last fire types and EVD combinations	EVD*LastFireType
	Presence is affected by the number of fires and is different between EVD 3 and EVD 7	EVD*Fires
	Presence is affected by time since fire and is different between EVD 3 and EVD 7	EVD*TSF
	Presence is affected by the number of fires and is different between some last fire types and EVD combinations	EVD*LastFireType*Fires
	Presence is affected by time since fire and is different between some last fire types and EVD combinations	EVD*LastFireType *TSF
	Presence is affected by the number of fires and time since fire and is different between some last fire types and EVD combinations	EVD*LastFireType *(Fires+TSF)

Analysis 2	Presence equal for all sites and histories	Null
	Presence is different between EVD 3 and EVD 7	EVD
	Presence is affected by any fire interval less than minimum TFI and is different between EVD 3 and EVD 7	EVD*MinTFI
	Presence is affected by number of fire intervals less than minimum TFI and is different between EVDs	EVD*MinTFIcount
	Presence is affected by fire history and is different between EVD 3 and EVD 7	EVD*FireHist
	Presence is affected by fire history and fire intervals less than minimum TFI and is different between EVDs	EVD*(FireHist+MinTFI)

2.5 Diurnal bird surveys

2.5.1 Bird survey site stratification and replication

The sites surveyed for birds comprised 124 sites from 22 landscapes, including two in the north-east (Table 8, Table 9). Visiting fewer sites enabled those sites to be surveyed in the spring / summer period of peak bird activity within the constraints of budget and staff availability during this time. The sites were selected to ensure sufficient replication with the available resources and to ensure the maximum contrasts between fire regimes were represented (1 versus 3+ fires). There were 113 sites surveyed in the first year (Oct 2011-Jan 2012), and 31 sites surveyed in the second year (Nov 2012) of which 20 were repeat surveys and 11 were new sites. Second year survey sites were selected to increase sampling effort in the 21-40 years age class while resampling some sites to account for any temporal variation between survey seasons (years). Sound recorders were deployed to a subset of 27 sites as part of a parallel study comparing the efficacy of human based surveys with longer term sound recordings, and these results will be reported elsewhere.

Table 8: Number of sites surveyed for birds by time since fire classes

*Two of the time since fire classes were combined to create four categories of time since fire for particular analyses

Time Since Last Fire (years)	EVD 3	EVD 7	Total sites
0–5	17	10	27
6–10*	5	5	10
11–20*	19	14	33
21–40	19	10	29
41+	16	9	25
All sites	**76**	**48**	**124**

Table 9: Number of sites surveyed for birds by fire frequency since 1970

Fires Since 1970 (number)	EVD 3	EVD 7	Total sites
0	16	9	25
1	30	19	49
2	8	8	16
3+	22	12	34
All sites	**76**	**48**	**124**

2.5.2 Bird survey technique and metrics

The study focused on diurnal forest birds because cost-effective field survey methods are available and the group has been shown to be highly informative for research monitoring purposes (Kavanagh *et al.* 2004). A timed area-search was used involving both sight and sound observations of birds over a two hectare area (Figure 4) within a 20 minute period (Loyn 1986). The 20 min / 2ha survey technique is a well-tested approach in Australian bird research (Barrett and Silcocks 2002). One key advantage of area searches over stationary or point counts is that, by walking around the two hectare area, the observer is able to flush birds that would otherwise be undetected (Hewish and Loyn 1989).

A number of measures were taken to minimise errors of detection of birds (Anderson 2001). Surveys were undertaken by seven observers experienced with the bird species in the study area. Six observers had more than 10 years' experience undertaking bird surveys and one had two years experience. Each site was assessed by two observers to reduce the effects of observer bias (Cunningham *et al.* 1999). Seasonal influences were minimised by focusing surveys between late October and December, when all species would be present and vocal. Surveys were undertaken when the temperature was estimated to be less than 30°C, there was no rain, and were not undertaken on days when the wind strength generated noise in the canopy that might mask bird calls. Sites were surveyed after the dawn chorus (later than 30 mins after sunrise) and 30 mins before sunset. All sites were surveyed twice (once each by different observers) on the same day, as estimates of species richness are associated with total time spent at a site, rather than time spread over different days (Slater 1994).

Survey sites were rectangles with lengths of 100 metres along the north-south axis and 200 metres along the east-west axis which effectively encompassed the flora survey area. Centre and corner point coordinates were pre-defined and loaded into GPS units before field surveys commenced. A single observer walked within the defined boundaries for 20 minutes, attempting to achieve full site coverage (Figure 4). The second observer conducted a 20 min / 2 ha survey following completion of the first observer's survey.

The following data were recorded:

- Count (by species) of individual birds heard and seen inside the 2 ha site and within the 20 minute survey period. These individuals are 'on site' and are included in analyses.

- Count, as above, of individual birds outside the 2 ha site but within the 20 minute survey period. These are 'off site' and are excluded from analyses but noted for VBA records.

- Species recorded before or after the 20 minute survey period as 'incidental records' and are excluded from analyses but noted for VBA records.

- Site covariates - time of day, cloud cover, wind strength, visibility and site access.

All detection types were submitted to the Victorian Biodiversity Atlas (DEPI 2013) to improve knowledge of the distribution patterns of bird species.
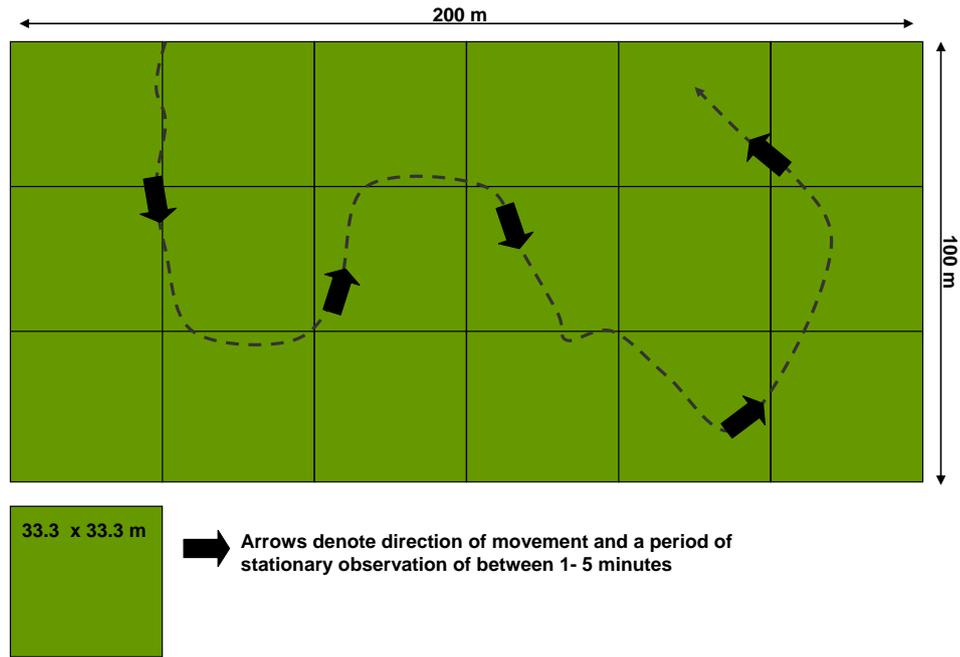
Figure 4: Example of observer movement during a 20 min / 2 ha bird survey

2.5.3 Bird guilds

Guilds (or functional groups) tend to enable better power to detect changes than when species are analysed individually. Guilds produce fewer sites with zero counts in the dataset and better model fits, whereas for individual species numerous sites may have zero counts resulting in insufficient data for analyses. For birds in Victoria, guilds have been identified on the basis of coarse-scale habitat use, and nesting and feeding preferences (Appendix 3). For example, a guild with a large membership is nectarivores, which take nectar from flowers. Most bird species take invertebrates as their main food, and this large group has been subdivided depending on which vegetation layer they forage from. Hollow-nesting birds are an important guild since hollows are restricted to trees generally more than 100 years old causing very long time lags in habitat suitability in areas that have lost this resource. For this study, survey data were grouped according to bird guilds that represent feeding and nesting characteristics that can be linked to changes in habitat suitability arising from possible effects of fire regime or other biophysical attributes (Appendix 3). Bird response variables were derived by summing the number of individual birds according to their guild to obtain the relative abundance (density) of a guild for subsequent analysis.

2.5.4 Data analyses

Bird guilds were selected for analyses where members of those guilds were detected across more than 25% of all counts. Data were modelled using generalized linear mixed-effects models (GLMM) with the R package lme4 (Bates and Sarkar 2007). A Poisson error distribution was selected for modelling response variables as recommended for count data in ecological analysis (Zuur *et al.* 2007). GLMM enable variation in the data associated with the location of sites to be accounted for through the use of random factors (Bolker *et al.* 2009). Both 'site' and 'landscape' factors were used, the latter in recognition of the spatial clustering of sites within each landscape.

A total of 27 candidate models were formulated to predict changes in the density of functional bird groups from combinations of fire regime, environmental and sampling variables (Table 10).

Table 10: Variables included in analyses of bird data

Variable	Levels
Fire frequency since 1970 (FF)	1 ,2, 3+
Time Since Fire (TSF)	TSF4, TSF5: respectively four or five classes
Fire Group (FG)	FG1: 0-5yrs and < 3 fires, FG2: 0-5yrs and 3+ fires, FG3: 6-20yrs and < 3 fires, FG4: 6-20yrs and 3+fires, FG5: 21-40yrs and 1-3+fires, FG6: 41+years
Minimum Tolerable Fire Interval (TFI)	0: Above TFI, 1: Below TFI
Last fire type (FT)	planned / bushfire / unknown
Ecological Vegetation Division (EVD)	EVD 3, EVD 7
Observer	Obs1-7
Region	North East or Gippsland
Season	1st Year (spring/early summer 2011) 2nd Year (spring 2012)

Models tested were:

- Null

- EVD

- EVD + Fire regime (TSF4 / TSF5 / FF / Below TFI / FG / last FT)

- EVD*Fire regime

- EVD + Season + Region

- Season + Region

- Observer + Region

Scatter plots of residuals versus fitted values of each model were generated and checked for goodness of model fit. Model fits were acceptable where scatter plot of residuals indicated the difference between observed and fitted values were small and unbiased. Accepted models were included in model selection using the Aikakie Information Criterion (AIC) to evaluate and compare the fits of alternative models to the data (Burnham and Andersen 2010). Once models were ranked according to their AIC value the evidence ratio was used to assess the degree of confidence that the best model (with the lowest AIC value) was superior to alternative models. Evidence ratios from 1-8 suggest that alternative models are similarly likely and that no single model can be ranked first. Models with evidence ratios ~ 8 and above are very unlikely (Burnham and Andersen 2010) and so were not considered further in the results.

2.6 Ground-dwelling mammal surveys

2.6.1 Site stratification and replication

Mammals were surveyed at 89 of the 132 sites between September and December 2011 across 17 landscapes. We needed to sample a subset of sites to match the available project resources. However, we were able to sample in all five fire history categories used in the HawkEye project in every landscape. Table 11 shows the number of mammal survey sites in each time since fire and Table 12 the number of sites by fire frequency category.

Table 11: Number of sites surveyed for mammals by time since last fire

Time Since Last Fire (years)	EVD 3	EVD 7	All sites
0–5	13	10	23
6–10	3	5	8
11–20	16	14	30
21–40	5	2	7
41+	12	9	21
All sites	49	40	89

Table 12: Number of sites surveyed for mammals by number of fires since 1970

Fires Since 1970 (number)	EVD 3	EVD 7	Total
0	12	9	21
1	18	14	32
2	4	5	9
3+	15	12	27
All sites	49	40	89

2.6.2 Mammal survey technique

Ground-dwelling mammals are useful to survey because they are sensitive to changes in forest understorey structure (Catling and Burt 1995), and native mammals may become more vulnerable to introduced predators if the amount of understorey cover is reduced (Loyn and McAlpine 2001). Furthermore, a number of mammal species are listed as key fire response species, being both likely to be affected by fire intervals and amenable to monitoring using standard techniques (MacHunter *et al.* 2009).

Several techniques for surveying ground-dwelling mammals were compared and automated camera traps were considered to be the most suitable for this study for a number of reasons. They are particularly suitable for general surveys conducted over a large geographical scale, and are well established and efficient for long-term wildlife surveys (Nelson and Scroggie 2009). Cameras are most suitable for surveying across a range of differently sized mammals, including some that are too big to enter commonly used physical traps. Camera traps are often used for ground-dwelling mammals but they can also frequently capture images of arboreal species such as Common and Mountain Brushtail Possums (Macak *et al.* 2012) and non-mammal fauna species such as birds (e.g. Superb Lyrebird) and reptiles (e.g Lace Goanna). Camera surveys are cost-effective when compared with live trapping (De Bondi *et al.* 2010) and hair tubes (Paull *et al.* 2012), and have been shown to be more effective in detecting mammals in East Gippsland (Diment 2010).

The main disadvantage of camera traps compared to live trapping is that they do not generate absolute abundance data. However, sophisticated statistical techniques are available (termed "occupancy estimation") for analysing the presence/absence data obtained from these devices (MacKenzie *et al.* 2002). The analysis of presence/absence data using occupancy estimation allows for the estimation of two parameters: occupancy – the probability that a site is occupied by a species; and detection probability – the probability that the species will be detected on a survey occasion, given that it is actually present (MacKenzie *et al.* 2002). Occupancy estimation thus accounts for imperfect detection (a common problem in wildlife surveys) by explicitly including detection probability in the analyses. The use of occupancy as a state variable for detecting differences in animal populations as a result of habitat differences is well established in the literature and may be preferable to indices of abundance where animal distribution and range are of interest (MacKenzie *et al.* 2006, and the references therein).

2.6.3 Equipment and site setup

The cameras were set up and sites prepared according to guidelines set out in Nelson and Scroggie (2009). Four automated cameras were used to survey each site, all cameras at a site were installed on the same day. Two camera traps were baited to survey for herbivorous or omnivorous mammals ('herbivore cameras') and two were baited to survey for carnivorous ('predator cameras'). Cameras were left in place for a minimum of 21 days (maximum 24 days). All cameras at a particular site were collected on the same day.

Herbivore cameras

Two herbivore cameras were placed approximately 50 m from the survey site centre (measured using hand-held GPS units (Garmin GPSMAP 62s, Garmin Ltd., Olathe, USA). Two different camera models were used at each site; a PixController DigitalEye™ unit (PixController Inc., Pennsylvania, USA) containing a 12.1 megapixel Sony white-flash digital camera and a Reconyx HC500 or PC900 infra-red flash unit (Reconyx Inc., Wisconsin, USA). We attached the cameras to the nearest suitable tree to the 50 m mark using wire and the camera was secured using a Python cable lock (Master Lock Company, LLC., Oak Creek, USA).

The bait was a mixture of rolled oats, peanut butter and golden syrup. One heaped teaspoon of bait was placed inside each stainless steel tea infuser. Six tea infusers were then placed inside a stainless steel cage. The cage was attached to a plastic garden stake and protected from the rain by a metal lid. One of these bait stations was placed at each camera location, 2 m from the camera and 40–50 cm from the ground. To maximise the chance of capturing an animal near the bait station the vegetation was cleared between the camera and bait station as well as to about 1 m behind and either side of the bait station.

Predator cameras

Two predator cameras (Reconyx PC900, Reconyx Inc., Wisconsin, USA) were placed 150 m from the survey site centre. Camera locations were selected prior to visiting the site and then located using handheld Garmin GPS units (Garmin Ltd., Olathe, USA). We attached the cameras to the nearest suitable tree to the desktop-selected location using a Python cable lock (Master Lock Company, LLC., Oak Creek, USA).

The bait system comprised a tea infuser containing a piece of felt doused in tuna oil and a fresh chicken drumstick. These items were placed inside a metal cage box and wired to the top. The cage was attached to a metal star picket and was about 1.5 m from the ground. The bait station was placed 3 m from the camera and the vegetation around the bait station was cleared to maximise the chance of photographing an animal when it crossed in front of the camera.

Camera settings

The cameras were set to take photos 24 hours per day with the other settings chosen according to prior experience with each make:

PixController – Medium sensitivity and highest resolution with one shot per trigger and a 30 second interval between triggers.

Reconyx – Highest sensitivity and resolution with three shots per trigger, a one second interval between photos and a 15 second interval between triggers.

2.6.4 Photo Identification and Data Analyses

Where possible all animals captured in photos were identified to species level. Difficult identifications were referred to a second expert for confirmation and if this was inconclusive it was assigned to a generic category. Photos were sorted into folders representing the species name with a subfolder representing the number of individuals in the photo.

Photos were analysed using the programs *ReNamer* (gives the photo files a specific name for subsequent analyses, *DataOrganize*, *DataAnalyze* and *OccupancyMatrix* (Sanderson 2012). These programs produce a summary of the species captured (*DataAnalyze*) and occupancy matrices (*OccupancyMatrix*) for each species which can be used in subsequent analyses.

We produced occupancy matrices for ten mammal species and one bird species (Superb Lyrebird) using *OccupancyMatrix* (Sanderson 2012). Data from all four cameras at a site were combined to construct a unique detection history for each species at each site, with each of 21 days considered to be a separate survey occasions (in cases where cameras were operational for more than 21 days the extra days were excluded). These matrices were analysed using single season occupancy analyses with co-variates

(MacKenzie *et al.* 2002, MacKenzie *et al.* 2006). Such analyses allow for estimation of the site occupancy and detection probabilities and takes into account imperfect detection. The covariates included in the models were easting (continuous), time since fire (continuous), number of fires since 1970 (continuous) and EVD (two levels EVD 3 & EVD 7). We also considered the interactions between variables with the exception of easting. All variables with the exception of EVD were modelled as continuous. Goodness-of-fit was measured using simulated Pearson χ2 statistics from the full model for each species, which is akin to a posterior predictive Bayesian p-value (Gelman *et al.* 2004). All analyses were conducted in *R 2.15.1* (R Development Core Team 2013) using the package *Unmarked* (Fiske and Chandler 2011) and *MuMln* (Barton 2013). Due to the number of possible models, multi-model inference was used (Burnham and Andersen 2010). The outputs of interest were the importance of each term and an average of models with a Δ*AICc* < 4. We also calculated the probability of occupancy and detection for all sites.

3. Results

3.1 Vascular flora

3.1.1 Flora data summary

A total of 548 taxa were recorded across 132 sites (Table 13). Appendix 2 (Table 21) contains a list of all taxa recorded, ordered by plant functional types. There were large differences in the number of taxa representing each plant functional type, ranging from six in the 'Serotinous obligate seeder shrubs' category to 197 in the 'Resprouter herbs' category. In addition, the 'Serotinous obligate seeder shrubs' group was recorded from only a few sites in EVD 3, whereas the 'Rhizomatous herbs – vigorous' group' although represented by just a few taxa, was almost ubiquitous in EVD 7. However, most plant functional types in this study occurred at more than 50% of sites. Introduced plants were a very minor component of the vegetation at all sites in both EVDs.

Table 13: Number of taxa representing each plant functional type, and number of sites at which plant functional type recorded by EVD

Plant functional type	Taxa	Sites EVD 3	Sites EVD 7
Canopy trees	35	69	63
Serotinous obligate seeder shrubs	6	6	36
Obligate seeder shrubs – long juvenile	21	46	22
Obligate seeder shrubs – short juvenile	76	67	63
Resprouter shrubs – long juvenile	24	40	59
Resprouter shrubs – short juvenile	63	65	62
Obligate seeder herbs	77	66	63
Resprouter herbs	197	69	63
Rhizomatous herbs – vigorous	8	41	62
Ephemeral herbs	14	59	37
Introduced plants	27	16	12
Total	**548**	**69**	**63**

3.1.2 Model selection

The models with the most evidence for fire variables as predictors for occurrence of plant functional types were for 'serotinous obligate seeder shrubs', obligate seeder shrubs – short juvenile', 'obligate seeder herbs', 'rhizomatous herbs – vigorous' and 'ephemeral herbs' (Table 14). Results for ephemeral herbs were considered unreliable because of seasonal differences resulting from when the data were collected. Fire variables were not in the best models for plant functional types with life history characteristics considered to be less sensitive to fire, such as resprouter shrubs, resprouter herbs and canopy trees (Table 14).

Table 15 shows the estimates and confidence intervals for the best models for each plant functional type. Records of introduced plants were very few and so estimates are not shown for this group. Appendix 2 (Table 23) lists all the models and their QAICc for the plant functional types.

Table 14: Models with the most evidence for fire variables as predictors for occurrence of plant functional types

Plant Functional Type	Analysis 1 Model with lowest QAICc	Analysis 2 Model with lowest QAICc
Canopy trees	Presence	Presence
Serotinous obligate seeder shrubs	Presence~EVD*TSF	Presence~EVD
Obligate seeder shrubs – long juvenile	Presence~EVD	Presence~EVD
Obligate seeder shrubs – short juvenile	Presence~EVD*TSF	Presence~EVD*FireHist
Resprouter shrubs – long juvenile	Presence~EVD	Presence~EVD
Resprouter shrubs – short juvenile	Presence~EVD	Presence~EVD
Obligate seeder herbs	Presence~EVD*TSF	Presence~EVD*MinTFI
Resprouter herbs	Presence~EVD	Presence
Rhizomatous herbs – vigorous	Presence~EVD*Fires	Presence~EVD*MinTFI
Ephemeral herbs	Presence~EVD*LastFireType	Presence~EVD
Introduced plants	Presence	Presence

Table 15: Plant functional type frequency predicted by fire variables; models with lowest QAICc shown with estimate, upper and lower confidence intervals.

	Response variable	Predictor variable	Estimate	Lower CI	Upper CI
Analysis 1	Canopy trees	Null	1.98477	1.790	2.179
	Serotinous obligate seeder shrubs	EVD*TSF	-0.05646	-0.208	0.095
	Obligate seeder shrubs – long juvenile	EVD	-1.9603	-2.826	-1.095
	Obligate seeder shrubs – short juvenile	EVD*TSF	-0.040456	-0.084	0.003
	Resprouter shrubs – long juvenile	EVD	1.1376	0.646	1.629
	Resprouter shrubs – short juvenile	EVD	1.1653	0.616	1.715
	Obligate seeder herbs	EVD*TSF	-0.01837	-0.061	0.024
	Resprouter herbs	EVD	-0.3825	-0.879	0.114
	Rhizomatous herbs – vigorous	EVD*Fires	-0.7046	-1.214	-0.196
	Ephemeral herbs	EVD*LastFireTyp	0.1687	-1.320	1.658
Analysis 2	Canopy trees	Null	1.9912	1.817	2.165
	Serotinous obligate seeder shrubs	EVD	3.3858	1.919	4.853
	Obligate seeder shrubs – long juvenile	EVD	-1.6487	-2.369	-0.929
	Obligate seeder shrubs – short juvenile	EVD*FireHist	2.8635	1.293	4.434
	Resprouter shrubs – long juvenile	EVD	1.1809	0.726	1.635
	Resprouter shrubs – short juvenile	EVD	0.9695	0.480	1.459
	Obligate seeder herbs	EVD*MinTFI	0.3409	-0.506	1.188
	Resprouter herbs	Null	2.1127	1.866	2.359
	Rhizomatous herbs – vigorous	EVD*MinTFI	-1.2596	-2.449	-0.070
	Ephemeral herbs	EVD	-1.0219	-1.537	-0.507

3.1.3 Relationships between plant functional types and fire history

Obligate seeder shrubs with long-lived seed reserves and short periods to reproductive maturity

The time since fire model had the most evidence as a predictor of occurrence for this plant functional type. The analysis for EVD 7 showed the highest occurrence (~80%) of these plants was at sites in the early years following fire, dropping to ~40% at sites 40 years post-fire (Figure 5). For EVD 3 no differences were detected between sites with different periods since fire (Figure 5). For species in this group see Appendix 2.
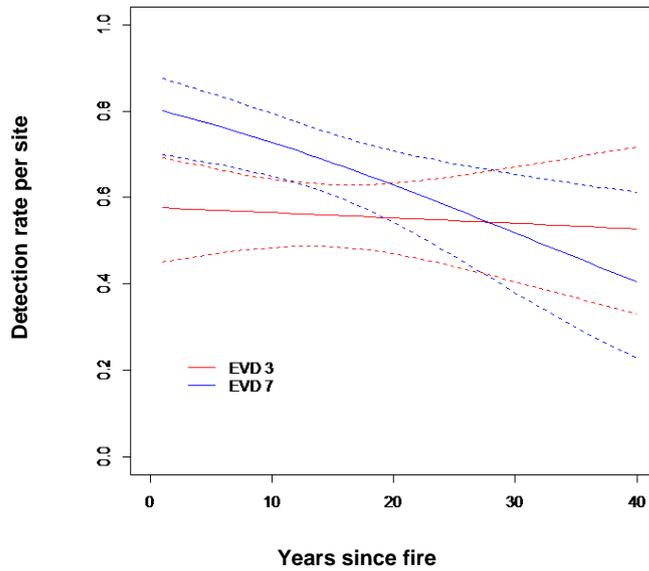
Figure 5: 'Obligate seeder shrubs – short juvenile', occurrence per site and time since fire (with 95% CI) and interaction with EVD

Obligate seeder shrubs with seed reserves exhausted by disturbance and long periods to reproductive maturity

The time since fire model had the most evidence as a predictor of occurrence for this plant functional type. The analysis for EVD 7 showed a weak trend for higher occurrence of these plants at sites some decades after fire (Figure 6). There were fewer species representing this functional type and they were at much lower densities than other shrub species. For EVD 3 there were negligible numbers of these plants recorded at our sites. For species in this group see Appendix 2.
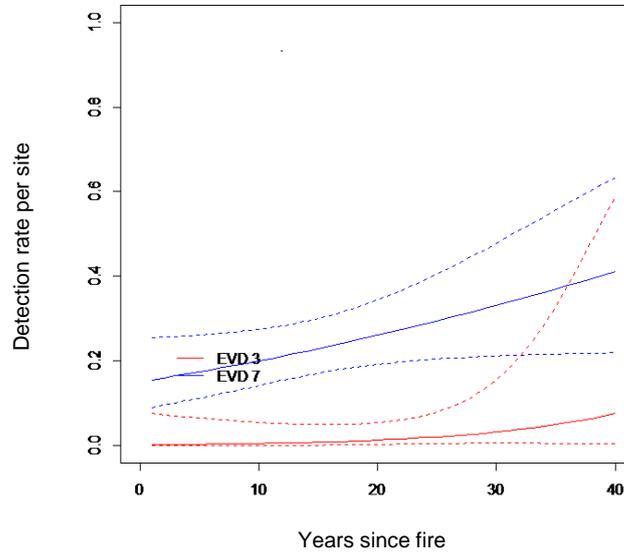
Figure 6: 'Serotinous obligate seeder shrubs', occurrence per site and time since fire (with 95% CI) and interaction with EVD

Obligate-seeder herbs

The time since fire model had the most evidence as a predictor of occurrence for this plant functional type. In EVD 7, the presence of these species declined from ~ 80% following fire to ~40% at sites 40 years post-fire (

Figure 7). In EVD 3 there was also reduced visible occurrence of obligate-seeder herbs at sites with longer times since fire (

Figure 7). For species in this group see Appendix 2.
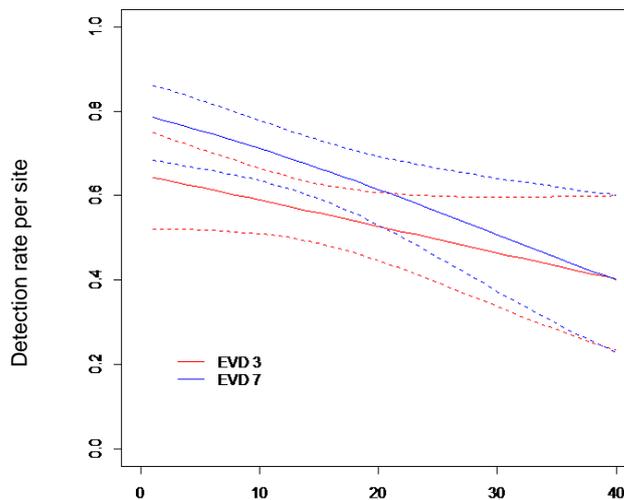
Years since fire

Figure 7: 'Obligate seeder herbs', occurrence per site and time since fire (with 95% CI) and interaction with EVD

Rhizomatous vigorously resprouting herbs

The fire frequency model had the most evidence as a predictor of occurrence for this plant functional type. Our results for EVD 3 showed a higher occurrence of these plants at sites with three or more fires since 1970 (Figure 8). For EVD 7 there was a high occurrence of these species at all sites regardless of fire frequency (Figure 8). This plant functional type was also the only one to show a relationship with minimum Tolerable Fire Interval (TFI). For EVD 3 there was a higher occurrence of these plants at sites where fire occurred at less than the minimum TFI (Figure 9).

Number of fires since 1970
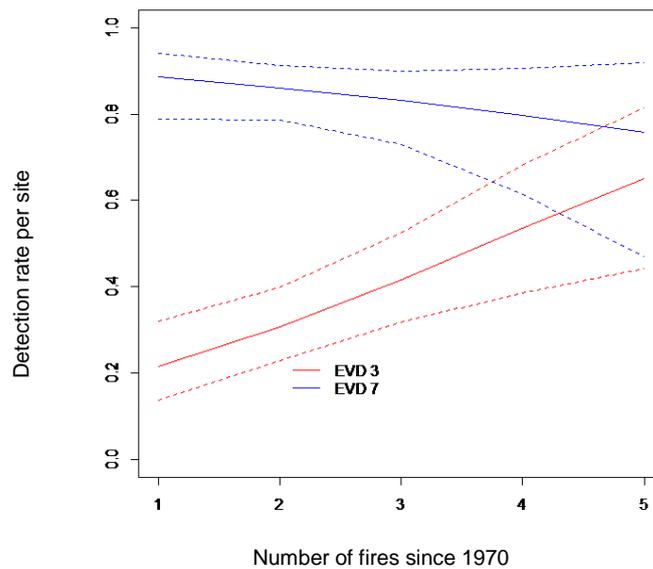
Figure 8: 'Rhizomatous herbs – vigorous', occurrence per site and fire frequency (with 95% CI) and interaction with EVD.
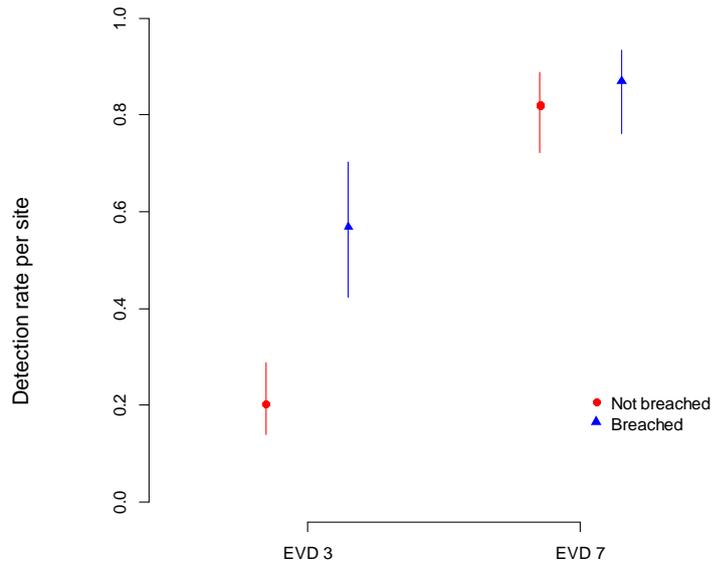
Figure 9: 'Rhizomatous herbs – vigorous', occurrence per site in relation to minimum Tolerable Fire Interval and EVD

3.2 Diurnal birds

3.2.1 Bird data summary

There were 88 bird species detected across 125 sites during the 20 min / 2 ha surveys and an additional 11 species recorded off-site during surveys or as incidental records (Table 24 in Appendix 3). Emu was the only additional species detected via camera surveys (from one site). Six additional species were detected from sound recordings (Little Corella, Little Lorikeet, Little Raven, Little Wattlebird, Scarlet Honeyeater, Tree Martin). Species widely distributed across sites were White-throated Treecreeper (93% of all sites), Spotted Pardalote (85%), Brown Thornbill (85%), Yellow-faced Honeyeater (82%), Striated Thornbill (67%), Grey Fantail (65%), Grey Shrike-thrush (55%) and Red Wattlebird (54%). Three species were found in few sites using 20 min / 2ha surveys (Superb Lyrebird (11% of all sites), Wonga Pigeon (12%) and Spotted Quail-thrush (14%)) but results from camera data showed a markedly higher prevalence (respectively 48%, 53% and 39%).

A total of 19 bird guilds (5 nesting guilds, 12 feeding guilds and two habitat guilds) were represented on-site and one additional habitat guild (birds that either feed or nest near water) was detected from off-site records (Table 16). Fifteen of the guilds were detected at more than 25% of counts and were considered for GLMM to explore possible trends associated with fire regimes (Table 16). Guilds that were more sparsely distributed across sites included those comprising fewer species (Table 24) and those whose habitats were uncharacteristic of the habitats represented on the study sites (e.g. birds of open-county and aerial feeding birds).

Table 16: Detection of bird guilds across 344 x 20 minute / 2 hectare surveys

See (Table 25 in Appendix 3) for a description of bird guilds.

Guild	# of counts detected	% of counts detected	Modelled response
Nesting			
Ground	236	69	Yes
Large hollow	171	50	Yes
Small hollow	265	77	Yes
Vegetation	339	99	Yes
Outside Victoria	1	0	No
Feeding			
Insect – air	5	1	No
Insect – bark	258	75	Yes
Insect – canopy	313	91	Yes
Insect – damp ground	160	47	Yes
Insect – open ground under trees	163	47	Yes
Insect – open ground far from cover	9	3	No
Insect – low shrubs	3	1	No
Insect – trees / shrubs	270	78	Yes
Seeds from near ground	24	7	No
Frugivore	100	29	Yes
Nectarivore	274	80	Yes
Carnivore	191	56	Yes
Habitat			
Forest	343	100	Yes
Open	17	5	No

3.2.2 Observer variation

The mean detection of birds per count varied between observers from 11.6 to 18.9 birds per 20 min / 2 ha count (Table 17). Observers 1 & 4 counted notably more birds per count than the other observers.

Table 17: Summary statistics of individual birds detected per count by each of seven observers

Observer	# counts	Av	Max	Min	St.dev.
1	32	18.9	49	5	11.2
2	36	17.4	39	4	9.9
3	31	11.6	18	5	4.0
4	31	19.3	38	7	7.8
5	100	14.7	33	2	7.7
6	87	14.3	41	1	7.9
7	27	15.2	43	4	9.1

3.2.3 Models of bird guilds and fire regime

The element of fire regime that predictived changes in the density of bird guilds most strongly was fire frequency. This relationship was negative for nectarivores (Figure 10) and positive for carnivores and for birds feeding on insects on the open ground under trees (Table 18). Time since fire had a muted relationship with the birds feeding on insects on the open ground under trees, with the lowest densities detected in sites that had no fire since 1970. Limited or no relationship with time since fire was evident for the remaining guilds. Sites that had at least one inter-fire interval below the Tolerable Fire Interval were associated with lower densities of ground nesting birds (Figure 12) and nectarivores. Fire type showed a weak negative relationship for birds feeding on insects from open ground under trees (fewer birds following bushfire compared with planned burns), but no relationships were evident for other bird guilds.

Seasonal changes in the abundance of small hollow nesting birds and birds feeding on insects on ground under trees were detected with fewer birds in those guilds observed in the second survey season (Figure 13) whereas carnivores were found to increase over the same period. Marked differences in bird community assemblage were associated with region. Several guilds were more abundant in sites north of the Great Dividing Range, except for birds feeding on insects on damp ground under trees which were in greater numbers in Gippsland (Table 18 & Figure 13). Differences in the bird community assemblage were also associated with EVD. This was driven by changes in density of frugivores (Figure 14) and to a lesser extent on birds feeding on insects on bark (Figure 11) and birds feeding on insects on damp ground under trees. Observation variability was also influential in predicting differences in the apparent density of several guilds (Table 18).

Summaries of GLMMs are provided in the Appendix 3 (nesting guilds: Table 26, feeding guilds: Table 27, and habitat guilds: Table 28). They show that there were no single best models to predict changes in the density of bird guilds: all guilds had more than one model within 2 AIC of the best model. The best model for the vegetation nesting guild and for the forest bird habitat guild explained about 70% of the variation in the data through differences in observers and region (Table 26 & Table 28 respectively). Models for other guilds explained from ~10% to ~60% of the variation in the data, with the least deviance explained associated with guilds comprising fewer species reflecting the paucity of data for modelling the responses of those guilds.

Table 18: Summary of variables predicting density of bird guilds from General Linear Mixed Models

See Bird methods (Table 10) for explanation of predictor variables and Appendix 3 (Table 25) for description of bird guilds.

Guild	EVD 7	Fire Frequency	FF x EVD 7	Below TFI	Fire Type (bushfire)	Season (Year 2)	Region (North east)	Observer
Nesting								
Ground				↓				
Large hollow								Y
Small hollow						↓	↑	
Vegetation								Y
Feeding								
Insect - bark	↓		↓				↑	
Insect - canopy							↑	Y
Insect – damp ground	↑						↓	
Insect – open ground		↑			↓	↓	↑	
Insect – trees / shrubs								
Frugivore	↓							
Nectarivore		↓		↓				
Carnivore		↑				↑		Y
Habitat								
Forest							↑	Y
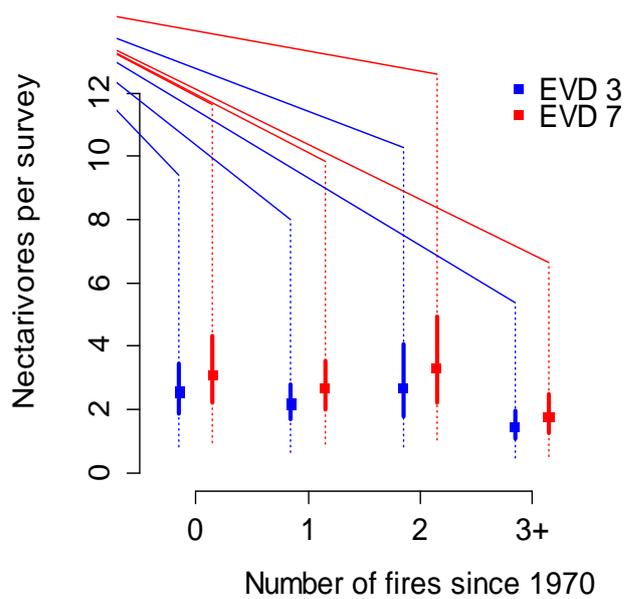
Figure 10: Predicted mean density of nectarivores per 20 min / 2ha bird survey in relation to fire frequency and vegetation type

Points represent the GLMM estimated bird density in Grassy / Heathy Dry Forest (EVD 3) and Tall Mixed Forest (eastern) (EVD 7) with their associated 95% confidence intervals (thick lines) and prediction intervals (dotted lines). Confidence intervals are for the expected values (means) for fixed effects only and prediction intervals account for the random effects (site and landscape), the latter indicating substantial variation in predicted mean bird density in areas beyond the study area.
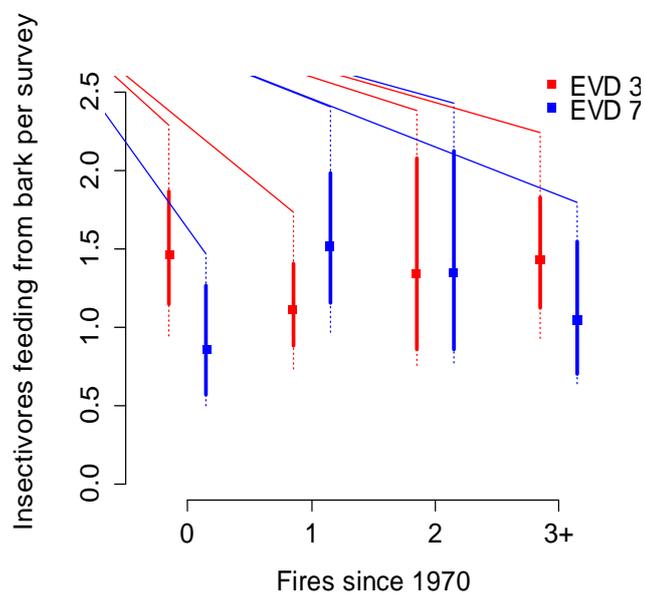
Figure 11: Predicted mean density of birds feeding on insects on bark per 20 min / 2 ha survey in relation to vegetation type interacting with fire frequency since 1970

Points represent the GLMM estimated bird density in Grassy / Heathy Dry Forest (EVD 3) and Tall Mixed Forest (eastern) (EVD 7) with their associated 95% confidence intervals (thick lines) and prediction intervals (dotted lines). Confidence intervals are for the expected values (means) for fixed effects only and prediction intervals account for the random effects (site and landscape), the latter indicating greater variation in predicted mean bird density in areas beyond the study area.
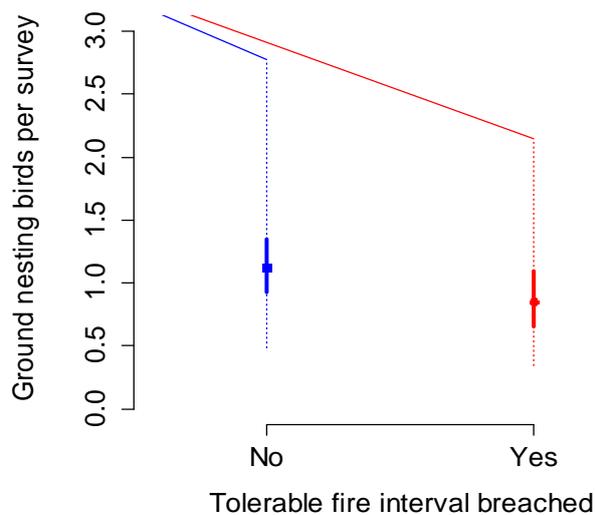
Figure 12: Predicted mean density of ground nesting birds per 20 min / 2 ha survey in relation to Tolerable Fire Interval

Points represent the GLMM estimated bird density with successive fires above TFI (blue) compared to success fires below TFI (red) with their associated 95% confidence intervals (dotted lines) and prediction intervals (thin lines). Confidence intervals are for the expected values (means) for fixed effects only and prediction intervals account for the random effects (site and landscape), the latter indicating greater variation in predicted mean bird density in areas beyond the study area.
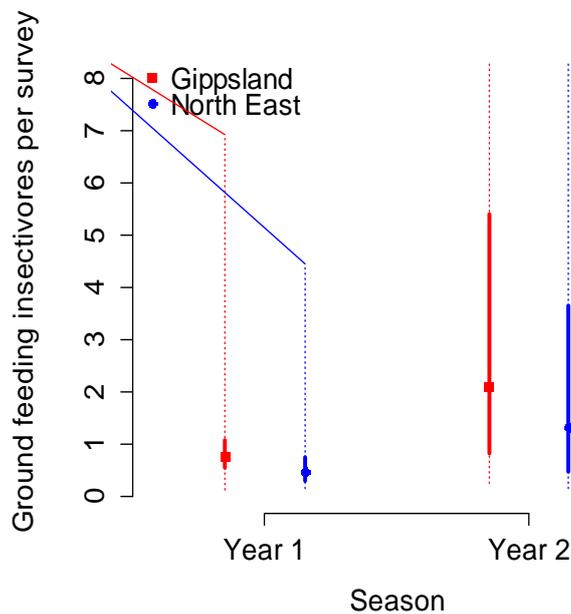
Figure 13: Predicted mean density of birds feeding on insects on damp ground under trees per 20 min / 2 ha survey in relation to region and season

Points represent the GLMM estimated bird density with their associated 95% confidence intervals (thick lines) and prediction intervals (dotted lines). Confidence intervals are for the expected values (means) for fixed effects only and prediction intervals account for the random effects (site and landscape), the latter indicating greater variation in predicted mean bird density in areas beyond the study area.
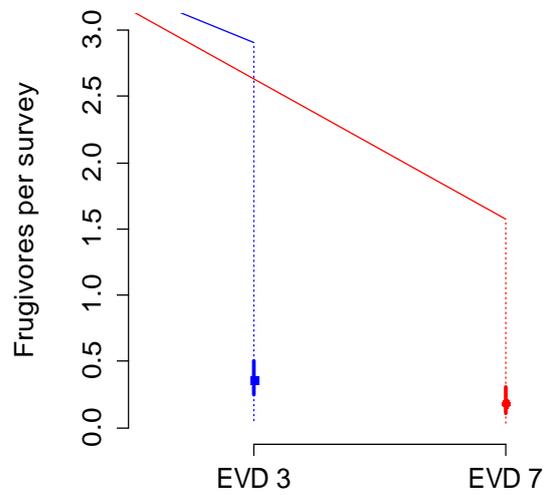
Figure 14: Predicted mean density of frugivores per 20 min / 2 ha survey in relation to vegetation type

Points represent the GLMM estimated bird density in Grassy / Heathy Dry Forest (EVD 3) and Tall Mixed Forest (eastern) (EVD 7) with their associated 95% confidence intervals (thick lines) and prediction intervals (dotted lines). Confidence intervals are for the expected values (means) for fixed effects only and prediction intervals account for the random effects (site and landscape), the latter indicating greater variation in predicted mean bird density in areas beyond the study area.

3.3 Ground-dwelling mammals

3.3.1 Camera data summary

A total of 7,444 trap days produced 22089 animal photographs. Twenty-three mammal species were detected (Appendix 4, Table 29). A number of non-mammal vertebrates were also detected, most notably Lace Goanna (48% of sites), Superb Lyrebird (48% of sites) Spotted Quail-thrush (39% of sites) and Wonga Pigeon (53% of sites) were recorded. Figure 15 shows sample imagery of mammals recorded by automated cameras in this project.

Figure 15: Examples of animals captured by automated cameras in this study

A) Black Wallaby (*Wallabia bicolor*), B) Eastern Pygmy Possum (*Cercartetus nanus*), C) Southern Brown Bandicoot (*Isodon obesulus*), and D) Long-footed Potoroo (*Potorous longipes*).

3.3.2 Model fit, occupancy and detection probability estimates

For most species the simulated sampling distribution for the Pearson χ2 statistic was larger than the observed value in at least 10% of simulations on at least 0.1 occasions, suggesting that the full model's fit of the data was not poor (Table 19). The exceptions were for Eastern Grey Kangaroo, Long-nosed Bandicoot and Long-nosed Potoroo where model fit was poor.

Table 19 shows the occupancy detection probability estimates for selected species recorded in this study. Occupancy estimates were generally similar to the naïve occupancy for most species with the exception of Short-beaked Echidna and Eastern Grey Kangaroo. Those species also had low daily detection probabilities, suggesting that the 21 day survey period was too short to survey them with confidence. For the other species

in Table 19, daily detection probabilities were high (0.11 – 0.36), suggesting a high overall probability (0.91 – 0.999) of detection during the 21 day survey period.

Table 19: Occupancy (Ψ), detection probability (*p*) and goodness-of-fit estimates (GOF) for selected species detected by camera traps.

Species	Ψ ± SE	*p* ± SE	GOF
Short-beaked Echidna	0.64 ± 0.09	0.06 ± 0.01	0.192
Agile Antechinus	0.29 ± 0.05	0.17 ± 0.02	0.354
Common Wombat	0.77 ± 0.05	0.12 ± 0.01	0.417
Long-nosed Bandicoot	0.21 ± 0.05	0.11 ± 0.02	0.017
Mountain Brushtail Possum	0.40 ± 0.06	0.11 ± 0.01	0.265
Common Brushtail Possum	0.64 ± 0.05	0.24 ± 0.01	0.329
Long-nosed Potoroo	0.07 ± 0.03	0.19 ± 0.01	0.002
Eastern Grey Kangaroo	0.17 ± 0.06	0.05 ± 0.02	0.003
Black Wallaby	0.88 ± 0.04	0.24 ± 0.01	0.212
Bush Rat	0.57 ± 0.05	0.36 ± 0.01	0.854
Superb Lyrebird	0.49 ± 0.08	0.19 ± 0.01	0.156

3.3.3 Relationship between occupancy and fire history

There was no evidence that occupancy was related to either time since fire or fire frequency for any mammal species in this study. Appendix 4 contains more detail of model outputs. The only predictor of occupancy in mammals was for the Common Brushtail Possum which had a lower probability of occupancy in EVD 7 than EVD 3. There was an interaction between fire frequency and EVD for the Superb Lyrebird where the probability of occupancy declined with the number of fires in EVD 7 but not in EVD 3.

3.3.4 Relationship between detection probability and fire history

Table 20 shows a summary of the variables found to predict detection probability. All of the modelled variables and their interactions predicted detection probability in at least one species. Of the fire variables the number of fires since 1970 had a negative influence on detection probability of Black Wallaby. Time since fire also negatively influenced detection probability in this species but had a positive influence for Bush Rat. EVD also influenced detection probability. Long-nosed Bandicoot was more detectable in EVD 7 whereas Common Brushtail Possum and Black Wallaby were more detectable in EVD 3. There were also a number of interactions between variables that predicted detection probability.

Table 20: Summary of variables predicting detection for selected species detected by camera traps.

Species	Easting	EVD 7	No. of fires	TSF	EVD 7 x # fires	EVD 7 x TSF	# fires x TSF	# fires x TSF x EVD
Short-beaked Echidna								
Agile Antechinus	↑				↑	↑		↑
Common Wombat					↑			
Long-nosed Bandicoot		↑						
Mountain Brushtail Possum								
Common Brushtail Possum		↓			↑			↓
Long-nosed Potoroo	↓						↑	
Eastern Grey Kangaroo	↑					↓		
Black Wallaby	↓	↓	↓	↓	↑	↑		
Bush Rat				↑	↑	↑	↓	↓
Superb Lyrebird							↑	

4. Discussion

4.1 Vascular flora

4.1.1 Relationships between plant functional types and fire variables

Our results provided support for our initial predictions about the relationships of fire variables with some plant functional types considered to be sensitive to fire intervals. Results for the shrub species varied between the two EVDs, reflecting environmental differences.

Plants from the 'obligate seeder shrubs – short juvenile' group were predicted to respond positively to frequent fire because they have long-lived seed reserves and short periods to reproductive maturity (Gill and Catling 2002, Bradstock and Kenny 2003). The analysis of our data for this functional type in EVD 7 supported this prediction, with the highest occurrence of these plants at sites in the early years following fire. Morrison *et al.* (1995) also found decreases in members of this functional type with time since fire. Although less detectable at sites representing longer times since fire, viable seed for shrubs of this functional type may persist in the soil for decades (Orscheg and Enright 2011). For EVD 3 no differences were detected between sites with different periods since fire. This may be explained by the open nature and low growth rates of these forests, which reduce competitive effects of other shrubs. Common species in this group were *Acacia terminalis*, *Cassinia longifolia* and *Rhytidosporum procumbens*.

The 'serotinous obligate seeder shrubs' group was predicted to be most vulnerable to repeated frequent fires because their seed reserves are exhausted by disturbance and they have long periods to reproductive maturity (Gill and Catling 2002, Bradstock and Kenny 2003). The analysis of our data for this functional type in EVD 7 showed some support for this prediction, with a weak trend for higher occurrence of these plants at sites some decades after fire. Other Australian studies have shown increases in abundance of *Banksia* species (members of this functional type) with time since fire (Morrison *et al.* 1995, Duff *et al.* 2013). The increased detection rate at longer times since fire in our study may reflect an increase in size of individuals rather than increased numbers. These older and larger plants are essential to building up canopy seed-banks for population replacement, as the oldest individuals have the largest store of elevated and viable seed (Jenkins *et al.* 2010). There were fewer species representing this functional type and they were at much lower densities than other shrub species. The most common representatives in this group were *Allocasuarina littoralis* and *Hakea decurrens* subsp. *physocarpa*. *A. littoralis* is an example of the difficulty in categorising taxa into single functional types. In a NSW study of the effects of timber harvesting and planned burning, this species was classified as predominantly resprouting after disturbance because fire severities were low (Penman and York 2010). For EVD 3 there were negligible numbers of these plants recorded at our sites.

Obligate seeder herbs were expected to be more common at recently burnt sites because they grow and produce seed quickly after fires, and this response has been observed in other studies (e.g. Keith *et al.* 2007). This relationship was reflected in our analyses, with high occurrence in the early years following fire and reduced occurrence with longer times since fire. The species are often small in stature and competition from taller resprouting herbs and from shrubs may be a factor in this reduction. Frequently occurring members of this group were *Comesperma volubile*, *Glycine clandestina*, *Gonocarpus teucrioides s.s.* and *Opercularia varia.*

Plants such as *Tetrarrhena juncea* Forest Wire-grass and *Pteridium esculentum* Austral Bracken ('rhizomatous herbs – vigorous' group) are commonly assumed to be advantaged by frequent fire, because they have vigorous vegetative regeneration and are able to quickly exploit the more open conditions after fires. The higher occurrence of these plants at sites with three or more fires since 1970 in EVD 3 appears to provide support for frequent fire being advantageous for these plants. For EVD 7 the high occurrence of these species at all sites regardless of fire history may have been influenced by logging history, with the associated use of regeneration burns. However, research into the effects of repeated low-intensity fire in mixed-species foothill forest in central Victoria revealed differing trends for these two species (Tolhurst 2003). Result from that study found that repeated fire at approximately three-year intervals led to a decrease in cover of *T. juncea*, whereas the response of *P. esculentum* varied according to season of burn. It is difficult to make direct comparisons between these results, because our study sites had longer fire intervals and frequency of

species occurrence was measured, whereas the study by Tolhurst (2003) had shorter repeat fire intervals and estimated cover of the species.

Predictions for shrubs in the 'obligate seeder shrub – long juvenile' group were difficult to make because although times to reproductive maturity after fire are relatively long, there is uncertainty about seed longevity. Results from our analyses did not provide evidence for relationships to fire variables.

As expected, the analyses of a number of other plant functional types did not provide evidence for variation in occurrence in relation to fire variables. The canopy tree species in the target EVDs are resprouters and the fires in recent decades in the study area have largely been fuel reduction burns which do not generally result in dense seedling regeneration, as the mature trees survive the fires. Furthermore, these taxa typically have very long generation times and changes in establishment or survival due to recent fire regimes would take many decades to become apparent. Resprouter shrubs are able to quickly re-establish vegetatively after fires, and hence their presence is less affected by fire intervals. However, other studies have found a decline in abundance of resprouter shrubs with short inter-fire intervals (Knox and Clarke 2005). The resprouter herb group was dominated by tussock grasses, geophytes and long-lived graminoids which are adaptable to different fire intervals, either through avoidance (e.g. geophytes) or well-protected buds (e.g. tussock grasses). Results for ephemeral herbs were considered unreliable because seasonal conditions at the time of survey can greatly affect and essentially determine their presence and visibility at a site. Introduced plants were primarily herbs, and were recorded at too few sites for useful analysis. Many of these were annual plants for which abundance or detectability is dependent on seasonal conditions.

All of the results are based on the recording of above-ground plant parts, which does not take into account the longevity of soil-stored seeds, which are essential for the survival and future abundance of many plant species. Determining soil seed stores, including their longevities, is notoriously difficult, but this is essential if we are to manage these vegetation types in the long term, using fire.

Limitations

A number of factors place limitations on the conclusions that can be drawn from this study. Fire history records are variable in quality and frequently do not include patchiness, which may result in an overestimation of the amount of fire. Fire severity and intensity have not been part of the fire records. The assumed distinction in severity between fires defined as 'bushfire' or 'planned burn' in the *FireHAT* database is not always clear (e.g. bushfires deriving from planned fires). Although the sites selection procedures avoided areas with a history of logging in the past 20 years, it is likely that some logging disturbance was not mapped. The low number of species and sites for the 'serotinous obligate seeder shrubs' group may be a consequence of past unmapped fire disturbance, including regeneration burns following clear-felling which have not been well mapped historically. Lack of knowledge about the longevity of soil seed-banks affects the interpretation of the presence of the 'obligate seeder shrubs – short juvenile' group, and the facility with which other species also regenerate from seed. The grouping of 550 taxa into plant functional types was difficult for taxa where resprouting or seed germination responses vary according to fire severity, and in these cases the most common response was selected. The vegetation types under study are expected to be relatively fire adapted and so the results from this study may not necessarily be translated to other more fire sensitive vegetation types or locations.

4.2 Diurnal birds

4.2.1 Relationships between bird guilds and fire variables

Fire frequency

Of the two elements of fire regime considered in this study, fire frequency appears to have the most noticeable relationship with the density of birds, particularly for nectarivores (dominated by honeyeaters). The density of birds in this guild was 43% lower in sites with three or more fires in a 40 year period compared with sites that were unburnt over that same time. Sites with one or two fires showed no significant differences in nectarivore density compared with longer unburnt sites. This suggests a threshold of decline in nectarivores only where three or more fires occur within a 40 year period. Nectar feeding birds are highly mobile in response to flowering events and foraging opportunities would be limited by canopy scorch from fire during

the flowering period (Law *et al.* 2000) This can result in mass exodus of these birds after severe bushfire (Loyn 1997). Canopy scorch in these forests occurs from high intensity fires and so is less likely to result from planned fire (which is usually intended to reduce fuel loads in the lower strata vegetation, generally leaving the canopy intact). However, lack of a signal in this dataset contrasting the effects of bushfire to planned fire may suggest that high fire frequency, independent of severity, is of concern and possibly relates to loss of foraging resources from nectar producing lower strata vegetation. An alternative explanation is that the classification of fires in the *FireHat* database is unreliable and planned fires often mimic bushfires in severity and intensity. Detrimental effects of frequent fires on birds have also been reported in heathy forests in New South Wales and wet montane forests in the Central Highlands of Victoria (Recher 2005, Lindenmayer *et al.* 2010).

Conversely, the current study also demonstrated positive effects of fire frequency for two guilds (carnivores and insectivores that feed from open ground among trees), though these were not as strong as the negative model for nectarivores. Carnivores have often been found to respond positively in the short term to individual fires, especially in northern Australia (Woinarski and Recher 1997) and to a lesser extent in East Gippsland (Loyn 1997) in response to increased prey availability (carcasses/injured animals) post fire and improved hunting success over open ground. Insectivores that feed from open ground below trees are known to respond positively to bushfires in the short term but then decline as shrubs regenerate (Loyn 1997). Their positive response overall suggests that in the areas represented by these study sites, fire regimes may have done more to open up the forest understorey than to establish areas too dense for this guild. Further evidence and modelling are needed to establish whether this would be true of fire regimes elsewhere or in the future.

A surprising result from the camera surveys in this study was that the probability of occupancy for the Superb Lyrebird was lower with more frequent fire in EVD 3, but not in EVD 7. There have been few published studies of how this species responds to fire, or other disturbance. In contrast to our findings previous studies have suggested that this species might benefit from frequent fire as this can eliminate Forest Wire-grass (Cowley *et al.* 1969, Catling and Newsome 1981, Suckling and MacFarlane 1983) and enhance production of *Acacia* seeds (Catling and Newsome 1981). Superb Lyrebirds have been shown to recolonise areas within two years of an extensive bushfire (Hodgson and Heislers 1972, Loyn 1985), and to survive an extensive severe bushfire in East Gippsland (Loyn 1997). It has also been found that Superb Lyrebirds return to an area about six years post logging and generally become more abundant as the shrub layer develops, as do other species with similar foraging requirements (damp ground below taller shrubs) (Loyn 1985). However, (Hingston and Grove 2010) found that lyrebirds were most common in mid-aged regrowth (42-43 years after clearfelling) in Tasmania. It is possible that frequent fire reduces foraging opportunities for Superb Lyrebirds, in EVD 3. However, further work is required to determine the mechanism by which fire frequency mediates occupancy in this species and also why it operates in one vegetation community (EVD 3) and not in another (EVD 7). To our knowledge this is the first study to report on lyrebird occupancy using remote cameras as this is not a standard technique for this species. The results from this study should therefore be interpreted with caution. It is likely that these birds were not attracted to the bait but rather the cleared area in from of the camera, which may provide enhanced forging opportunities. Indeed, the photographs suggest that unlike most mammal species Lyrebirds did not investigate the bait station. It is notable however that cameras detected lyrebirds at more sites than the 2ha area count employed for bird surveys in this study.

Fire interval

Shorter inter-fire intervals were associated with fewer ground nesting birds including Spotted Quail-thrush and Spotted Pardalote. Areas where successive fires occurred below the minimum Tolerable Fire Interval (TFI) at least once in the last 40 years had a 25% lower density of ground nesting birds compared with areas with a fire history consistently above minimum TFIs. The drop in density may relate to changes in the ground flora composition, stemming from an increase in the occurrence of Forest Wire-grass and Austral Bracken at sites burnt below the minimum TFI (see section 4.1.1). While vegetation cover is an important facet of protection of ground nesting birds from predation (Colombelli-Négrel and Kleindorfer 2009), the type of cover afforded by Forest Wire-grass and Austral Bracken may be less suitable than other species of ground flora. Nectarivores were the only other guild showing a significant negative relationship to successive fires occurring below the minimum TFI, suggesting that nectar producing flora may have been reduced in those sites, or that nectar flows may be less in younger plants. Further investigation is needed to unravel these possible relationships between bird density and changes in habitat suitability arising from fire history but the results from this study

show that successive fires occurring below the minimum TFI are negatively associated with the abundances of at least two bird guilds.

Time since fire

Time since fire was not informative in explaining changes in the variation in bird density across sites. This result contrasts with other research (Loyn 1985, Woinarski 1999, Paton *et al.* 2005, Recher 2005, Campbell *et al.* 2011, Bradshaw *et al.* 2013) reporting marked responses of birds in both a positive and negative sense to time since fire. Any effect of time since fire on the density of bird guilds may have been obscured by other elements of fire regime (e.g. severity, patchiness), observer, seasonal and regional variation which may have overwhelmed underlying trends associated with time since fire. Longitudinal studies of fire effects on birds have shown that seasonal variation (such as periods of drought and rainfall) heavily influences changes in bird abundance post fire (Paton *et al.* 2005) and highlights the need to monitor sites through time to elucidate possible trends that might otherwise be masked by factors specific to a study's snapshot in time. Elsewhere in the world species level responses to fire within a guild have been found to be inconsistent, with disturbance tolerant species replacing intolerant species following repeated fires (Bradshaw *et al.* 2013). This suggests that further investigation of the current data at a species level may be better at detecting trends than the current guild level analyses.

4.3 Ground-dwelling mammals

4.3.1 Relationships between ground-dwelling mammals and fire variables

We initially predicted that most mammal species would show an increase in probability of occupancy with increasing time since fire. However, for the forest types in this study, we found no evidence that time since fire had any influence on the probability of occupancy for the 10 mammal species modelled. Furthermore, we made the consequential prediction that the probability of occupancy for most mammals would decline as fire frequency increases. Again we did not find any evidence that fire frequency affects probability of occupancy for the mammals modelled in this study. EVD was a significant predictor of occupancy for the Common Brushtail Possum, which was more likely to occur in EVD 7 than EVD 3.

Black Wallaby and Common Wombat were found at a high proportion of sites (0.88 and 0.73 respectively) with little scope for variation in occupancy between sites with different fire histories. Therefore it is unsurprising that there were no associations with fire history for these species at the site occupancy level. It has been previously suggested that large wallabies have a preference for recently burnt sites in south east NSW (Catling *et al.* 2001); however a recent Victorian study suggested that this species is insensitive to time since fire (Macak *et al.* 2012). The Common Wombat has also been found at similar proportions of sites in burnt and unburnt forest (Macak *et al.* 2012) and therefore may also be insensitive to fire. However, it is possible that fire would influence activity patterns of these species. For example, Common Wombats were found to increase their home range after fire in response to food scarcity (Green and Sanecki 2006). Large animals such as wallabies and wombats have large home ranges (Menkhorst 1996), enabling them to occupy high proportions of sites even when populations may have been reduced.

Limitations

There are a number of possible reasons why we did not detect an effect of either time since fire or of fire frequency on native mammal occupancy in this study. It is possible that occupancy in the native mammals modelled in this study is not sensitive to fire history. It is also possible that occupancy does not vary with fire history and that animals respond to fire though changes in abundance or though altering their activity patterns (e.g. the wombat example above). Insight into how abundance varies with fire regime could be gained though analysis of relative abundance (intensity of use). However, analytical techniques for reliably deriving relative abundance from presence/absence data are not currently available. It is plausible that occupancy is a measure of relative abundance (MacKenzie *et al.* 2006), however, as the relationship between these two variables is unknown it is not possible to speculate on the nature of this relationship.The effect of fire on occupancy may also be too small for it to be detected in this study. This may be overcome by more intensive sampling, however (Robley *et al.* 2013) found that fire history did not predict native mammal occupancy across 124 sites (c.f. 89 sites in this study). A further possibility is that animals respond acutely to fire, i.e. within a short period after the fire and our site stratification did not allow us to detect this response.

In this study we used a space for time substitution design for studying the impact of fire on the biota. This approach is essentially a snapshot of the current situation and we have attempted to reconstruct the historical influence of different fire regimes. Therefore, any results are influenced by the prevailing climatic conditions at the time of survey and also the underlying spatial variation between sites. Both of these factors may obscure any signal from fire regime in the data. Long-term monitoring of sites is necessary to counter the influence of climatic conditions during one survey event (e.g. see Clarke 2008). Effects of spatial variation may be mitigated by smaller scale studies, limited in their geographic scope. This however, would mean that any inference about the impacts of fire could only be made across a smaller geographic area.

4.5 Implications for fire management

4.5.1 Flora

Our results provide some additional information for the TFI model for fire planning for East Gippsland. We have focussed on minimum TFIs because this is most relevant to current fire management issues. The minimum TFIs recommended by Cheal (2010) for EVD 7 are 8 years for low severity fires and 25 years for high severity fires. The recommended minimum TFIs for EVD 3 are 10 and 15 years for low and high severity fires respectively. These TFI recommendations are intended to be supplemented by site-specific knowledge.

The only statistically significant result for fires at less than the minimum Tolerable Fire Interval is for the plant functional type dominated by Forest Wire-grass and Austral Bracken. In EVD 3, there is a higher occurrence of these plants at sites where fire has occurred at less than the minimum TFI. This aligns with our results showing higher occurrence of these plants at sites with a larger number of recorded fires. However, interpretation of these results for fire management does not take into account changes in plant cover related to fire intervals (e.g. Tolhurst 2003).

Other groups considered to be sensitive to short fire intervals (e.g. 'serotinous obligate seeder shrubs') did not show significant results for fire at less than the minimum TFIs in our study. However, work in New South Wales shows that frequent fires disadvantage these plant functional types and are likely to lead to their decline (e.g. Bradstock et al. 1997). General TFI models used in planning fires need to be complemented by site-specific decisions about suitable fire intervals based on the occurrence of fire-sensitive species.

Monitoring the effects of increased fire on biodiversity is one of the key drivers of the Hawkeye project. The occurrence of 'obligate seeder shrubs – short juvenile' and 'rhizomatous herbs – vigorous' plant functional types is considerably higher at recently burnt sites. Different fire intervals may favour some species over others (Keith *et al.* 2007, Enright *et al.* 2012), and our study suggests certain plant functional types may become more dominant if short fire intervals become more widespread in the drier forests of East Gippsland. Further monitoring would be useful to assess whether there is a simplification of species richness in the shrub and ground layers in the longer term.

Given the short periods of time after fire (5 to10 years) when fuel hazard is considered low enough to have some effect on mitigation of bushfires (Price and Bradstock 2012), maintaining suitable fire intervals for biodiversity conservation is a challenge (Haslem *et al.* 2011). Some plant functional types (e.g. serotinous obligate seeder shrubs) are likely to require longer time intervals between fires to maintain populations. Increases in the abundance of taxa considered to contribute more to fuel loads (e.g. leguminous shrubs, Austral Bracken and Forest Wire-grass) may be an outcome of increased fire frequency (Cary *et al.* 2012). Our data suggest that fuel hazard may remain below maximum levels for several years after fire, despite the proliferation of Austral Bracken and Forest Wire-grass on some sites with frequent fires. This aspect needs to be examined further, in particular to identify any differences between effects of bushfire and planned burns on these influential plant species and their implications for fuel hazard.

4.5.2 Birds

A factor constraining many ecology studies is that causal relationships, in this case fire effects on birds, cannot necessarily be inferred from correlative evidence (Johnson 2002). Nevertheless, our observation that two diurnal bird guilds are disadvantaged by burning below the minimum Tolerable Fire Intervals for vegetation types studied accords with predictions, and with limited evidence from elsewhere. It seems likely that this is a causal relationship, and such effects can be expected in future in response to burning regimes that breach minimum Tolerable Fire Intervals. Similarly, our study suggests that there would be negative

consequences to fire regimes comprising more than two fires in a 40 year period, especially for the nectarivore guild, and positive consequences for other guilds (carnivores and insectivores that feed from open ground below trees). Further work is need to determine whether similar effects apply in vegetation types that are less adapted to fire such as along gullies and riparian areas which act as refuges for several bird species (Loyn 1997).

4.5.3 Mammals

As we were unable to detect an effect of fire history on site occupancy of ground-dwelling mammals in this study there are no clear implications for fire management for this taxonomic group. However, the lack of evidence from this study should not be taken to mean that mammals are not fire-sensitive or that they should not be considered in fire planning. Relative abundance is a more relevant measure to consider in future work, especially for wide-ranging species that show high levels of site occupancy. For example, modelling suggests that maximum abundance of small mammals might be achieved by having a high proportion of forest in the 11-34 year age class (Di Stefano *et al.* 2013). The negative effects of fire are more likely to be apparent in less fire-prone vegetation, and in vegetation which had not already been subject to frequent repeated fires over several decades). Gullies and similar 'damp' vegetation types develop and maintain important structural elements over extended periods without fires (Collins *et al.* 2012) and may act as refuges for a range of mammal species in the event of fires in adjoining habitats (Macfarlane 1988). In this study we did not survey arboreal mammals, but other studieshave shown that this group is likely to be negatively affected, particularly if fire reduces the number of hollow bearing trees (Inions *et al.* 1989).

4.6 Future research

4.6.1 Flora

The considerable amount of vascular flora data generated by this project could be used in further analyses. Investigating the responses of individual species to fire variables would be limited to those species which had sufficient site detections. Further inferences about the responses of plant functional types to fire, for EVD 3 and EVD 7 in other areas of Victoria or for other EVDs, could be gained by combining our dataset with flora data from the Victorian 'Statewide Landscape Fire and Environmental Monitoring Program' surveys, which were collected using the same method.

Broad studies such as this one can fail to detect changes to those species most sensitive to frequent fire because these species are often in low numbers due to past fire disturbance. Greater insights into the effects of fire on these species could be gained by demographic studies on recruitment of those species likely to be at risk from increased fire (eg. serotinous obligate seeder shrubs), and by resampling sites where these species have previously been recorded. Further insights could be obtained by analysing data already collected and stored in the Flora Information System (now the Victorian Biodiversity Atlas), building on exploratory work begun as part of this study.

One of the objectives of the Hawkeye component of this project is ongoing monitoring of a subset of sites. An advantage of this approach over space-for-time methods is that the effects of fire are not obscured by spatial variation.

The relationships between vegetation structure and plant functional types have not been explored in this project. Resources did not permit sufficient structural data to be collected for analysis, but it would be useful for future projects to collect more detailed data of this sort.

Non-vascular plants and lichens, which are considered to be sensitive to frequent fire, are rarely studied in relation to fire regimes. It would be useful to augment the data on lichen morphogroups already collected at the study sites, to verify our preliminary findings which indicated that lichens on some substrates had a negative relationship with time since fire.

4.6.2 Birds

Elsewhere diurnal forest birds have been adopted for research and monitoring purposes for their cost effectiveness and the relatively large datasets that can be efficiently generated (Kavanagh *et al.* 2004). This study has supported the use of diurnal birds as focal taxa particularly for the larger guilds such as

nectarivores. Guilds comprising fewer members require greater levels of survey effort to ensure that sufficient data are available to be confident of detecting possible trends arising from effects of fire.

Observer variation was influential in explaining differences between sites and was not accounted for through years of birding experience. The large number of sites in this study, and the need to undertake surveys within the peak breeding season, meant that the use of several observers was necessary. Nevertheless, in future studies using fewer observers would help to reduce the noise in the data arising from observer variation, whilst recognizing that all such data are an index of bird abundance and bird species presence, and not an absolute population determination.

This project gave some insights into study design issues, which can inform future research. Results on the effects of fire were somewhat limited by variation due to: (i) season (background climatic variability possibly a stronger influence than the biological legacy of fire); (ii) region (sites located across a wide geographic area and in two bioregions); and (iii) vegetation (responses of birds was not the same across different EVDs). This variation could be overcome by: (i) undertaking annual monitoring of sites; (ii) a geographically constrained study area and/or increased sampling effort; and (iii) increasing replication within EVDs.

The relationships between vegetation structure and bird occurence were not investigated explicitly in this project, though some data were collected on structural features of each site. It would be useful for future research to collect detailed structural measurements, to link the underlying changes in habitat structure directly to changes in bird density (Bradshaw *et al.* 2013).   Such information could help reveal ecological mechanisms that may mediate responses to fire regime (Loyn 2012) . This could help understand some of the variability caused by differences in individual fires, related to topography and weather during the fire and in subsequent regeneration phases. Our categorisation of fires as 'bushfire' or 'planned burn' was necessarily coarse, with great variation known to occur within each category. Species level analysis is also recommended to investigate the patterns of individual species that might be obscured by their guild classification (Bradshaw *et al.* 2013).

4.6.3 Mammals

Future studies (particularly those more restricted in their geographic scope) might benefit from using a mixture of field methods such as trapping to get an index of abundance for particular target species and remote cameras for a more general survey of the mammal fauna. Spotlighting surveys for arboreal mammals might also be considered, as this group contains a number of key fire response species (MacHunter *et al.* 2009); project resources did not permit collection of data on these animals in this study. Further work could include measures of activity or relative abundance at each site, especially for species with high rates of site occupancy. There is also ongoing work into establishing the relationship between occupancy and relative abundance with may allow for the re-analyses of the data presented in this report.

There is evidence that bat activity is lower in recently burnt forest compared to unburnt forest (Jemison *et al.* 2012). Results from analyses of the microbat data from the study sites showed relationships between bat activity and fire frequency for some species, which is likely to be influenced by differences in density and structure of vegetation. Measuring these variables against fire histories in studies that record corresponding microbat activity, could further elucidate the nature of this relationship.

4.7 Conclusion

The models generated by this study describe the responses of flora and fauna species or guilds/functional types to a range of fire regimes. In general, flora functional types responded as predicted to time since fire, in one or other EVD studied. Obligate seeder shrubs (with long-lived seed reserves and short periods to reproductive maturity) and obligate seeder herbs decreased with time since fire in EVD7. These groups would be expected to benefit from regimes of frequent fire, which reduce mean times since fire. Conversely, obligate seeder shrubs (with seed-banks exhausted by fire and long juvenile periods) increased with time since fire in EVD7, supporting the need for long fire intervals to set seed, as predicted. Vigorous rhizomatous herbs (Austral Bracken and Forest Wire-grass) increased with fire frequency in EVD3, and became most prevalent where fires had occurred at less than minimum Tolerable Fire Intervals. This supports the view that frequent fires may promote dominance of these species, with consequent effects on habitat structure (and observed negative effects on ground nesting birds).

For birds the strongest relationships related to fire frequency, with nectarivores responding negatively to frequent fires, and two other guilds showing weaker positive responses. Ground nesting birds were scarce at sites that had been burnt below the minimum Tolerable Fire Interval. Camera trapping revealed no significant effects of fire regime on site occupancy of mammals, but suggested that Superb Lyrebirds would be disadvantaged by frequent fires in EVD7. Detectability of mammal species varied with fire regimes (increasing with fire frequency for Black Wallaby and decreasing for Bush Rat) and may reflect responses of those species in terms of relative abundance rather than site occupancy.

Some caveats on these results should be noted. They relate specifically to two broad vegetation types in East Gippsland, and it is likely that different fire responses occur in other vegetation types. Whilst the sample size was relatively large, there are potential sources of error in the historical data used to select sites and characterise fire history, and in the sampling methods. It is unlikely that the pattern of events that influenced past outcomes (e.g. extent, duration and intensity of drought) will be the same pattern influencing future outcomes. The muted response of some taxa to fire regimes may also be partly a product of environmental variation and its effects on the precision of our models. The study examined a subset of the biota and so a precautionary approach is warranted to fire planning and implementation, taking account of other studies and future work dealing with groups such as lichens, fungi, owls, arboreal mammals, microbats and invertebrates. Monitoring to ensure that trends are consistent with this study could provide some level of confidence that similar outcomes will occur. Also, monitoring the species at most risk from fire, including serotinous obligate seeder shrubs, nectivorous birds and lyrebirds where they are likely to be affected by planned fire, could determine whether this predicted risk is realised.

There are some immediate implications for management from the results of this study. Frequent burning will benefit some plant and bird groups and disadvantage others (and probably also mammals). Hence it is important to continue generating a mix of fire regimes across the landscape, and a mix of age-classes. The concept of Tolerable Fire Intervals (Cheal 2010) has become an important plank in fire management (Platt et al. 2012), recommending inter-fire periods for broad vegetation types to maintain their constituent flora species and dependent fauna species. Burning more frequently than Tolerable Fire Intervals may benefit some vigorous rhizomatous herbs at least in EVD3, and have adverse effects on ground nesting birds. This should be avoided unless found necessary locally for compelling strategic reasons. The results will contribute to the key strategic goal of the Hawkeye program, which is to evaluate the risks and benefits associated with an increase in fire frequency resulting from planned burning.

The large database from this project will be used both for the ongoing Hawkeye monitoring program and in other related projects. Validation of the fire history layer would be useful to assist in precision of modelled relationships between fire and biodiversity. Further research is needed on species-level effects, examining changes in relative abundance not just site occupancy, of the most sensitive species, in order to evaluate and model a range of plausible fire management strategies across the landscape. Studies with more precise targeting of the effects of fire severity, rather than simply 'bushfire' and 'planned burn' delineation, are needed. Such research can help inform options for the conservation of biodiversity in the context of protection of human life and property.

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Appendix 1: Retrospective Project Database
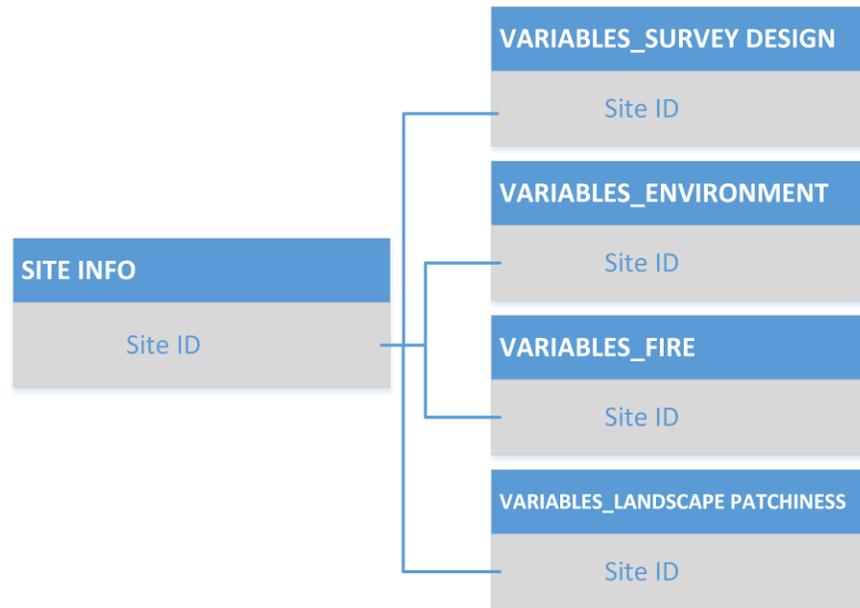
Figure 16. Database relationships for tables common to all groups
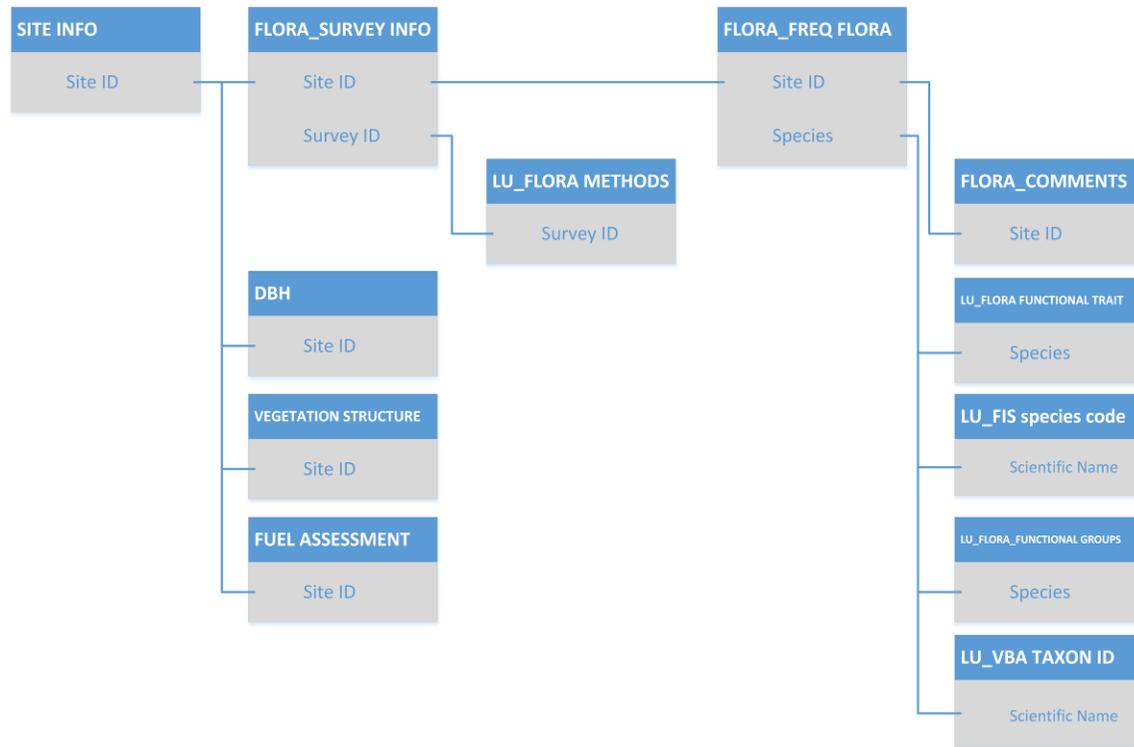
Figure 17. Database relationships for habitat assessment and flora survey tables
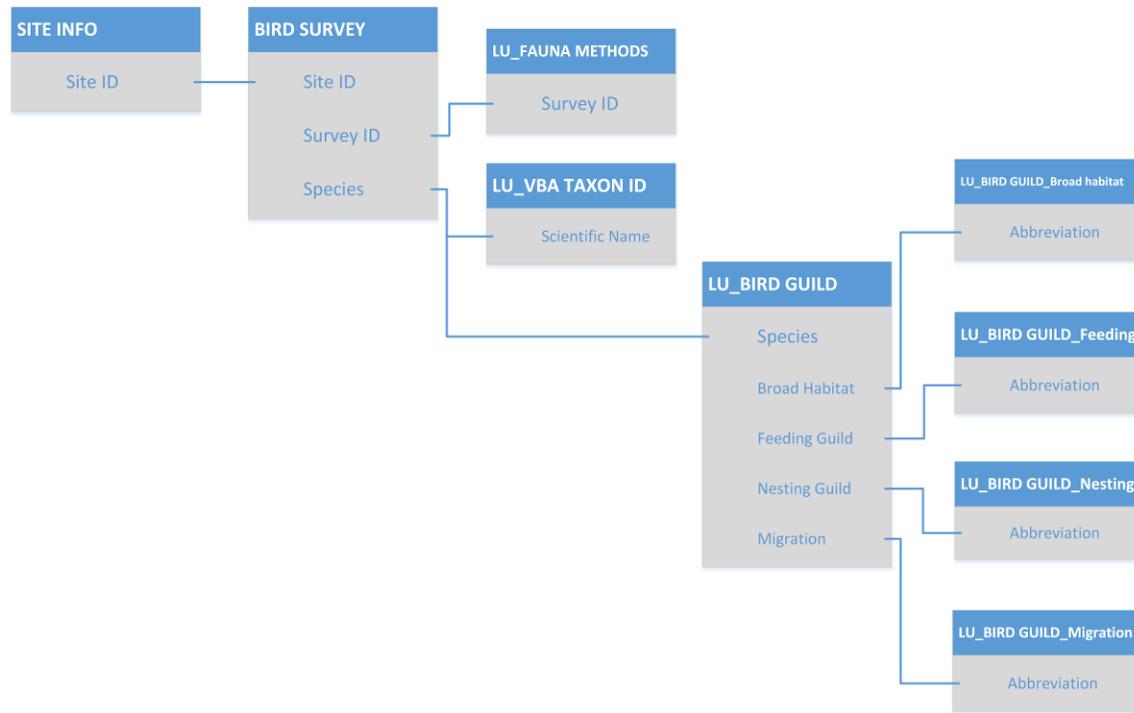
Figure 18. Database relationships for bird survey tables
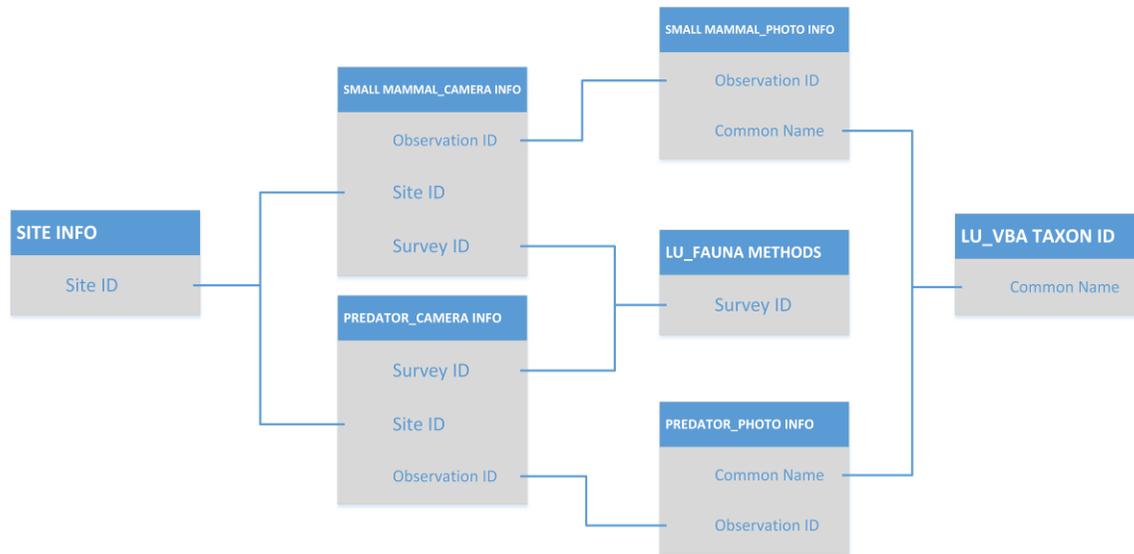
Figure 19. Database relationships for ground-dwelling mammal survey tables

Appendix 2: Vascular Flora

Table 21: Flora taxa detected in HawkEye / Retrospective sites and their associated plant functional type

Plant functional type	Taxon name	Taxon id VBA	# site detections
Canopy Tree	*Angophora floribunda*	500230	9
Canopy Tree	*Corymbia gummifera*	501288	3
Canopy Tree	*Eucalyptus agglomerata*	501243	1
Canopy Tree	*Eucalyptus angophoroides*	501247	3
Canopy Tree	*Eucalyptus baueriana*	501249	2
Canopy Tree	*Eucalyptus baxteri s.s.*	503759	8
Canopy Tree	*Eucalyptus bosistoana*	501253	2
Canopy Tree	*Eucalyptus botryoides*	501254	8
Canopy Tree	*Eucalyptus bridgesiana s.s.*	503758	6
Canopy Tree	*Eucalyptus consideniana*	501264	29
Canopy Tree	*Eucalyptus conspicua*	501766	1
Canopy Tree	*Eucalyptus croajingolensis*	504495	7
Canopy Tree	*Eucalyptus cypellocarpa*	501267	34
Canopy Tree	*Eucalyptus dives*	501272	17
Canopy Tree	*Eucalyptus elata*	501274	1
Canopy Tree	*Eucalyptus globoidea*	501281	88
Canopy Tree	*Eucalyptus globulus*	501282	1
Canopy Tree	*Eucalyptus globulus subsp. bicostata*	501283	7
Canopy Tree	*Eucalyptus globulus subsp. maidenii*	501284	1
Canopy Tree	*Eucalyptus globulus subsp. pseudoglobulus*	501285	1
Canopy Tree	*Eucalyptus goniocalyx s.l.*	501286	9
Canopy Tree	*Eucalyptus goniocalyx s.s.*	503732	5
Canopy Tree	*Eucalyptus mackintii*	503712	2
Canopy Tree	*Eucalyptus macrorhyncha*	501294	49
Canopy Tree	*Eucalyptus mannifera subsp. mannifera*	501296	14
Canopy Tree	*Eucalyptus melliodora*	501297	1
Canopy Tree	*Eucalyptus muelleriana*	501300	17
Canopy Tree	*Eucalyptus nortonii*	501303	3
Canopy Tree	*Eucalyptus obliqua*	501304	13
Canopy Tree	*Eucalyptus polyanthemos*	501310	14
Canopy Tree	*Eucalyptus polyanthemos subsp. vestita*	504335	23
Canopy Tree	*Eucalyptus radiata subsp. radiata*	503828	5
Canopy Tree	*Eucalyptus sieberi*	501318	70
Canopy Tree	*Eucalyptus spp.*	508415	3
Canopy Tree	*Eucalyptus tricarpa subsp. tricarpa*	507656	23
Serotinous Obligate Seeder Shrub	*Allocasuarina littoralis*	500677	23
Serotinous Obligate Seeder Shrub	*Banksia spinulosa var. cunninghamii*	500367	6
Serotinous Obligate Seeder Shrub	*Hakea decurrens subsp. physocarpa*	505071	17
Serotinous Obligate Seeder Shrub	*Hakea eriantha*	501563	7
Serotinous Obligate Seeder Shrub	*Hakea spp.*	508516	1
Serotinous Obligate Seeder Shrub	*Hakea ulicina*	501574	1
Obligate Seeder Shrub - Long Juv.	*Acacia dealbata subsp. dealbata*	505875	30
Obligate Seeder Shrub - Long Juv.	*Acacia falciformis*	500033	36
Obligate Seeder Shrub - Long Juv.	*Acacia obliquinervia*	500067	6
Obligate Seeder Shrub - Long Juv.	*Bertya cunninghamii subsp. pubiramula*	500389	3
Obligate Seeder Shrub - Long Juv.	*Beyeria lasiocarpa*	500393	1
Obligate Seeder Shrub - Long Juv.	*Beyeria viscosa*	500396	1
Obligate Seeder Shrub - Long Juv.	*Dodonaea viscosa*	501095	1
Obligate Seeder Shrub - Long Juv.	*Dodonaea viscosa subsp. cuneata*	501089	1
Obligate Seeder Shrub - Long Juv.	*Dodonaea viscosa subsp. spatulata*	504421	1
Obligate Seeder Shrub - Long Juv.	*Myrsine howittiana*	502916	1
Obligate Seeder Shrub - Long Juv.	*Persoonia confertiflora*	502462	16
Obligate Seeder Shrub - Long Juv.	*Persoonia rigida*	502468	1
Obligate Seeder Shrub - Long Juv.	*Pittosporum undulatum*	502543	5
Obligate Seeder Shrub - Long Juv.	*Pomaderris aspera*	502650	3
Obligate Seeder Shrub - Long Juv.	*Pomaderris betulina subsp. betulina*	502652	1
Obligate Seeder Shrub - Long Juv.	*Pomaderris elliptica var. elliptica*	502663	1
Obligate Seeder Shrub - Long Juv.	*Pomaderris eriocephala*	502657	1
Obligate Seeder Shrub - Long Juv.	*Pomaderris ferruginea*	502658	2
Obligate Seeder Shrub - Long Juv.	*Pomaderris intermedia*	502673	1
Obligate Seeder Shrub - Long Juv.	*Pomaderris lanigera*	502660	1
Obligate Seeder Shrub - Long Juv.	*Pomaderris spp.*	508921	4

Obligate Seeder Shrub – Short Juv.	*Acacia aculeatissima*	500008	1
Obligate Seeder Shrub – Short Juv.	*Acacia brownii*	500018	3
Obligate Seeder Shrub – Short Juv.	*Acacia cognata*	500021	4
Obligate Seeder Shrub – Short Juv.	*Acacia floribunda*	500036	1
Obligate Seeder Shrub – Short Juv.	*Acacia genistifolia*	500038	5
Obligate Seeder Shrub – Short Juv.	*Acacia gunnii*	500041	2
Obligate Seeder Shrub – Short Juv.	*Acacia leprosa var. graveolens*	505139	3
Obligate Seeder Shrub – Short Juv.	*Acacia longifolia subsp. longifolia*	500053	16
Obligate Seeder Shrub – Short Juv.	*Acacia mearnsii*	500056	13
Obligate Seeder Shrub – Short Juv.	*Acacia mucronata subsp. longifolia*	500062	10
Obligate Seeder Shrub – Short Juv.	*Acacia myrtifolia*	500063	16
Obligate Seeder Shrub – Short Juv.	*Acacia obtusifolia*	500068	1
Obligate Seeder Shrub – Short Juv.	*Acacia oxycedrus*	500071	1
Obligate Seeder Shrub – Short Juv.	*Acacia paradoxa*	500072	3
Obligate Seeder Shrub – Short Juv.	*Acacia pravissima*	500077	1
Obligate Seeder Shrub – Short Juv.	*Acacia pycnantha*	500078	10
Obligate Seeder Shrub – Short Juv.	*Acacia rubida*	500081	4
Obligate Seeder Shrub – Short Juv.	*Acacia spp.*	508003	10
Obligate Seeder Shrub – Short Juv.	*Acacia stricta*	500091	8
Obligate Seeder Shrub – Short Juv.	*Acacia suaveolens*	500092	5
Obligate Seeder Shrub – Short Juv.	*Acacia terminalis*	500095	45
Obligate Seeder Shrub – Short Juv.	*Acacia ulicifolia*	500098	8
Obligate Seeder Shrub – Short Juv.	*Acacia verniciflua s.l.*	500099	5
Obligate Seeder Shrub – Short Juv.	*Acacia verticillata*	500100	6
Obligate Seeder Shrub – Short Juv.	*Astrotricha spp.*	508091	1
Obligate Seeder Shrub – Short Juv.	*Boronia nana var. hyssopifolia*	504276	1
Obligate Seeder Shrub – Short Juv.	*Bossiaea heterophylla*	500438	2
Obligate Seeder Shrub – Short Juv.	*Bossiaea obcordata*	500439	5
Obligate Seeder Shrub – Short Juv.	*Bossiaea prostrata*	500440	16
Obligate Seeder Shrub – Short Juv.	*Bossiaea spp.*	508140	2
Obligate Seeder Shrub – Short Juv.	*Cassinia aculeata*	500666	8
Obligate Seeder Shrub – Short Juv.	*Cassinia longifolia*	500668	71
Obligate Seeder Shrub – Short Juv.	*Cassinia ozothamnoides*	501560	1
Obligate Seeder Shrub – Short Juv.	*Cassinia trinerva*	500669	1
Obligate Seeder Shrub – Short Juv.	*Comesperma ericinum*	500797	17
Obligate Seeder Shrub – Short Juv.	*Dillwynia cinerascens s.l.*	501050	1
Obligate Seeder Shrub – Short Juv.	*Dillwynia glaberrima*	501051	2
Obligate Seeder Shrub – Short Juv.	*Dillwynia phylicoides*	501057	6
Obligate Seeder Shrub – Short Juv.	*Dillwynia sericea*	501058	1
Obligate Seeder Shrub – Short Juv.	*Dillwynia spp.*	508336	2
Obligate Seeder Shrub – Short Juv.	*Dodonaea triquetra*	501093	3
Obligate Seeder Shrub – Short Juv.	*Gompholobium huegelii*	501481	3
Obligate Seeder Shrub – Short Juv.	*Goodia lotifolia*	501517	1
Obligate Seeder Shrub – Short Juv.	*Grevillea chrysophaea*	501530	2
Obligate Seeder Shrub – Short Juv.	*Indigofera australis*	501761	15
Obligate Seeder Shrub – Short Juv.	*Kunzea ericoides spp. agg.*	501856	31
Obligate Seeder Shrub – Short Juv.	*Lasiopetalum macrophyllum*	501874	2
Obligate Seeder Shrub – Short Juv.	*Leptomeria acida s.s.*	505694	1
Obligate Seeder Shrub – Short Juv.	*Olearia lirata*	502312	17
Obligate Seeder Shrub – Short Juv.	*Olearia phlogopappa*	502319	2
Obligate Seeder Shrub – Short Juv.	*Olearia ramulosa*	502322	5
Obligate Seeder Shrub – Short Juv.	*Olearia ramulosa var. ramulosa*	504785	1
Obligate Seeder Shrub – Short Juv.	*Olearia ramulosa var. stricta*	504787	1
Obligate Seeder Shrub – Short Juv.	*Olearia rugosa*	502324	1
Obligate Seeder Shrub – Short Juv.	*Oxylobium arborescens*	502393	1
Obligate Seeder Shrub – Short Juv.	*Oxylobium ellipticum*	502394	1
Obligate Seeder Shrub – Short Juv.	*Philotheca trachyphylla*	501227	1
Obligate Seeder Shrub – Short Juv.	*Pimelea axiflora subsp. axiflora*	504829	5
Obligate Seeder Shrub – Short Juv.	*Pimelea linifolia subsp. linifolia*	504819	24
Obligate Seeder Shrub – Short Juv.	*Platysace ericoides*	502571	6
Obligate Seeder Shrub – Short Juv.	*Platysace lanceolata*	502573	21
Obligate Seeder Shrub – Short Juv.	*Prostanthera hirtula*	502741	2
Obligate Seeder Shrub – Short Juv.	*Pultenaea daphnoides*	502844	12
Obligate Seeder Shrub – Short Juv.	*Pultenaea forsythiana*	504857	14
Obligate Seeder Shrub – Short Juv.	*Pultenaea gunnii subsp. gunnii*	504138	2
Obligate Seeder Shrub – Short Juv.	*Pultenaea hispidula*	502852	9
Obligate Seeder Shrub – Short Juv.	*Pultenaea linophylla*	502857	8
Obligate Seeder Shrub – Short Juv.	*Pultenaea mollis*	502859	3
Obligate Seeder Shrub – Short Juv.	*Pultenaea procumbens*	502867	1
Obligate Seeder Shrub – Short Juv.	*Pultenaea retusa*	502870	10
Obligate Seeder Shrub – Short Juv.	*Pultenaea scabra*	502871	12

Obligate Seeder Shrub – Short Juv.	*Pultenaea spp.*	508949	2
Obligate Seeder Shrub – Short Juv.	*Pultenaea vrolandii*	502880	1
Obligate Seeder Shrub – Short Juv.	*Rhytidosporum procumbens*	500402	63
Obligate Seeder Shrub – Short Juv.	*Sannantha pluriflora*	500358	2
Obligate Seeder Shrub – Short Juv.	*Spyridium parvifolium*	503235	6
Resprouter Shrub - Long Juvenile	*Acacia implexa*	500045	6
Resprouter Shrub - Long Juvenile	*Acacia melanoxylon*	500057	4
Resprouter Shrub - Long Juvenile	*Allocasuarina paludosa*	500683	1
Resprouter Shrub - Long Juvenile	*Banksia marginata*	500363	7
Resprouter Shrub - Long Juvenile	*Banksia serrata*	500366	14
Resprouter Shrub - Long Juvenile	*Bedfordia arborescens*	500382	1
Resprouter Shrub - Long Juvenile	*Brachyloma daphnoides*	500483	7
Resprouter Shrub - Long Juvenile	*Coprosma hirtella*	500817	4
Resprouter Shrub - Long Juvenile	*Coprosma quadrifida*	500822	14
Resprouter Shrub - Long Juvenile	*Elaeocarpus reticulatus*	501137	25
Resprouter Shrub - Long Juvenile	*Exocarpos cupressiformis*	501350	21
Resprouter Shrub - Long Juvenile	*Exocarpos strictus*	501353	1
Resprouter Shrub - Long Juvenile	*Monotoca elliptica s.s.*	504980	3
Resprouter Shrub - Long Juvenile	*Notelaea ligustrina*	502280	2
Resprouter Shrub - Long Juvenile	*Notelaea venosa*	502282	1
Resprouter Shrub - Long Juvenile	*Olearia argophylla*	502299	1
Resprouter Shrub - Long Juvenile	*Persoonia chamaepeuce*	502470	3
Resprouter Shrub - Long Juvenile	*Persoonia juniperina*	502463	5
Resprouter Shrub - Long Juvenile	*Persoonia levis*	502464	2
Resprouter Shrub - Long Juvenile	*Persoonia linearis*	502465	49
Resprouter Shrub - Long Juvenile	*Polyscias sambucifolia*	502643	8
Resprouter Shrub - Long Juvenile	*Polyscias sambucifolia subsp. 1*	504634	2
Resprouter Shrub - Long Juvenile	*Polyscias sambucifolia subsp. 2*	503401	3
Resprouter Shrub - Long Juvenile	*Xanthorrhoea minor subsp. lutea*	503588	35
Resprouter Shrub – Short Juvenile	*Acrotriche prostrata*	500122	2
Resprouter Shrub – Short Juvenile	*Acrotriche serrulata*	500123	42
Resprouter Shrub – Short Juvenile	*Amperea xiphoclada var. xiphoclada*	500206	26
Resprouter Shrub – Short Juvenile	*Aotus ericoides*	500237	5
Resprouter Shrub – Short Juvenile	*Astroloma humifusum*	500304	11
Resprouter Shrub – Short Juvenile	*Bauera rubioides*	500371	1
Resprouter Shrub – Short Juvenile	*Bursaria spinosa*	505690	3
Resprouter Shrub – Short Juvenile	*Bursaria spinosa subsp. spinosa*	500515	8
Resprouter Shrub – Short Juvenile	*Callistemon citrinus*	500562	1
Resprouter Shrub – Short Juvenile	*Calytrix tetragona*	500609	1
Resprouter Shrub – Short Juvenile	*Correa reflexa*	500832	32
Resprouter Shrub – Short Juvenile	*Correa reflexa var. speciosa*	504368	1
Resprouter Shrub – Short Juvenile	*Dampiera stricta*	500958	35
Resprouter Shrub – Short Juvenile	*Daviesia buxifolia*	500994	1
Resprouter Shrub – Short Juvenile	*Daviesia latifolia*	500996	23
Resprouter Shrub – Short Juvenile	*Daviesia leptophylla*	501000	12
Resprouter Shrub – Short Juvenile	*Daviesia mimosoides subsp. mimosoides*	504159	2
Resprouter Shrub – Short Juvenile	*Daviesia ulicifolia*	500999	11
Resprouter Shrub – Short Juvenile	*Daviesia ulicifolia subsp. ulicifolia*	504429	3
Resprouter Shrub – Short Juvenile	*Epacris impressa var. impressa*	504478	44
Resprouter Shrub – Short Juvenile	*Goodenia ovata*	501507	36
Resprouter Shrub – Short Juvenile	*Grevillea lanigera*	501540	2
Resprouter Shrub – Short Juvenile	*Hibbertia aspera subsp. aspera s.s.*	505436	28
Resprouter Shrub – Short Juvenile	*Hibbertia calycina*	501663	1
Resprouter Shrub – Short Juvenile	*Hibbertia empetrifolia subsp. empetrifolia s.s.*	505437	40
Resprouter Shrub – Short Juvenile	*Hibbertia obtusifolia*	501671	58
Resprouter Shrub – Short Juvenile	*Hibbertia riparia*	501675	3
Resprouter Shrub – Short Juvenile	*Hibbertia sericea s.s.*	505079	1
Resprouter Shrub – Short Juvenile	*Hibbertia serpyllifolia*	501678	4
Resprouter Shrub – Short Juvenile	*Hibbertia spp.*	508535	3
Resprouter Shrub – Short Juvenile	*Hovea heterophylla*	501705	25
Resprouter Shrub – Short Juvenile	*Hovea spp.*	508543	1
Resprouter Shrub – Short Juvenile	*Leptospermum brevipes*	501951	2
Resprouter Shrub – Short Juvenile	*Leptospermum continentale*	501956	18
Resprouter Shrub – Short Juvenile	*Leucopogon attenuatus*	501971	1
Resprouter Shrub – Short Juvenile	*Leucopogon ericoides*	501978	2
Resprouter Shrub – Short Juvenile	*Leucopogon juniperinus*	501982	3
Resprouter Shrub – Short Juvenile	*Leucopogon lanceolatus var. lanceolatus*	501983	36
Resprouter Shrub – Short Juvenile	*Leucopogon spp.*	508664	1
Resprouter Seeder Shrub – Short Juvenile	*Lomatia ilicifolia*	502051	35
Resprouter Shrub – Short Juvenile	*Melaleuca ericifolia*	502147	4
Resprouter Shrub – Short Juvenile	*Melaleuca squarrosa*	502153	3

Resprouter Shrub – Short Juvenile	*Melichrus urceolatus*	502159	1
Resprouter Shrub – Short Juvenile	*Monotoca scoparia*	502220	16
Resprouter Shrub – Short Juvenile	*Olearia erubescens*	502304	6
Resprouter Shrub – Short Juvenile	*Olearia myrsinoides*	502316	2
Resprouter Shrub – Short Juvenile	*Ozothamnus conditus*	501613	1
Resprouter Shrub – Short Juvenile	*Ozothamnus cuneifolius*	501614	2
Resprouter Shrub – Short Juvenile	*Phyllanthus hirtellus*	502501	34
Resprouter Shrub – Short Juvenile	*Pimelea curviflora var. aff. subglabrata*	504533	9
Resprouter Shrub – Short Juvenile	*Pimelea humilis*	502523	52
Resprouter Shrub – Short Juvenile	*Platylobium formosum*	502568	53
Resprouter Shrub – Short Juvenile	*Prostanthera denticulata*	502740	3
Resprouter Shrub – Short Juvenile	*Ricinocarpos pinifolius*	502938	5
Resprouter Shrub – Short Juvenile	*Tetratheca bauerifolia*	503350	11
Resprouter Shrub – Short Juvenile	*Tetratheca ciliata*	503351	17
Resprouter Shrub – Short Juvenile	*Tetratheca labillardierei*	503352	1
Resprouter Shrub – Short Juvenile	*Tetratheca pilosa subsp. latifolia*	504994	43
Resprouter Shrub – Short Juvenile	*Tetratheca spp.*	509129	6
Resprouter Shrub – Short Juvenile	*Xanthosia pilosa*	503592	12
Resprouter Shrub – Short Juvenile	*Xanthosia tasmanica*	504088	1
Resprouter Shrub – Short Juvenile	*Xanthosia tridentata*	503594	32
Obligate Seeder Herb	*Asperula scoparia subsp. scoparia*	500284	11
Obligate Seeder Herb	*Asplenium flabellifolium*	500288	1
Obligate Seeder Herb	*Cassytha glabella*	500671	14
Obligate Seeder Herb	*Cassytha glabella f. glabella*	504680	1
Obligate Seeder Herb	*Cassytha melantha*	500672	5
Obligate Seeder Herb	*Cassytha phaeolasia*	500673	21
Obligate Seeder Herb	*Cassytha pubescens s.s.*	500674	15
Obligate Seeder Herb	*Cassytha spp.*	508201	6
Obligate Seeder Herb	*Chrysocephalum baxteri*	501608	2
Obligate Seeder Herb	*Comesperma volubile*	500801	53
Obligate Seeder Herb	*Cymbonotus preissianus*	500903	6
Obligate Seeder Herb	*Einadia hastata*	501132	2
Obligate Seeder Herb	*Einadia trigonos subsp. trigonos*	501134	1
Obligate Seeder Herb	*Epilobium spp.*	508397	1
Obligate Seeder Herb	*Euchiton collinus s.s.*	501466	20
Obligate Seeder Herb	*Euchiton involucratus s.s.*	501465	2
Obligate Seeder Herb	*Euchiton spp.*	508427	4
Obligate Seeder Herb	*Eustrephus latifolius*	501346	4
Obligate Seeder Herb	*Galium binifolium*	501404	3
Obligate Seeder Herb	*Galium binifolium subsp. binifolium*	507856	8
Obligate Seeder Herb	*Galium binifolium subsp. conforme*	507857	12
Obligate Seeder Herb	*Galium curvihirtum*	501407	4
Obligate Seeder Herb	*Galium gaudichaudii*	501409	7
Obligate Seeder Herb	*Galium gaudichaudii subsp. gaudichaudii*	507859	2
Obligate Seeder Herb	*Galium gaudichaudii subsp. parviflorum*	507860	5
Obligate Seeder Herb	*Galium leiocarpum*	501413	19
Obligate Seeder Herb	*Galium leptogonium*	507854	1
Obligate Seeder Herb	*Galium liratum*	501410	5
Obligate Seeder Herb	*Galium spp.*	508464	31
Obligate Seeder Herb	*Geranium potentilloides*	501431	3
Obligate Seeder Herb	*Geranium sp. 2*	505343	8
Obligate Seeder Herb	*Glycine clandestine*	501455	48
Obligate Seeder Herb	*Glycine microphylla*	503741	2
Obligate Seeder Herb	*Glycine spp.*	508486	1
Obligate Seeder Herb	*Glycine tabacina s.l.*	501457	2
Obligate Seeder Herb	*Gonocarpus humilis*	501484	28
Obligate Seeder Herb	*Gonocarpus spp.*	508491	1
Obligate Seeder Herb	*Gonocarpus teucrioides s.s.*	504882	43
Obligate Seeder Herb	*Hardenbergia violacea*	501596	31
Obligate Seeder Herb	*Hybanthus monopetalus*	501711	1
Obligate Seeder Herb	*Hydrocotyle hirta*	501722	3
Obligate Seeder Herb	*Hydrocotyle sibthorpioides*	501728	1
Obligate Seeder Herb	*Kennedia prostrate*	501847	1
Obligate Seeder Herb	*Kennedia rubicunda*	501848	13
Obligate Seeder Herb	*Lagenophora gracilis*	501861	36
Obligate Seeder Herb	*Lagenophora stipitata*	501863	38
Obligate Seeder Herb	*Leptorhynchos nitidulus*	501943	4
Obligate Seeder Herb	*Leptorhynchos tenuifolius*	501947	1
Obligate Seeder Herb	*Leptostigma reptans*	502268	1
Obligate Seeder Herb	*Lobelia purpurascens*	502732	4
Obligate Seeder Herb	*Logania pusilla*	502033	3

Obligate Seeder Herb	*Opercularia aspera*	502339	15
Obligate Seeder Herb	*Opercularia hispida*	502340	30
Obligate Seeder Herb	*Opercularia ovate*	502341	1
Obligate Seeder Herb	*Opercularia varia*	502344	72
Obligate Seeder Herb	*Plantago spp.*	508901	5
Obligate Seeder Herb	*Pomax umbellata*	502677	38
Obligate Seeder Herb	*Scleranthus diander*	503061	1
Obligate Seeder Herb	*Senecio bathurstianus*	504958	1
Obligate Seeder Herb	*Senecio glomeratus*	503107	1
Obligate Seeder Herb	*Senecio hispidulus s.s.*	504959	1
Obligate Seeder Herb	*Senecio linearifolius*	503115	2
Obligate Seeder Herb	*Senecio linearifolius var. latifolius*	505518	2
Obligate Seeder Herb	*Senecio minimus*	503119	2
Obligate Seeder Herb	*Senecio pinnatifolius var. pinnatifolius*	505243	1
Obligate Seeder Herb	*Senecio prenanthoides*	503126	19
Obligate Seeder Herb	*Senecio quadridentatus*	503124	3
Obligate Seeder Herb	*Senecio spp.*	509058	13
Obligate Seeder Herb	*Senecio tenuiflorus spp. agg.*	503129	10
Obligate Seeder Herb	*Senecio velleioides*	503131	2
Obligate Seeder Herb	*Solanum prinophyllum*	503186	5
Obligate Seeder Herb	*Solanum pungetium*	503188	2
Obligate Seeder Herb	*Stellaria flaccida*	503250	1
Obligate Seeder Herb	*Uncinia tenella*	503474	1
Obligate Seeder Herb	*Veronica calycina*	503503	13
Obligate Seeder Herb	*Veronica plebeia*	503512	22
Obligate Seeder Herb	*Viola betonicifolia subsp. betonicifolia*	504052	16
Obligate Seeder Herb	*Xerochrysum viscosum*	501633	1
Resprouter Herb	*Acaena agnipila*	500104	2
Resprouter Herb	*Acaena echinata*	500106	2
Resprouter Herb	*Acaena novae-zelandiae*	500105	5
Resprouter Herb	*Acaena spp.*	508004	1
Resprouter Herb	*Acianthus exsertus s.l.*	500111	1
Resprouter Herb	*Acianthus pusillus*	504439	1
Resprouter Herb	*Acianthus spp.*	508007	14
Resprouter Herb	*Adiantum aethiopicum*	500129	11
Resprouter Herb	*Ajuga australis*	500168	4
Resprouter Herb	*Anisopogon avenaceus*	500231	20
Resprouter Herb	*Arthropodium milleflorum s.l.*	500269	2
Resprouter Herb	*Arthropodium minus*	500270	1
Resprouter Herb	*Arthropodium spp. (s.s.)*	508079	4
Resprouter Herb	*Arthropodium strictum s.l.*	501038	4
Resprouter Herb	*Austrostipa pubinodis*	503288	1
Resprouter Herb	*Austrostipa rudis*	503289	3
Resprouter Herb	*Austrostipa rudis subsp. nervosa*	504941	7
Resprouter Herb	*Austrostipa rudis subsp. rudis*	504942	3
Resprouter Herb	*Austrostipa spp.*	509099	9
Resprouter Herb	*Billardiera mutabilis*	504291	47
Resprouter Herb	*Billardiera scandens s.l.*	500403	53
Resprouter Herb	*Blechnum cartilagineum*	500404	3
Resprouter Herb	*Brachyscome aculeata*	500448	2
Resprouter Herb	*Brachyscome spathulata subsp. spathulata*	500478	2
Resprouter Herb	*Brachyscome spp.*	508146	9
Resprouter Herb	*Brunonia australis*	500508	4
Resprouter Herb	*Bulbine bulbosa*	500510	2
Resprouter Herb	*Burchardia umbellata*	500512	33
Resprouter Herb	*Caesia calliantha*	500519	2
Resprouter Herb	*Caesia parviflora*	500518	11
Resprouter Herb	*Caesia parviflora var. minor*	504340	1
Resprouter Herb	*Caesia parviflora var. parviflora*	504341	5
Resprouter Herb	*Caladenia carnea s.s.*	503680	1
Resprouter Herb	*Caladenia spp.*	508171	1
Resprouter Herb	*Carex breviculmis*	500627	11
Resprouter Herb	*Carex spp.*	508194	11
Resprouter Herb	*Cheilanthes sieberi subsp. sieberi*	500733	5
Resprouter Herb	*Chiloglottis spp.*	508223	8
Resprouter Herb	*Chiloglottis valida*	504888	4
Resprouter Herb	*Chrysocephalum semipapposum*	501628	2
Resprouter Herb	*Clematis aristata*	500788	44
Resprouter Herb	*Clematis glycinoides*	500789	1
Resprouter Herb	*Clematis microphylla s.l.*	500790	9
Resprouter Herb	*Corybas spp.*	508260	8

Resprouter Herb	*Cryptostylis leptochila*	500883	4
Resprouter Herb	*Cryptostylis spp.*	508275	5
Resprouter Herb	*Cryptostylis subulata*	500884	1
Resprouter Herb	*Derwentia derwentiana subsp. derwentiana*	504718	1
Resprouter Herb	*Derwentia perfoliata*	502416	1
Resprouter Herb	*Desmodium gunnii*	501008	18
Resprouter Herb	*Desmodium spp.*	508325	1
Resprouter Herb	*Desmodium varians*	504425	5
Resprouter Herb	*Deyeuxia monticola var. monticola*	501021	1
Resprouter Herb	*Deyeuxia quadriseta*	501023	18
Resprouter Herb	*Deyeuxia rodwayi*	501024	1
Resprouter Herb	*Deyeuxia scaberula*	501025	1
Resprouter Herb	*Deyeuxia spp.*	508326	8
Resprouter Herb	*Dianella caerulea s.l.*	501027	67
Resprouter Herb	*Dianella longifolia s.l.*	501028	5
Resprouter Herb	*Dianella revoluta s.l.*	501029	19
Resprouter Herb	*Dianella sp. aff. revoluta (Montane)*	505556	18
Resprouter Herb	*Dianella spp.*	508327	2
Resprouter Herb	*Dianella tasmanica*	501030	15
Resprouter Herb	*Dichelachne crinita*	501033	2
Resprouter Herb	*Dichelachne hirtella*	504528	2
Resprouter Herb	*Dichelachne micrantha*	505797	3
Resprouter Herb	*Dichelachne rara*	503792	14
Resprouter Herb	*Dichelachne sieberiana*	503791	15
Resprouter Herb	*Dichelachne spp.*	508330	22
Resprouter Herb	*Dichondra repens*	501036	25
Resprouter Herb	*Diplarrena moraea*	501063	4
Resprouter Herb	*Dipodium punctatum s.l.*	501068	1
Resprouter Herb	*Diuris sulphurea*	501085	1
Resprouter Herb	*Drosera peltata*	503689	10
Resprouter Herb	*Drosera peltata subsp. auriculata*	501102	6
Resprouter Herb	*Drosera peltata subsp. peltata*	501107	7
Resprouter Herb	*Drosera pygmaea*	501108	2
Resprouter Herb	*Drymophila cyanocarpa*	501111	2
Resprouter Herb	*Elymus scaber var. scaber*	500146	2
Resprouter Herb	*Elymus spp.*	508386	1
Resprouter Herb	*Entolasia marginata*	501161	16
Resprouter Herb	*Eriochilus cucullatus*	501219	1
Resprouter Herb	*Euphrasia collina subsp. collina*	504466	1
Resprouter Herb	*Gahnia clarkei*	501387	3
Resprouter Herb	*Gahnia sieberiana*	501395	5
Resprouter Herb	*Gahnia spp.*	508460	2
Resprouter Herb	*Geitonoplesium cymosum*	501420	4
Resprouter Herb	*Geranium spp.*	508474	14
Resprouter Herb	*Gleichenia dicarpa*	501440	1
Resprouter Herb	*Glossodia major*	501445	1
Resprouter Herb	*Gonocarpus tetragynus*	501489	50
Resprouter Herb	*Goodenia spp.*	508492	2
Resprouter Herb	*Helichrysum leucopsideum*	501619	18
Resprouter Herb	*Helichrysum scorpioides*	501626	32
Resprouter Herb	*Helichrysum spp.*	508527	2
Resprouter Herb	*Hibbertia dentata*	501665	2
Resprouter Herb	*Hierochloe rariflora*	501687	6
Resprouter Herb	*Hydrocotyle laxiflora*	501723	51
Resprouter Herb	*Hydrocotyle spp.*	508548	14
Resprouter Herb	*Hypericum gramineum*	501741	67
Resprouter Herb	*Hypoxis spp.*	508557	1
Resprouter Herb	*Imperata cylindrica*	501760	3
Resprouter Herb	*Lagenophora spp.*	508634	4
Resprouter Herb	*Laxmannia gracilis*	501889	4
Resprouter Herb	*Lepidosperma elatius*	501919	1
Resprouter Herb	*Lepidosperma filiforme*	501920	12
Resprouter Herb	*Lepidosperma laterale var. laterale*	504700	92
Resprouter Herb	*Lepidosperma laterale var. majus*	504701	1
Resprouter Herb	*Lepidosperma longitudinale*	501926	1
Resprouter Herb	*Lepidosperma neesii*	501927	1
Resprouter Herb	*Lepidosperma spp.*	508653	2
Resprouter Herb	*Lepidosperma urophorum*	501930	3
Resprouter Herb	*Lindsaea linearis*	502014	19
Resprouter Herb	*Lobelia gibbosa sensu Albrecht (1999)*	504432	1
Resprouter Herb	*Lomandra confertifolia subsp. leptostachya*	502039	11

Resprouter Herb	*Lomandra filiformis*	502042	25
Resprouter Herb	*Lomandra filiformis subsp. coriacea*	504709	47
Resprouter Herb	*Lomandra filiformis subsp. filiformis*	504710	77
Resprouter Herb	*Lomandra longifolia*	502046	14
Resprouter Herb	*Lomandra longifolia subsp. exilis*	504713	60
Resprouter Herb	*Lomandra longifolia subsp. longifolia*	504714	11
Resprouter Herb	*Lomandra micrantha subsp. tuberculata*	504711	3
Resprouter Herb	*Lomandra multiflora subsp. multiflora*	502048	20
Resprouter Herb	*Lomandra spp.*	508684	9
Resprouter Herb	*Luzula meridionalis*	503841	7
Resprouter Herb	*Luzula meridionalis var. flaccida*	502070	19
Resprouter Herb	*Lycopodium deuterodensum*	502079	6
Resprouter Herb	*Marsdenia rostrata*	502125	4
Resprouter Herb	*Mentha diemenica*	502166	1
Resprouter Herb	*Microlaena stipoides var. stipoides*	502179	106
Resprouter Herb	*Microseris sp. 3*	503887	1
Resprouter Herb	*Microseris spp.*	508737	3
Resprouter Herb	*Microtis parviflora*	502187	1
Resprouter Herb	*Microtis spp.*	508739	3
Resprouter Herb	*Ophioglossum lusitanicum*	502345	1
Resprouter Herb	*Oxalis exilis*	502381	6
Resprouter Herb	*Oxalis perennans*	502386	34
Resprouter Herb	*Oxalis spp.*	508835	29
Resprouter Herb	*Pandorea pandorana*	502399	12
Resprouter Herb	*Patersonia glabrata*	502436	33
Resprouter Herb	*Plantago debilis*	502555	4
Resprouter Herb	*Plantago varia*	502566	15
Resprouter Herb	*Poa clelandii*	502584	13
Resprouter Herb	*Poa ensiformis*	502590	5
Resprouter Herb	*Poa hothamensis var. parviflora*	504531	12
Resprouter Herb	*Poa labillardierei var. labillardierei*	504694	1
Resprouter Herb	*Poa morrisii*	502602	18
Resprouter Herb	*Poa sieberiana*	502608	2
Resprouter Herb	*Poa sieberiana var. cyanophylla*	504866	5
Resprouter Herb	*Poa sieberiana var. hirtella*	504834	1
Resprouter Herb	*Poa sieberiana var. sieberiana*	504835	15
Resprouter Herb	*Poa spp.*	508909	95
Resprouter Herb	*Polystichum proliferum*	502645	1
Resprouter Herb	*Prasophyllum spp.*	508930	1
Resprouter Herb	*Pterostylis longifolia s.l.*	502802	5
Resprouter Herb	*Pterostylis nutans*	502806	8
Resprouter Herb	*Pterostylis parviflora s.l.*	502808	1
Resprouter Herb	*Pterostylis sp. aff. revoluta (Inland)*	502814	1
Resprouter Herb	*Pterostylis spp.*	508946	18
Resprouter Herb	*Ranunculus lappaceus*	502894	3
Resprouter Herb	*Ranunculus spp.*	508978	1
Resprouter Herb	*Rubus parvifolius*	502956	3
Resprouter Herb	*Rytidosperma fulvum*	504409	1
Resprouter Herb	*Rytidosperma longifolium*	500969	8
Resprouter Herb	*Rytidosperma pallidum*	500973	57
Resprouter Herb	*Rytidosperma penicillatum*	500974	4
Resprouter Herb	*Rytidosperma pilosum*	500975	7
Resprouter Herb	*Rytidosperma racemosum var. racemosum*	500977	7
Resprouter Herb	*Rytidosperma setaceum var. brevisetum*	504179	1
Resprouter Herb	*Rytidosperma spp.*	508313	32
Resprouter Herb	*Scaevola ramosissima*	503023	21
Resprouter Herb	*Schelhammera undulata*	503026	3
Resprouter Herb	*Schizaea bifida s.s.*	503030	1
Resprouter Herb	*Scutellaria humilis*	503089	1
Resprouter Herb	*Smilax australis*	503166	3
Resprouter Herb	*Stackhousia monogyna s.l.*	503244	17
Resprouter Herb	*Stackhousia spp.*	509093	1
Resprouter Herb	*Stackhousia viminea*	503247	1
Resprouter Herb	*Stellaria pungens*	503255	7
Resprouter Herb	*Stylidium graminifolium s.l.*	503303	18
Resprouter Herb	*Stypandra glauca*	503309	54
Resprouter Herb	*Thelymitra spp.*	509134	4
Resprouter Herb	*Themeda triandra*	503387	21
Resprouter Herb	*Thynninorchis huntianus*	500268	3
Resprouter Herb	*Thysanotus patersonii*	503399	9
Resprouter Herb	*Thysanotus spp.*	509145	2

Resprouter Herb	*Thysanotus tuberosus subsp. tuberosus*	504998	21
Resprouter Herb	*Tricoryne elatior*	503421	9
Resprouter Herb	*Tylophora barbata*	503467	26
Resprouter Herb	*Veronica spp.*	509216	1
Resprouter Herb	*Viola hederacea sensu Willis (1972)*	503528	87
Resprouter Herb	*Viola sieberiana spp. agg.*	503529	2
Resprouter Herb	*Viola spp.*	509221	2
Resprouter Herb	*Wahlenbergia gracilis*	503558	37
Resprouter Herb	*Wahlenbergia multicaulis*	503560	4
Resprouter Herb	*Wahlenbergia spp.*	509236	34
Resprouter Herb	*Wahlenbergia stricta subsp. stricta*	503559	12
Rhizomatous Herb	*Calochlaena dubia*	500887	10
Rhizomatous Herb	*Caustis flexuosa*	500688	12
Rhizomatous Herb	*Gahnia radula*	501394	54
Rhizomatous Herb	*Hypolepis muelleri*	501751	1
Rhizomatous Herb	*Lepidosperma concavum*	501917	3
Rhizomatous Herb	*Poa tenera*	502610	1
Rhizomatous Herb	*Pteridium esculentum*	502777	92
Rhizomatous Herb	*Tetrarrhena juncea*	503348	69
Ephemeral Herb	*Crassula sieberiana s.l.*	500866	1
Ephemeral Herb	*Crassula spp.*	508265	1
Ephemeral Herb	*Cynoglossum australe*	500908	2
Ephemeral Herb	*Cynoglossum spp.*	508289	2
Ephemeral Herb	*Cynoglossum suaveolens*	500910	4
Ephemeral Herb	*Daucus glochidiatus*	500989	13
Ephemeral Herb	*Echinopogon ovatus*	501122	26
Ephemeral Herb	*Euchiton sphaericus*	501471	1
Ephemeral Herb	*Goodenia elongata*	501496	1
Ephemeral Herb	*Lepidium pseudotasmanicum*	501910	1
Ephemeral Herb	*Linum marginale*	502017	1
Ephemeral Herb	*Poranthera microphylla s.l.*	502683	109
Ephemeral Herb	*Schoenus apogon*	503039	13
Ephemeral Herb	*Wahlenbergia gracilenta s.s.*	504124	3
Introduced Plant	*Aira caryophyllea subsp. caryophyllea*	500164	1
Introduced Plant	*Anagallis arvensis*	500223	1
Introduced Plant	*Anagallis arvensis var. arvensis*	505170	1
Introduced Plant	*Anthoxanthum odoratum*	500236	3
Introduced Plant	*Centaurium erythraea*	500702	10
Introduced Plant	*Centaurium spp.*	508208	6
Introduced Plant	*Cerastium glomeratum s.l.*	500719	1
Introduced Plant	*Cirsium vulgare*	500782	2
Introduced Plant	*Conyza bonariensis*	500812	1
Introduced Plant	*Conyza spp.*	508253	10
Introduced Plant	*Conyza sumatrensis*	500810	2
Introduced Plant	*Holcus lanatus*	501692	1
Introduced Plant	*Hypericum perforatum subsp. veronense*	501744	1
Introduced Plant	*Hypochaeris radicata*	501748	40
Introduced Plant	*Hypochaeris spp.*	508554	1
Introduced Plant	*Lactuca serriola*	501860	1
Introduced Plant	*Leontodon taraxacoides subsp. taraxacoides*	501895	1
Introduced Plant	*Medicago spp.*	508722	1
Introduced Plant	*Rubus fruticosus spp. agg.*	502952	2
Introduced Plant	*Sigesbeckia orientalis subsp. orientalis*	503149	2
Introduced Plant	*Sisyrinchium sp. A*	503164	1
Introduced Plant	*Sonchus asper s.l.*	503203	2
Introduced Plant	*Sonchus oleraceus*	503204	1
Introduced Plant	*Trifolium angustifolium var. angustifolium*	503423	1
Introduced Plant	*Trifolium arvense var. arvense*	503424	1
Introduced Plant	*Trifolium spp.*	509161	1
Introduced Plant	*Vulpia muralis*	503548	1

Table 22: Plant functional type models (glm) and QAICc - Analysis 1

Plant functional type	Model	QAICc
Canopy tree	Presence~1	203.9362
	Presence~LastFireType*TSF	205.5929
	Presence~LastFireType	205.7911
	Presence~EVD	205.9162
	Presence~EVD*Fires	207.9284
	Presence~EVD*TSF	207.9986
	Presence~LastFireType*Fires	208.6991
	Presence~EVD*LastFireType	209.9419
	Presence~EVD*LastFireType*TSF	212.1501
	Presence~EVD*LastFireType*Fires	216.4927
	Presence~EVD*LastFireType*(TSF+Fires)	220.0609
Serotinous obligate seeder shrubs	Presence~EVD*TSF	130.2919
	Presence~EVD*LastFireType	131.1636
	Presence~EVD	131.9085
	Presence~EVD*LastFireType*TSF	135.099
	Presence~EVD*Fires	135.5696
	Presence~EVD*LastFireType*Fires	136.3308
	Presence~EVD*LastFireType*(TSF+Fires)	139.5879
	Presence~LastFireType	171.968
	Presence~LastFireType*TSF	174.2226
	Presence~LastFireType*Fires	176.3016
	Presence~1	179.1492
Obligate seeder shrubs – long juvenile	Presence~EVD	128.0565
	Presence~EVD*Fires	131.5251
	Presence~EVD*LastFireType	131.5661
	Presence~EVD*TSF	131.5857
	Presence~EVD*LastFireType*TSF	134.6868
	Presence~EVD*LastFireType*Fires	139.2536
	Presence~EVD*LastFireType*(TSF+Fires)	142.6518
	Presence~1	153.4037
	Presence~LastFireType	155.4918
	Presence~LastFireType*TSF	157.7552
	Presence~LastFireType*Fires	159.6648
Obligate seeder shrubs – short juvenile	Presence~EVD*TSF	171.5638
	Presence~EVD	175.4227
	Presence~EVD*Fires	176.598
	Presence~LastFireType*TSF	178.8516
	Presence~EVD*LastFireType*TSF	178.8524
	Presence~1	179.046
	Presence~EVD*LastFireType	179.6356
	Presence~LastFireType	180.6137
	Presence~LastFireType*Fires	181.0428
	Presence~EVD*LastFireType*Fires	184.5966
	Presence~EVD*LastFireType*(TSF+Fires)	187.1578
Resprouter shrubs – long juvenile	Presence~EVD	160.2154

Plant functional type	Model	QAICc
	Presence~EVD*LastFireType	161.2517
	Presence~EVD*TSF	162.6995
	Presence~EVD*Fires	163.6271
	Presence~EVD*LastFireType*TSF	167.4695
	Presence~EVD*LastFireType*Fires	168.7735
	Presence~EVD*LastFireType*(TSF+Fires)	175.8519
	Presence~1	179.7759
	Presence~LastFireType	180.2329
	Presence~LastFireType*Fires	183.1565
	Presence~LastFireType*TSF	184.2307
Resprouter shrubs – short juvenile	Presence~EVD	146.1234
	Presence~EVD*LastFireType	147.4837
	Presence~EVD*Fires	149.8684
	Presence~EVD*TSF	150.1736
	Presence~EVD*LastFireType*TSF	153.2654
	Presence~EVD*LastFireType*Fires	155.7052
	Presence~1	161.8974
	Presence~LastFireType	162.3208
	Presence~EVD*LastFireType*(TSF+Fires)	162.5634
	Presence~LastFireType*TSF	166.0952
	Presence~LastFireType*Fires	166.5556
Obligate seeder herbs	Presence~EVD*TSF	180.7188
	Presence~LastFireType*TSF	181.0429
	Presence~EVD*Fires	181.7785
	Presence~EVD*LastFireType*TSF	184.3684
	Presence~EVD	187.5446
	Presence~EVD*LastFireType*(TSF+Fires)	189.6337
	Presence~1	190.2641
	Presence~EVD*LastFireType*Fires	190.4435
	Presence~LastFireType*Fires	190.573
	Presence~EVD*LastFireType	191.7533
	Presence~LastFireType	192.3795
Resprouter herbs	Presence~EVD	166.3208
	Presence~1	166.5098
	Presence~LastFireType	167.4452
	Presence~EVD*TSF	169.6729
	Presence~EVD*LastFireType	169.8627
	Presence~LastFireType*TSF	170.1973
	Presence~EVD*Fires	170.3709
	Presence~LastFireType*Fires	170.8678
	Presence~EVD*LastFireType*Fires	176.0032
	Presence~EVD*LastFireType*TSF	177.2294
	Presence~EVD*LastFireType*(TSF+Fires)	183.8152
Rhizomatous herbs – vigorous	Presence~EVD*Fires	135.7279
	Presence~EVD*LastFireType*Fires	139.375
	Presence~EVD	142.9902
	Presence~EVD*TSF	146.0687

Plant functional type	Model	QAICc
	Presence~EVD*LastFireType	146.0865
	Presence~EVD*LastFireType*(TSF+Fires)	148.0136
	Presence~EVD*LastFireType*TSF	154.2273
	Presence~LastFireType*Fires	212.0509
	Presence~1	212.0934
	Presence~LastFireType	213.0075
	Presence~LastFireType*TSF	214.9761
Ephemeral herbs	Presence~EVD*LastFireType	141.3473
	Presence~EVD	144.0417
	Presence~LastFireType	144.5903
	Presence~EVD*TSF	146.993
	Presence~EVD*LastFireType*Fires	147.312
	Presence~LastFireType*Fires	147.5885
	Presence~EVD*Fires	148.1312
	Presence~EVD*LastFireType*TSF	148.5959
	Presence~LastFireType*TSF	148.7064
	Presence~1	151.8031
	Presence~EVD*LastFireType*(TSF+Fires)	154.7631

Table 23: Plant functional type models (glm) and QAICc – Analysis 2

Plant functional type	Model	QAICc
Canopy tree	Presence~1	273.3871
	Presence~EVD*MinTFI	275.1822
	Presence~EVD	275.4590
	Presence~EVD*MinTFIcount	285.2226
	Presence~EVD*FireHist	290.9807
	Presence~EVD*(FireHist+MinTFI)	291.2316
	Presence~EVD*(FireHist+MinTFIcount)	305.6681
Serotinous obligate seeder shrubs	Presence~EVD	150.2575
	Presence~EVD*MinTFI	151.7753
	Presence~EVD*MinTFIcount	159.5369
	Presence~EVD*FireHist	168.6330
	Presence~EVD*(FireHist+MinTFI)	170.9234
	Presence~1	180.9145
	Presence~EVD*(FireHist+MinTFIcount)	208.5314
Obligate seeder shrubs – long juvenile	Presence~EVD	160.3293
	Presence~EVD*MinTFI	162.4718
	Presence~EVD*MinTFIcount	171.9872
	Presence~EVD*FireHist	178.5248
	Presence~EVD*(FireHist+MinTFI)	183.5461
	Presence~1	185.1681

Plant functional type	Model	QAICc
	Presence~EVD*(FireHist+MinTFIcount)	193.9681
Obligate seeder shrubs – short juvenile	Presence~EVD*FireHist	226.4627
	Presence~1	227.0822
	Presence~EVD	228.0105
	Presence~EVD*MinTFI	230.5425
	Presence~EVD*(FireHist+MinTFI)	231.3431
	Presence~EVD*MinTFIcount	244.6991
	Presence~EVD*(FireHist+MinTFIcount)	251.0456
Resprouter shrubs – long juvenile	Presence~EVD	210.6107
	Presence~EVD*MinTFI	211.8080
	Presence~EVD*MinTFIcount	217.5099
	Presence~EVD*(FireHist+MinTFI)	221.5831
	Presence~EVD*FireHist	228.3120
	Presence~EVD*(FireHist+MinTFIcount)	231.4167
	Presence~1	238.7867
Resprouter shrubs – short juvenile	Presence~EVD	184.1098
	Presence~EVD*MinTFI	185.1927
	Presence~EVD*MinTFIcount	196.2404
	Presence~1	197.4612
	Presence~EVD*FireHist	203.3988
	Presence~EVD*(FireHist+MinTFI)	203.8119
	Presence~EVD*(FireHist+MinTFIcount)	220.0815
Obligate seeder herbs	Presence~EVD*MinTFI	222.0911
	Presence~EV	223.0601
	Presence~1	225.5589
	Presence~EVD*FireHist	230.4878
	Presence~EVD*(FireHist+MinTFI)	231.8635
	Presence~EVD*MinTFIcount	232.2610
	Presence~EVD*(FireHist+MinTFIcount)	247.2959
Resprouter herbs	Presence~1	175.2165
	Presence~EVD	175.2302
	Presence~EVD*MinTFI	177.0388
	Presence~EVD*MinTFIcount	191.5614
	Presence~EVD*FireHist	196.7088
	Presence~EVD*(FireHist+MinTFI)	200.3224
	Presence~EVD*(FireHist+MinTFIcount)	216.5579
Rhizomatous herbs – vigorous	Presence~EVD*MinTFI	172.3118
	Presence~EVD*MinTFIcount	179.8287
	Presence~EVD*(FireHist+MinTFI)	186.4616
	Presence~EVD	188.3384
	Presence~EVD*FireHist	194.6750

Plant functional type	Model	QAICc
	Presence~EVD*(FireHist+MinTFIcount)	198.6560
	Presence~1	279.5453
Ephemeral herbs	Presence~EVD	182.1698
	Presence~EVD*MinTFI	185.9014
	Presence~1	196.8910
	Presence~EVD*FireHist	199.0673
	Presence~EVD*MinTFIcount	199.5669
	Presence~EVD*(FireHist+MinTFI)	201.4864
	Presence~EVD*(FireHist+MinTFIcount)	217.7595

Appendix 3: Diurnal Birds

Table 24: Bird species detected in the Retrospective/HawkEye (125) sites and their associated guild

Species are listed in taxonomic order according to Christidis & Boles (2008). Guild descriptions are provided in (Table 25). * Denotes introduced species.

Taxon #	VBA Taxon ID	Common Name	Scientific Name	% sites	# surveys	Broad Habitat Guild	Feeding Guild	Hollow Dependent	Nesting Guild	Taxon Group
63	10034	Common Bronzewing	Phaps chalcoptera	5	6	F	SG		V	pigeons
64	10035	Brush Bronzewing	Phaps elegans	1	1	F	SG		V	pigeons
75	10044	Wonga Pigeon	Leucosarcia melanoleuca	13	21	F	F		V	pigeons
91	10330	White-throated Nightjar	Eurostopodus mystacalis	1	1	F	A		G	nightjars
101	10334	White-throated Needletail	Hirundapus caudacutus	1	1	F	A		X	swifts
198	10096	Great Cormorant	Phalacrocorax carbo	Off site	0	W	W		W	cormorants
244	10221	Brown Goshawk	Accipiter fasciatus	Off site	0	F	V		V	diurnal raptors
252	10224	Wedge-tailed Eagle	Aquila audax	3	4	F	V		V	diurnal raptors
255	10239	Brown Falcon	Falco berigora	Off site	0	O	V		V	diurnal raptors
364	10014	Painted Button-quail	Turnix varia	6	11	F	SG		G	button-quail
409	10265	Glossy Black-Cockatoo	Calyptorhynchus lathami lathami	1	1	F	ST	H	LH	parrots
410	10267	Yellow-tailed Black-Cockatoo	Calyptorhynchus funereus	4	7	F	ST	H	LH	parrots
413	10268	Gang-gang Cockatoo	Callocephalon fimbriatum	13	27	F	ST	H	LH	parrots
415	10273	Galah	Cacatua roseicapilla	Off site	0	O	SG	H	LH	parrots
419	10269	Sulphur-crested Cockatoo	Cacatua galerita	3	4	O	SG	H	LH	parrots
421	10254	Rainbow Lorikeet	Trichoglossus haematodus	8	14	F	N	H	LH	parrots
424	10258	Musk Lorikeet	Glossopsitta concinna	2	4	F	N	H	LH	parrots
430	10281	Australian King-Parrot	Alisterus scapularis	10	18	F	F	H	LH	parrots
436	10282	Crimson Rosella	Platycercus elegans	40	80	F	ST	H	LH	parrots
437	10288	Eastern Rosella	Platycercus eximius	1	1	O	SG	H	LH	parrots
468	10342	Horsfield's Bronze-Cuckoo	Chrysococcyx basalis	1	1	F	C		BP	cuckoos
470	10344	Shining Bronze-Cuckoo	Chrysococcyx lucidus	15	25	F	C		BP	cuckoos
472	10337	Pallid Cuckoo	Cuculus pallidus	5	7	F	OT		BP	cuckoos
474	10338	Fan-tailed Cuckoo	Cacomantis flabelliformis	38	69	F	TS		BP	cuckoos
475	10339	Brush Cuckoo	Cacomantis variolosus	7	9	F	C		BP	cuckoos
481	10242	Southern Boobook	Ninox novaeseelandiae	Off site	0	F	V	H	LH	owls
493	10322	Laughing Kookaburra	Dacelo novaeguineae	32	68	F	V	H	LH	kingfishers

Taxon #	VBA Taxon ID	Common Name	Scientific Name	% sites	# surveys	Broad Habitat Guild	Feeding Guild	Hollow Dependent	Nesting Guild	Taxon Group
498	10326	Sacred Kingfisher	Todiramphus sanctus	14	23	F	V	H	LH	kingfishers
508	10350	Superb Lyrebird	Menura novaehollandiae	12	19	F	DG		V	passerines
511	10558	White-throated Treecreeper	Cormobates leucophaea	94	283	F	B	H	SH	passerines
513	10560	Red-browed Treecreeper	Climacteris erythrops	14	21	F	B	H	SH	passerines
514	60555	Brown Treecreeper	Climacteris picumnus	1	1	F	B	H	SH	passerines
522	10679	Satin Bowerbird	Ptilonorhynchus violaceus	7	12	F	F		V	passerines
527	10529	Superb Fairy-wren	Malurus cyaneus	46	116	F	OT		V	passerines
536	10526	Southern Emu-wren	Stipiturus malachurus	2	3	F	LS		V	passerines
552	10506	Pilotbird	Pycnoptilus floccosus	4	7	F	DG		V	passerines
556	10488	White-browed Scrubwren	Sericornis frontalis	40	89	F	DG		V	passerines
567	10504	Speckled Warbler	Chthonicola sagittatus	1	1	F	OT		V	passerines
569	10454	Brown Gerygone	Gerygone mouki	1	1	F	TS		V	passerines
573	10463	Western Gerygone	Gerygone fusca	Off site	0	F	C		V	passerines
578	10453	White-throated Gerygone	Gerygone olivacea	2	3	F	C		V	passerines
580	10470	Striated Thornbill	Acanthiza lineata	67	156	F	C		V	passerines
584	10484	Buff-rumped Thornbill	Acanthiza reguloides	23	49	F	OT		V	passerines
589	10475	Brown Thornbill	Acanthiza pusilla	85	314	F	TS		V	passerines
594	10565	Spotted Pardalote	Pardalotus punctatus	85	234	F	C		G	passerines
597	10976	Striated Pardalote	Pardalotus striatus	27	46	F	C	H	SH	passerines
598	10591	Eastern Spinebill	Acanthorhynchus tenuirostris	49	104	F	N		V	passerines
601	10605	Lewin's Honeyeater	Meliphaga lewinii	5	8	F	N		V	passerines
608	10614	Yellow-faced Honeyeater	Lichenostomus chrysops	82	232	F	N		V	passerines
614	10617	White-eared Honeyeater	Lichenostomus leucotis	6	13	F	N		V	passerines
616	10619	Yellow-tufted Honeyeater	Lichenostomus melanops	Off site	0	F	N		V	passerines
625	10633	Bell Miner	Manorina melanophrys	2	3	F	N		V	passerines
626	10634	Noisy Miner	Manorina melanocephala	1	1	O	N		V	passerines
633	10638	Red Wattlebird	Anthochaera carunculata	54	117	F	N		V	passerines
653	10630	Crescent Honeyeater	Phylidonyris pyrrhopterus	6	12	F	N		V	passerines
654	10631	New Holland Honeyeater	Phylidonyris novaehollandiae	7	21	F	N		V	passerines
659	10583	Brown-headed Honeyeater	Melithreptus brevirostris	10	14	F	N		V	passerines
661	10578	White-naped Honeyeater	Melithreptus lunatus	10	15	F	N		V	passerines
666	10645	Noisy Friarbird	Philemon corniculatus	6	14	F	N		V	passerines
667	10646	Little Friarbird	Philemon citreogularis	2	4	F	N		V	passerines

Taxon #	VBA Taxon ID	Common Name	Scientific Name	% sites	# surveys	Broad Habitat Guild	Feeding Guild	Hollow Dependent	Nesting Guild	Taxon Group
678	10436	Spotted Quail-thrush	Cinclosoma punctatum	16	23	F	OT		G	passerines
682	10421	Eastern Whipbird	Psophodes olivaceus	6	9	F	DG		V	passerines
686	10549	Varied Sittella	Daphoenositta chrysoptera	6	10	F	B		V	passerines
688	10424	Black-faced Cuckoo-shrike	Coracina novaehollandiae	27	43	F	C		V	passerines
689	10425	White-bellied Cuckoo-shrike	Coracina papuensis	2	2	F	C		V	passerines
691	10429	Common Cicadabird	Coracina tenuirostris	10	16	F	C		V	passerines
695	10416	Crested Shrike-tit	Falcunculus frontatus	2	2	F	B		V	passerines
696	10405	Olive Whistler	Pachycephala olivacea	1	1	F	DG		V	passerines
699	10398	Golden Whistler	Pachycephala pectoralis	44	104	F	TS		V	passerines
702	10401	Rufous Whistler	Pachycephala rufiventris	36	79	F	C		V	passerines
707	10408	Grey Shrike-thrush	Colluricincla harmonica	55	136	F	V		V	passerines
711	10671	Olive-backed Oriole	Oriolus sagittatus	23	44	F	F		V	passerines
714	10545	White-browed Woodswallow	Artamus superciliosus	1	1	F	A		V	passerines
716	10547	Dusky Woodswallow	Artamus cyanopterus	2	2	F	A		V	passerines
719	10702	Grey Butcherbird	Cracticus torquatus	4	5	O	V		V	passerines
722	10705	Australian Magpie	Cracticus tibicen	3	7	O	OG		V	passerines
723	10694	Pied Currawong	Strepera graculina	29	45	F	V		V	passerines
725	10697	Grey Currawong	Strepera versicolor	1	1	F	V		V	passerines
727	10362	Rufous Fantail	Rhipidura rufifrons	2	3	F	TS		V	passerines
729	10361	Grey Fantail	Rhipidura albiscapa	65	173	F	C		V	passerines
733	10364	Willie Wagtail	Rhipidura leucophrys	1	1	O	OG		V	passerines
737	10930	Australian Raven	Corvus coronoides	2	2	F	V		V	passerines
744	10365	Leaden Flycatcher	Myiagra rubecula	7	12	F	C		V	passerines
745	10366	Satin Flycatcher	Myiagra cyanoleuca	3	7	F	C		V	passerines
749	10373	Black-faced Monarch	Monarcha melanopsis	2	3	F	C		V	passerines
757	10693	White-winged Chough	Corcorax melanorhamphos	4	10	F	OT		V	passerines
763	10377	Jacky Winter	Microeca fascinans	Off site	0	F	OT		V	passerines
766	10380	Scarlet Robin	Petroica boodang	13	20	F	OT		V	passerines
768	10381	Red-capped Robin	Petroica goodenovii	Off site	0	F	OT		V	passerines
769	10382	Flame Robin	Petroica phoenicea	2	3	F	OG		V	passerines
770	10384	Rose Robin	Petroica rosea	2	3	F	TS		V	passerines
776	10392	Eastern Yellow Robin	Eopsaltria australis	47	114	F	DG		V	passerines
793	10509	Rufous Songlark	Cincloramphus mathewsi	Off site	0	F	OT		G	passerines

Taxon #	VBA Taxon ID	Common Name	Scientific Name	% sites	# surveys	Broad Habitat Guild	Feeding Guild	Hollow Dependent	Nesting Guild	Taxon Group
799	10574	Silvereye	Zosterops lateralis	12	22	F	F		V	passerines
816	10779	Bassian Thrush	Zoothera lunulata	2	2	F	DG		V	passerines
818	10991	Common Blackbird*	Turdus merula	Off site	0	F	DG		V	passerines
829	10564	Mistletoebird	Dicaeum hirundinaceum	6	8	F	F		V	passerines
839	10662	Red-browed Finch	Neochmia temporalis	2	2	F	SG		V	passerines

Table 25: Description of bird guilds

G=guild code, #S1=number of species detected in the guild on site, #S2= number of species detected on and off-site

G	#S1	#S2	
			Broad habitat guild description
F	82	90	forests, woodlands or other areas of native woody vegetation (e.g. tall shrublands). Some of these species winter in open country including pasture (Flame Robin) and saltmarsh (Neophema parrots).
O	6	8	open country including farmland. Many of these species depend on trees or remnant native vegetation, but also benefit from the open landscape and hence may be more common than in uncleared forest or woodland
W	-	2	water bird, inhabiting inland waters and in many cases coastal waters as well
			Feeding guild description
A	4	4	aerial feeder, taking insects in open air, usually far from foliage
B	5	5	bark forager, taking invertebrates from bark on trunks and branches of eucalypts and other trees
C	16	17	canopy forager, taking invertebrates from foliage of eucalypts and other large trees
DG	7	8	takes invertebrates from damp ground below shrubs, among dense understorey or among damp litter in wet forests or rainforest
F	6	6	frugivore, taking soft fruit along with other food such as nectar, invertebrates or seeds (parrots & pigeons)
LS	1	1	takes invertebrates from low shrubs, tall grass or other low vegetation
N	15	16	nectarivore, taking nectar along with other food such as seeds (parrots) and fruit or invertebrates
OG	3	3	takes invertebrates from open ground, quite often far from tree or shrub cover
OT	7	10	takes invertebrates from open ground among trees or scattered tall shrubs, but not from damp ground below dense cover, and does not usually venture far from woody vegetation
SG	6	7	takes seeds from ground or low plants such as grasses, herbs and saltmarsh
ST	4	4	takes seeds from trees and shrubs or wide range of strata, or other food such as gall insects or insect larvae extracted from wood
TS	6	6	takes invertebrates from foliage of tall shrubs, which may form middle storey of eucalypt forests or stand alone, e.g. mangroves
V	8	11	carnivore, taking vertebrates as an important part of diet, often along with large invertebrates and other food such as fruit (passerines)
W	-	2	feeds in or around water
			Nesting guild description
BP	5	5	brood parasite
G	4	5	on ground
LH	11	13	large or medium-sized hollow in tree or termite mound
SH	4	4	small hollow in tree
V	63	70	in vegetation generally (often among low or tall shrubs, but may sometimes be in trees)
W	-	2	in water (may be colonial)
X	1	1	does not nest in Australia

Table 26: Generalised linear mixed models (GLMMs) of nesting bird guild density

Density of bird nesting guilds (birds per 20 minute / 2 hectare counts) predicted by a combinations or fire, environmental and sampling variables. All models within two AIC of the best model are shown with their percentage deviance explained

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
Ground nesting	< Min TFI	-0.545	-0.271	0.003	0.052	0.3
Ground nesting	EVD	-0.503	-0.191	0.122	0.232	
	< Min TFI	-0.534	-0.262	0.011	0.060	0.3
Ground nesting	Null	-0.152	0.016	0.183	0.853	0.3
Ground nesting	EVD	-0.522	-0.207	0.109	0.199	0.3
Ground nesting	EVD	-0.545	-0.183	0.179	0.323	
	< Min TFI	-0.594	-0.253	0.089	0.147	
	Interaction	-0.594	-0.024	0.546	0.933	0.3
Ground nesting	< Min TFI	-0.549	-0.273	0.003	0.052	
	2nd Year	-0.287	0.005	0.297	0.974	
	North East	-0.243	0.299	0.842	0.280	0.3
Large Hollow	Obs 2	-0.502	-0.054	0.394	0.815	
	Obs 3	-1.174	-0.599	-0.024	0.041	
	Obs 4	-0.572	-0.057	0.458	0.830	
	Obs 5	-0.676	-0.244	0.189	0.269	
	Obs 6	-1.207	-0.716	-0.225	0.004	
	Obs 7	-1.204	-0.605	-0.007	0.048	
	North East	-0.790	0.124	1.038	0.790	0.5
Large Hollow	Null	-0.501	-0.231	0.039	0.094	0.4
Small Hollow	1 fire	-0.175	0.071	0.316	0.572	
	2 fires	-0.190	0.151	0.492	0.385	
	3+ fires	-0.351	-0.078	0.194	0.573	
	2nd Year	-0.585	-0.300	-0.015	0.039	
	North East	0.282	0.714	1.146	0.001	0.2
Small Hollow	6-10yrs	-0.791	-0.338	0.115	0.144	
	11-20yrs	-0.364	-0.093	0.178	0.501	
	21-40yrs	-0.354	-0.057	0.239	0.705	
	41+yrs	-0.375	-0.100	0.174	0.474	
	2nd Year	-0.588	-0.285	0.018	0.066	
	North East	0.295	0.713	1.130	0.001	0.2
Small Hollow	FG2	-0.422	-0.050	0.323	0.793	
	FG3	-0.387	-0.038	0.312	0.833	
	FG4	-0.658	-0.293	0.071	0.115	
	FG5	-0.416	-0.073	0.269	0.675	
	FG6	-0.445	-0.120	0.204	0.467	0.2

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
	2nd Year	-0.582	-0.280	0.023	0.070	
	North East	0.291	0.720	1.149	0.001	
Nest in vegetation	Obs 2	-0.202	-0.049	0.104	0.532	
	Obs 3	-0.503	-0.307	-0.111	0.002	
	Obs 4	-0.011	0.171	0.354	0.065	
	Obs 5	-0.268	-0.121	0.026	0.106	
	Obs 6	-0.243	-0.080	0.082	0.331	
	Obs 7	-0.186	0.012	0.211	0.904	
	North East	-0.131	0.209	0.549	0.229	0.7
Nest in vegetation	Null	2.192	2.295	2.397	<2e-16	0.7

Table 27: Generalised linear mixed models (GLMMs) of bird feeding guild

Density of bird feeding guilds (birds per 20 minute / 2 hectare counts) predicted by combinations or fire, environmental and sampling variables. All models within two AIC of the best model are shown with their percentage deviance explained

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
Feeding on insects from bark	6-10yrs	-0.650	-0.203	0.244	0.373	
	11-20yrs	-0.293	-0.015	0.262	0.914	
	21-40yrs	-0.359	-0.046	0.267	0.774	
	41+yrs	-0.290	-0.010	0.270	0.943	
	2nd Year	-0.598	-0.288	0.022	0.069	
	North East	0.079	0.447	0.814	0.017	0.1
Feeding on insects from bark	EVD7	-0.994	-0.544	-0.093	0.018	
	1 fire	-0.581	-0.274	0.033	0.080	
	2 fires	-0.572	-0.092	0.388	0.707	
	3+ fires	-0.330	-0.022	0.285	0.886	
	EVD7: 1 fire	0.313	0.851	1.388	0.002	
	EVD7: 2 fires	-0.176	0.553	1.282	0.137	
	EVD7: 3+ fires	-0.393	0.228	0.850	0.472	0.1
Feeding on insects from bark	Fire Type unknown	-0.751	0.088	0.926	0.838	
	Fire Type bushfire	-0.298	-0.102	0.093	0.305	0.1
Feeding on insects from bark	FG2	-0.331	0.064	0.459	0.751	
	FG3	-0.342	0.026	0.395	0.888	
	FG4	-0.450	-0.073	0.304	0.705	
	FG5	-0.381	-0.011	0.358	0.952	
	FG6	-0.320	0.022	0.365	0.898	
	2nd Year	-0.597	-0.287	0.023	0.069	0.1

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
	North East	0.076	0.444	0.813	0.018	
Feeding on insects from bark	EVD7	-0.322	-0.082	0.158	0.502	
	Fire Type unknown	-0.766	0.072	0.910	0.867	
	Fire Type bushfire	-0.293	-0.098	0.098	0.328	0.1
Feeding on insects from canopy	Obs 2	-0.240	0.001	0.243	0.990	
	Obs 3	-0.742	-0.419	-0.097	0.011	
	Obs 4	-0.204	0.089	0.381	0.551	
	Obs 5	-0.283	-0.046	0.192	0.708	
	Obs 6	-0.380	-0.121	0.138	0.360	
	Obs 7	-0.167	0.143	0.452	0.367	
	North East	0.029	0.386	0.743	0.034	0.5
Feeding on insects from canopy	2nd Year	-0.292	-0.107	0.078	0.256	
	North East	0.099	0.420	0.741	0.010	0.5
Feeding on insects from damp ground	EVD 7	0.103	0.555	1.008	0.016	
	< Min TFI	-0.865	-0.388	0.089	0.111	0.5
Feeding on insects from damp ground	EVD 7	0.074	0.530	0.986	0.023	0.5
Feeding on insects from damp ground	EVD 7	0.093	0.647	1.201	0.022	
	< Min TFI	-0.905	-0.265	0.375	0.417	
	EVD 7:< Min TFI	-1.228	-0.273	0.682	0.575	0.5
Feeding on insects from damp ground	2nd Year	-0.426	-0.057	0.313	0.764	
	North East	-1.850	-0.923	0.004	0.051	0.5
Feeding on insects from damp ground	Null	-0.753	-0.522	-0.290	0.000	0.5
Feeding on insects from damp ground	< Min TFI	-0.838	-0.350	0.139	0.161	0.5
Feeding on insects from damp ground	EVD 7	0.099	0.554	1.009	0.017	
	Fire Type unknown	-0.808	0.890	2.589	0.304	
	Fire Type bushfire	-0.453	0.002	0.457	0.994	0.5
Feeding on insects from damp ground	< Min TFI	-0.813	-0.328	0.158	0.186	
	2nd Year	-0.451	-0.081	0.289	0.669	
	North East	-1.801	-0.884	0.033	0.059	0.5
Feeding on insects from open ground under trees	Fire Type unknown	-2.193	-0.330	1.534	0.729	
	Fire Type bushfire	-0.912	-0.471	-0.030	0.036	
	2nd Year	-0.779	-0.413	-0.046	0.027	
	North East	0.041	0.997	1.953	0.041	0.6
Feeding on insects from open ground under trees	2nd Year	-0.826	-0.463	-0.101	0.012	
	North East	0.033	1.018	2.002	0.043	0.6
Feeding on insects from open ground under trees	6-20yrs	-0.591	-0.030	0.531	0.917	
	21-40yrs	-0.476	0.160	0.796	0.623	0.6

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
	41+yrs	-1.173	-0.539	0.094	0.095	
	2nd Year	-0.834	-0.458	-0.083	0.017	
	North East	-0.091	0.951	1.992	0.074	
Feeding on insects from open ground under trees	< Min TFI	-0.446	0.015	0.475	0.950	
	2nd Year	-0.826	-0.462	-0.099	0.013	
	North East	0.031	1.017	2.003	0.043	0.6
Feeding on insects from open ground under trees	1 fire	-0.019	0.564	1.147	0.058	
	2 fires	-0.226	0.551	1.328	0.165	
	3+ fires+	-0.047	0.564	1.176	0.071	
	2nd Year	-0.796	-0.430	-0.063	0.022	
	North East	-0.041	0.978	1.998	0.060	0.6
Feeding on insects from trees and shrubs	EVD 7	-0.020	0.265	0.551	0.069	
	6-10yrs	-0.245	0.315	0.875	0.270	
	11-20yrs	-0.750	-0.343	0.064	0.099	
	21-40yrs	-0.329	0.075	0.480	0.716	
	41+yrs	-0.645	-0.220	0.206	0.311	0.6
Feeding on insects from trees and shrubs	EVD 7	-0.034	0.259	0.551	0.083	0.6
Feeding on insects from trees and shrubs	Null	0.595	0.748	0.902	<0.001	0.6
Feeding on insects from trees and shrubs	6-10yrs	-0.215	0.348	0.912	0.226	
	11-20yrs	-0.728	-0.319	0.091	0.127	
	21-40yrs	-0.334	0.074	0.482	0.722	
	41+yrs	-0.647	-0.218	0.211	0.318	0.6
Feeding on insects from trees and shrubs	2nd Year	-0.112	0.107	0.326	0.337	
	North East	-0.052	0.407	0.866	0.082	0.6
Feeding on insects from trees and shrubs	EVD 7	-0.028	0.265	0.557	0.076	
	< Min TFI	-0.392	-0.092	0.208	0.549	0.6
Feeding on insects from trees and shrubs	< Min TFI	-0.379	-0.079	0.221	0.606	0.6
Feeding on insects from trees and shrubs	6-10yrs	-0.190	0.366	0.922	0.197	
	11-20yrs	-0.686	-0.279	0.128	0.179	
	21-40yrs	-0.369	0.046	0.461	0.829	
	41+yrs	-0.638	-0.208	0.222	0.343	
	2nd Year	-0.135	0.094	0.324	0.421	
	North East	-0.113	0.341	0.796	0.141	0.6
Frugivores	EVD 7	-1.247	-0.646	-0.044	0.036	0.5
Frugivores	EVD 7	-1.787	-1.013	-0.238	0.010	
	< Min TFI	-1.204	-0.512	0.180	0.147	
	EVD 7:< Min TFI	-0.174	0.998	2.170	0.095	0.5

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
Frugivores	2nd Year	-0.092	0.372	0.837	0.116	
	North East	-0.092	0.788	1.669	0.079	0.5
Frugivores	EVD 7	-1.234	-0.629	-0.024	0.042	
	< Min TFI	-0.727	-0.159	0.409	0.584	0.5
Frugivores	Null	-1.583	-1.284	-0.985	<0.001	0.5
Frugivores	< Min TFI	-0.777	-0.196	0.384	0.508	
	2nd Year	-0.114	0.352	0.819	0.139	
	North East	-0.076	0.800	1.676	0.074	0.5
Nectarivores	EVD 7	-0.012	0.267	0.546	0.061	
	< Min TFI	-0.712	-0.421	-0.130	0.005	0.6
Nectarivores	EVD 7	-0.214	0.130	0.474	0.458	
	< Min TFI	-0.982	-0.594	-0.205	0.003	
	EVD 7:< Min TFI	-0.190	0.395	0.980	0.186	0.6
Nectarivores	< Min TFI	-0.696	-0.404	-0.112	0.007	0.6
Nectarivores	1 fire	-0.503	-0.145	0.212	0.426	
	2 fires	-0.377	0.093	0.563	0.698	
	3+ fires	-0.953	-0.555	-0.157	0.006	0.6
Nectarivores	EVD 7	-0.075	0.202	0.480	0.154	
	1 fire	-0.504	-0.149	0.206	0.411	
	2 fires	-0.407	0.062	0.531	0.796	
	3+ fires+	-0.949	-0.554	-0.158	0.006	0.6
Nectarivores	< Min TFI	-0.681	-0.389	-0.096	0.009	
	2nd Year	-0.127	0.098	0.323	0.394	
	North East	-0.241	0.220	0.682	0.350	0.6
Carnivores	Obs 2	-0.368	0.162	0.692	0.548	
	Obs 3	-0.264	0.326	0.917	0.279	
	Obs 4	0.084	0.653	1.222	0.025	
	Obs 5	-0.579	-0.039	0.501	0.887	
	Obs 6	-0.953	-0.374	0.204	0.205	
	Obs 7	-1.305	-0.585	0.134	0.111	
	North East	-0.790	0.073	0.936	0.868	0.5
Carnivores	1 fire	-0.059	0.362	0.783	0.092	
	2 fires	-0.728	-0.089	0.550	0.786	
	3+ fires	0.052	0.509	0.967	0.029	
	2nd Year	0.429	0.740	1.050	0.000	
	North East	-0.472	0.323	1.117	0.426	0.4
Carnivores	2nd Year	0.365	0.662	0.959	0.000	

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
	North East	-0.460	0.330	1.120	0.413	0.4
Carnivores	< Min TFI	-0.124	0.210	0.543	0.218	
	2nd Year	0.392	0.693	0.994	0.000	
	North East	-0.452	0.333	1.117	0.406	0.4
Carnivores	Fire Type unknown	-1.913	-0.227	1.458	0.792	
	Fire Type bushfire	-0.628	-0.290	0.048	0.092	
	2nd Year	0.429	0.743	1.057	0.000	
	North East	-0.466	0.327	1.121	0.419	0.4
Carnivores	6-20yrs	-0.282	0.149	0.580	0.498	
	21-40yrs	-0.579	-0.070	0.440	0.789	
	41+yrs	-0.830	-0.345	0.139	0.162	
	2nd Year	0.439	0.776	1.114	0.000	
	North East	-0.486	0.356	1.198	0.407	0.4

Table 28: Generalised linear mixed models (GLMMs) of bird habitat guild density

Density of forest birds (birds per 20 minute / 2 hectare counts) predicted by combinations or fire, environmental and sampling variables. All models within two AIC of the best model are shown with their percentage deviance explained

Response variable	Predictor variables	CI (lower)	Estimate	CI (upper)	p	Dev exp %
Forest	Obs 2	-0.111	0.017	0.144	0.798	
	Obs 3	-0.544	-0.376	-0.208	0.000	
	Obs 4	-0.024	0.131	0.286	0.097	
	Obs 5	-0.225	-0.100	0.024	0.115	
	Obs 6	-0.274	-0.136	0.002	0.053	
	Obs 7	-0.196	-0.027	0.142	0.754	
	North East	-0.033	0.248	0.529	0.084	0.7
Forest	< Min TFI	-0.301	-0.133	0.035	0.121	
	2nd Year	-0.121	-0.022	0.078	0.669	
	North East	0.070	0.339	0.607	0.013	0.6

Appendix 4: Ground-dwelling Mammals

Table 29. Percentage of sites at which mammal species were indentified from camera images

VBA taxon ID	Common name	Scientific name	Percentage of sites
1242	Black Wallaby	*Wallabia bicolor*	88
1165	Common Wombat	*Vombatus ursinus*	66
1113	Common Brushtail Possum	*Trichosurus vulpecula*	66
1395	Bush Rat	*Rattus fuscipes*	57
1003	Short-beaked Echidna	*Tachyglossus aculeatus*	48
1536	House Cat	*Felis catus*	36
1115	Mountain Brushtail Possum	*Trichosurus cunninghami*	35
1028	Agile Antechinus	*Antechinus agilis*	28
1097	Long-nosed Bandicoot	*Perameles nasuta*	19
1162	Koala	*Phascolarctos cinereus*	13
1265	Eastern Grey Kangaroo	*Macropus giganteus*	11
1532	Red Fox	*Vulpes vulpes*	11
1179	Long-footed Potoroo	*Potorous longipes*	7
1179	Long-nosed Potoroo	*Potorous tridactylus*	7
1836	Dog	*Canis familiaris*	6
1129	Common Ringtail Possum	*Pseudocheirus peregrinus*	6
1261	Red-necked Wallaby	*Macropus rufogriseus*	4
1092	Southern Brown Bandicoot	*Isoodon obesulus obesulus*	4
1527	Sambar Deer	*Rusa unicolor*	4
1069	White-footed Dunnart	*Sminthopsis leucopus*	3
1150	Eastern Pygmy-possum	*Cercartetus nanus*	3
1510	European Rabbit	*Oryctolagus cuniculus*	2
1523	Fallow Deer	*Dama dama*	1
1138	Sugar Glider	*Petaurus breviceps*	1

Table 30. Relative importance of each model term for each species

Model term	Short-beaked Echidna	Agile Antechinus	Common Wombat	Long-nosed Bandicoot	Mountain Brushtail Possum	Common Brushtail Possum	Long-nosed Potoroo	Eastern Grey Kangaroo	Black Wallaby	Bush Rat	Superb Lyrebird
Ψ(Easting)	0.96	0.38	0.09	0.30	0.41	0.19	0.92	0.31	1.00	0.00	0.11
Ψ (EVD)	1.00	0.17	0.09	0.44	0.16	1.00	0.36	0.43	0.68	0.35	0.56
Ψ(FF)	0.75	0.12	0.38	0.17	0.15	0.12	0.18	0.06	0.82	0.15	0.55
Ψ(TSF)	0.57	0.12	0.43	0.87	0.75	0.12	0.18	0.83	0.77	0.17	0.13
Ψ(EVD:FF)	0.41	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.68	0.00	0.49
Ψ(EVD:TSF)	0.07	0.00	0.00	0.23	0.05	0.00	0.00	0.19	0.06	0.00	0.00
Ψ(FF:TSF)	0.03	0.00	0.02	0.02	0.02	0.00	0.05	0.00	0.77	0.00	0.01
Ψ(EVD:FF:TSF)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
p(Easting)	0.14	0.87	0.13	0.59	0.16	0.64	1.00	1.00	0.87	0.00	0.50
p(EVD)	0.35	1.00	0.43	1.00	0.10	1.00	0.46	1.00	1.00	1.00	0.62
p(FF)	0.28	1.00	0.27	0.89	0.11	1.00	1.00	0.12	1.00	1.00	0.98
p(TSF)	0.64	1.00	1.00	0.64	0.32	0.98	1.00	1.00	1.00	1.00	1.00
p(EVD:FF)	0.06	1.00	0.12	0.12	0.00	1.00	0.05	0.00	1.00	1.00	0.21
p(EVD:TSF)	0.00	1.00	0.18	0.04	0.00	0.33	0.05	1.00	0.94	1.00	0.06
p(FF:TSF)	0.02	1.00	0.05	0.08	0.00	0.72	1.00	0.00	0.76	1.00	0.97
p(EVD:FF:TSF)	0.00	1.00	0.00	0.00	0.00	0.24	0.00	0.00	0.11	0.16	0.00

Table 31. Short-beaked Echidna occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	-0.9196	0.6484	1.418	0.1561
Ψ(Easting)	-1.5036	0.8598	1.749	0.0803
Ψ(EVD7)	3.848	7.9722	0.483	0.6293
Ψ(FF)	1.0876	0.7388	1.472	0.141
Ψ(EVD7:FF)	-2.4044	8.3227	0.289	0.7727
p(Int)	-2.6297	0.2445	10.757	<2e-16
p(TSF)	-0.2256	0.2156	1.047	0.2953
Ψ(TSF)	0.4063	0.8064	0.504	0.6143
p(EVD7)	-0.416	0.3603	1.155	0.2483
p(FF)	-0.1343	0.2865	0.469	0.6391
p(Easting)	-0.1287	0.1689	0.762	0.4461
Ψ(EVD7:TSF)	-0.8684	1.4545	0.597	0.5505
p(EVD7:FF)	-0.5443	0.3597	1.514	0.1302
Ψ(FF:TSF)	-0.172	0.78	0.221	0.8255
p(FF:TSF)	-0.1985	0.2159	0.92	0.3578

Table 32. Agile Antechinus occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	-0.82784	0.35773	2.314	0.02066
p(Int)	-2.29024	0.48262	4.745	2.10E-06
p(Easting)	0.59751	0.25735	2.322	0.02024
p(EVD7)	1.25567	0.68288	1.839	0.06595
p(FF)	-0.21692	0.48165	0.45	0.65245
p(TSF)	-0.43884	0.56247	0.78	0.43527
p(EVD7:FF)	1.77389	0.55027	3.224	0.00127
p(EVD7:TSF)	2.06112	0.65529	3.145	0.00166
p(FF:TSF)	0.07404	0.44269	0.167	0.86718
p(EVD7:FF:TSF)	1.42905	0.53332	2.68	0.00737
Ψ(Easting)	0.44828	0.33583	1.335	0.18192
Ψ(EVD7)	0.54634	0.64537	0.847	0.39724
Ψ(FF)	0.12737	0.33618	0.379	0.70478
Ψ(TSF)	0.07136	0.3752	0.19	0.84915

Table 33. Common Wombat occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	1.20025	0.35062	3.423	0.000619
p(Int)	-2.05311	0.13047	15.736	< 2e-16
p(TSF)	-0.254	0.13614	1.866	0.062079
Ψ(FF)	0.49843	0.43875	1.136	0.255948
Ψ(TSF)	0.54514	0.45924	1.187	0.235214
p(EVD7)	0.17516	0.21792	0.804	0.421511
p(FF)	-0.13995	0.148	0.946	0.344319
p(EVD7:FF)	0.55747	0.27483	2.028	0.042516
p(EVD7:TSF)	0.41379	0.28468	1.454	0.146074
Ψ(EVD7)	0.10439	0.63	0.166	0.868391
Ψ(Easting)	-0.02745	0.31258	0.088	0.93003
p(Easting)	-0.04567	0.10758	0.425	0.671153
p(FF:TSF)	-0.13594	0.12985	1.047	0.295146
Ψ(FF:TSF)	-0.12474	0.55817	0.223	0.823166

Table 34. Long-nosed Bandicoot occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	10.81456	54.70288	0.198	0.84328
Ψ(TSF)	17.63005	83.37723	0.211	0.83254
p(Int)	-5.09393	0.94298	5.402	1.00E-07
p(EVD7)	2.9687	1.14235	2.599	0.00936
p(FF)	0.65919	0.53753	1.226	0.22007
Ψ(Easting)	1.55638	1.67728	0.928	0.35345
Ψ(EVD7)	-25.5075	80.56239	0.317	0.75153
p(Easting)	-0.80214	0.46197	1.736	0.0825
Ψ(EVD7:TSF)	-59.47853	153.52085	0.387	0.69844
p(TSF)	-0.52762	0.48711	1.083	0.27874
Ψ(FF)	4.99781	19.372	0.258	0.79641
p(EVD7:FF)	0.36759	1.27958	0.287	0.7739
Ψ(EVD7:FF)	-29.54204	40.89415	0.722	0.47005
p(FF:TSF)	-0.20052	0.30121	0.666	0.50559
Ψ(FF:TSF)	0.8266	0.6569	1.258	0.20827
p(EVD7:TSF)	0.05767	0.9746	0.059	0.95282

Table 35. Mountain Brushtail Possum occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	-0.59637	0.29351	2.032	0.0422
Ψ(TSF)	0.29109	0.28142	1.034	0.301
p(Int)	-2.08632	0.15808	13.198	<2e-16
Ψ(Easting)	-0.3904	0.29199	1.337	0.1812
p(TSF)	-0.01882	0.1158	0.163	0.8709
p(Easting)	-0.1015	0.16139	0.629	0.5294
p(FF)	0.06027	0.15899	0.379	0.7046
Ψ(EVD7)	0.17352	0.62427	0.278	0.781
Ψ(FF)	-0.13148	0.32066	0.41	0.6818
p(EVD7)	0.02774	0.3048	0.091	0.9275
Ψ(EVD7:TSF)	0.73416	0.62151	1.181	0.2375
Ψ(FF:TSF)	0.33285	0.38784	0.858	0.3908

Table 36. Common Brushtail Possum occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	1.64267	0.45232	3.632	0.000282
Ψ(EVD7)	-1.84158	0.59135	3.114	0.001844
p(Int)	-1.01724	0.12449	8.172	< 2e-16
p(Easting)	0.16264	0.08941	1.819	0.068897
p(EVD7)	-0.2304	0.23226	0.992	0.321213
p(FF)	-0.40219	0.13237	3.038	0.002378
p(TSF)	0.30682	0.17974	1.707	0.087815
p(EVD7:FF)	0.89487	0.24061	3.719	0.0002
p(FF:TSF)	0.27671	0.14966	1.849	0.064476
p(EVD7:TSF)	-0.22982	0.34984	0.657	0.511218
p(EVD7:FF:TSF)	-0.54893	0.25903	2.119	0.034075
Ψ(Easting)	-0.28176	0.32856	0.858	0.391141
Ψ(FF)	0.12075	0.31202	0.387	0.69877
Ψ(TSF)	-0.08805	0.27475	0.32	0.748612

Table 37. Long-nosed Potoroo occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	-6.9029	52.6377	0.131	0.8957
Ψ(Easting)	4.6542	12.465	0.373	0.7089
Ψ(EVD7)	9.4728	85.998	0.11	0.9123
p(Int)	-7.0206	461.8859	0.015	0.9879
p(Easting)	-3.9227	1.6983	2.31	0.0209
p(FF)	2.4281	953.9841	0.003	0.998
p(TSF)	0.9436	176.9444	0.005	0.9957
p(FF:TSF)	4.2588	1.072	3.973	7.10E-05
p(EVD7)	17.7206	679.4712	0.026	0.9792
Ψ(FF)	-3.8788	8.7501	0.443	0.6576
Ψ(TSF)	-2.686	5.7326	0.469	0.6394
p(EVD7:FF)	7.5316	4315.8526	0.002	0.9986
p(EVD7:TSF)	-2.1024	800.6688	0.003	0.9979
Ψ(FF:TSF)	-18.3755	15.9093	1.155	0.2481

Table 38. Eastern Grey Kangaroo occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	38.6299	144.5541	0.267	0.78929
Ψ(TSF)	5.6897	126.4358	0.045	0.96411
p(Int)	-4.8353	0.7595	6.366	< 2e-16
p(Easting)	0.7911	0.3829	2.066	0.03883
p(EVD7)	-0.4213	1.0667	0.395	0.69288
p(TSF)	0.1435	0.46	0.312	0.75497
p(EVD7:TSF)	-4.1156	1.4742	2.792	0.00524
Ψ(Easting)	-5.8651	15.3815	0.381	0.70297
Ψ(EVD7)	-28.429	445.7945	0.064	0.94915
Ψ(EVD7:TSF)	173.7856	256.5765	0.677	0.4982
p(FF)	-0.3037	0.4021	0.755	0.45016
Ψ(FF)	-0.5171	0.7728	0.669	0.50346

Table 39. Black Wallaby occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	5.37325	9.7117	0.553	0.580075
Ψ(Easting)	-5.91061	4.77425	1.238	0.215709
Ψ(EVD7)	4.11023	12.54017	0.328	0.743089
Ψ(FF)	2.95511	22.55603	0.131	0.895766
Ψ(TSF)	-5.15085	3.34061	1.542	0.1231
Ψ(EVD7:FF)	-11.92386	25.04361	0.476	0.633986
Ψ(FF:TSF)	-9.05991	6.70056	1.352	0.176339
p(Int)	-1.16261	0.11476	10.131	< 2e-16
p(Easting)	-0.18524	0.07855	2.358	0.018358
p(EVD7)	-0.33093	0.16119	2.053	0.040074
p(FF)	-0.36632	0.10593	3.458	0.000544
p(TSF)	-0.43338	0.13313	3.255	0.001133
p(EVD7:FF)	0.64746	0.18711	3.46	0.00054
p(EVD7:TSF)	0.38111	0.18782	2.029	0.042451
p(FF:TSF)	-0.20339	0.10503	1.937	0.052803
p(EVD7:FF:TSF)	-0.19962	0.22497	0.887	0.374893
Ψ(EVD7:TSF)	2.18356	3.35981	0.65	0.515753

Table 40. Bush Rat occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	0.328136	0.355693	0.923	0.356254
p(Int)	-1.379201	0.290029	4.755	2.00E-06
p(EVD7)	-0.714228	0.450917	1.584	0.113206
p(FF)	0.063531	0.102692	0.619	0.536143
p(TSF)	0.026547	0.007234	3.67	0.000243
p(EVD7:FF)	0.44903	0.133753	3.357	0.000788
p(EVD7:TSF)	0.054152	0.015996	3.385	0.000711
p(FF:TSF)	-0.017834	0.006419	2.779	0.00546
Ψ(EVD7)	0.569939	0.487546	1.169	0.242405
Ψ(TSF)	0.011205	0.018108	0.619	0.536035
p(EVD7:FF:TSF)	0.006508	0.011681	0.557	0.577448
Ψ(FF)	-0.057176	0.165824	0.345	0.730244

Table 41. Superb Lyrebird occupancy model parameter estimates

Model term	Estimate	SE	z value	Pr(>|z|)
Ψ(Int)	-0.04378	0.31385	0.14	0.889
Ψ(EVD7)	-0.2553	0.53264	0.479	0.6317
Ψ(FF)	0.29262	0.37979	0.77	0.441
Ψ(EVD7:FF)	-1.57236	0.64739	2.429	0.0152
p(Int)	-1.58905	0.20315	7.822	<2e-16
p(FF)	-0.01566	0.1649	0.095	0.9244
p(TSF)	-0.05619	0.1932	0.291	0.7712
p(FF:TSF)	0.45666	0.17978	2.54	0.0111
p(Easting)	-0.19139	0.11717	1.633	0.1024
p(EVD7)	0.42261	0.30196	1.4	0.1616
p(EVD7:FF)	-0.51029	0.38254	1.334	0.1822
Ψ(Easting)	-0.07772	0.282	0.276	0.7829
Ψ(TSF)	0.08952	0.39527	0.226	0.8208
p(EVD7:TSF)	-0.05115	0.32997	0.155	0.8768
Ψ(FF:TSF)	-0.50508	0.4656	1.085	0.278

Appendix 5: The effect of fire regimes on lichens

Introduction

Lichens provide important ecological functions, such as fixing atmospheric nitrogen, which then provides a significant source of nitrogen for plants (Lepp 2011). Lichens are regarded as susceptible to decline in abundance and diversity when subject to frequent fire (Scott *et al.* 1997). This is because they are destroyed by direct heat and flames, and recolonisation is dependent on transportation of lichen propagules by air, fauna and water (Mistry 1998). Changes in moisture and shade following fire also contribute to the impact on lichens (Pharo and Beattie 1997). Fire behaviour influences the recovery of lichen communities after fire, with low flame heights and patchy fires being associated with the survival of lichens immediately after fires as well as affecting the subsequent speed of recolonisation (Mistry 1998).

The loss or alteration of their microhabitats due to fire is also likely to affect the time lichens take to recover. The availability of important growing substrates, such as fallen wood on the ground, may be limited after fires (Scott *et al.* 1997) and can take considerable time to be replenished. Logs have been found to support comparatively high lichen species richness (Pharo and Beattie 2002) so any reduction in log availability is expected to disadvantage lichens.

Research into the effects of fire on lichens is very sparse, particularly in Australia. Studies from elsewhere are mainly from environments different to Australia (e.g. Davies and Legg 2008, Hamalainen *et al* 2014), and so may have limited applicability. Studies in south-eastern Australia have shown that time since fire affects lichen diversity (Pharo and Beattie 1997). Research in central Brazil found that lichen abundance declined at sites with more frequent fire (Mistry 1998).

We predicted *a priori* that lichens would be present at lower levels at more recently burnt sites and would show a slow increase as time elapses after fires. It was expected that lichen morphological groups on different substrates would be affected differently by fire, with the greatest impact being on woody debris because features at ground level are most uniformly affected by fire (Pharo and Beattie 1997).

Methods

Site stratification and replication

Lichen surveys were conducted at 49 sites in Gippsland, between October 2011 and February 2012. This was a subset of the total sites sampled for vascular flora. Those sites with no reliably recorded fire history (12) were excluded from this report. A greater number of sites were sampled from EVD 3 (21) than EVD 7 (16). Sites burnt in the last seven years, and those burnt between 14 and 22 years ago were most commonly represented. The majority of sites had experienced either one fire (14) or more than four fires (14) since 1970. Sites that had experienced planned burns (28) were more common than bushfire (9). Tables 42, 43 & 44 summarise the sites by fire history and EVD.

Table 42: Number of sites surveyed for lichens, by time since last fire

Time Since Last Fire (years)	EVD 3	EVD 7	Total
0–7	11	6	17
14–22	8	8	16
40+	2	2	4
Total	21	16	37

Table 43: Number of sites surveyed for lichens, by the number of fires since 1970

Fires Since 1970 (number)	EVD 3	EVD 7	Total
0	2	2	4
1	7	7	14
2–3	2	3	5
4+	10	4	14
Total	21	16	37

Table 44: Number of sites surveyed for lichens, by fire type

Fire Type	EVD 3	EVD 7	Total
Planned burn	17	11	28
Bushfire	4	5	9
Total	21	16	37

Measurement variables and sampling design

Lichen species that grow on bark have been shown to be useful indicators of fire history (Mistry 1998). Lichens vary in occurrence according to different woody substrates, and a study of lichens and fire in NSW (Pharo and Beattie 1997, 2002) used logs, tree trunks and fallen branches as sampling units. We used two groupings of substrates: dead fallen wood or living stems and trunks. Identification of individual lichen species is difficult, and the use of morphological groups has been found to be an efficient monitoring method (Eldridge and Rosentreter 1998). Two broad growth forms were chosen to differentiate how tightly or loosely the lichens were attached to the woody substrate. These were: projecting (Figure 20 - incorporating foliose and fruticose) and flat (Figure 21 - incorporating crustose and squamulose). These groups are analogous to the two broad growth forms (foliose and crustose) used by Pharo and Beattie (1997 and 2002) in analysing lichen responses to environmental variables.

Four lichen morphogroups were targeted for survey:

- Projecting growth forms on dead fallen wood
- Flat growth forms on dead fallen wood
- Projecting growth forms on living stems and trunks
- Flat growth forms on living stems and trunks

Figure 20: Foliose lichen (Photo: Josephine MacHunter)

Figure 21: Crustose and squamulose lichens (Photo: David Meagher)

Lichens were sampled using the same frequency measurement as for vascular plants, which was based on recording the presence of morphogroups in a number of plots at a site and then calculating a percentage occurrence. The reasons for choosing a frequency method are outlined in the section on vascular flora methods (2.4.2).

Sampling procedures and frequency calculation

Twenty-one sub-plots of 1m x 1m were sampled at each site, seven along each of three transects. The procedures for the site set-up were the same as for vascular flora (see section 2.4.3). Within each plot all living stems/trunks to 2 metres and dead fallen wood were surveyed for the presence of lichens. Two broad growth forms were sampled: projecting (incorporating foliose and fruticose) and flat (incorporating crustose and squamulose).

All data were entered into the *Microsoft* Access database created for the project. Frequency values were calculated for each site by giving a score of '1' for the occurrence of one or more members of a lichen morphogroup in a plot. These scores were summed for each site and then divided by the total number of plots (21) to give a percentage occurrence for each morphogroup at a site.

Data analyses

Analyses of the data from this project investigated the relationships between response variables (lichen morphogroups) and explanatory variables (time since fire, number of fires since 1970, bushfire or planned burn).

The analyses were carried out, using explanatory variables of EVD and several fire covariates (Table 45). Time since fire was treated as a continuous variable. Twelve sites had no recorded fire history and therefore could not be assigned a defensible numerical time since fire, and so were excluded from the analyses.

Multiple quasi-binomial generalised linear models (GLM) were constructed relating to statistical hypotheses to evaluate our *a priori* predictions about the effect of fire on the presence of different lichen morphogroups. See section 2.4.5 for an explanation of the statistical procedures used, and the hypotheses/models considered.

Table 45: Variables included in lichen analysis

Variable	Abbreviation	Possible values	Variable type
EVD	EVD	3, 7	Categorical
Time since fire	TSF	1 to 46 years	Numeric
Fires since 1970	Fires	1 to 5 fires	Numeric
Most recent fire type	LastFireType	planned, bushfire	Categorical

Results

Model selection

The models with the most evidence for fire variables as predictors for occurrence of lichen morphogroups were for 'projecting growth forms on dead fallen wood', 'flat growth forms on dead fallen wood' and 'projecting growth forms on living stems and trunks' (Table 46). Fire variables were not in the best models for the lichen morphogroup with 'flat growth forms on living stems and trunks'. Table 47 shows the estimates of the model coefficients and confidence intervals for the best models for each lichen morphogroup.

Table 46: Models with the most evidence as predictors for occurrence of lichen morphogroups

Lichen morphogroup	Model with lowest QAICc
Projecting growth forms on dead fallen wood	Presence~EVD*TSF
Flat growth forms on dead fallen wood	Presence~EVD*TSF
Projecting growth forms on living stems and trunks	Presence~LastFireType*TSF
Flat growth forms on living stems and trunks	Presence

Table 47: Lichen morphogroup frequency predicted by fire variables; models with lowest QAICc shown with estimate, upper and lower confidence intervals.

Response variable	Predictor variable	Estimate	Lower CI	Upper CI
Projecting growth forms on dead fallen wood	EVD*TSF	-0.016	-0.076	0.044
Flat growth forms on dead fallen wood	EVD*TSF	0.047	-0.011	0.104
Projecting growth forms on living stems/trunks	LastFireType*TSF	0.045	-0.132	0.221
Flat growth forms on living stems/trunks	Null	-2.394	-2.945	-1.843

Relationships between lichen morphogroups and fire history

Projecting growth forms on dead fallen wood

The time since fire model had the most evidence as a predictor of occurrence for this morphogroup (Figure 22). The analysis showed a trend for greater detection of these lichens at longer periods after fire, with the highest occurrence at over 40 years since fire. The positive trajectory of these lichens appears to continue after this time. There was a greater presence of lichens in EVD 3 compared to EVD 7 at any time since fire, with a stronger recovery of lichens in EVD 3 in later years. The wide confidence intervals reflect the lack of site data between 23 and 43 years after fire, with four sites (two for each EVD) representing 44 to 46 years after fire.
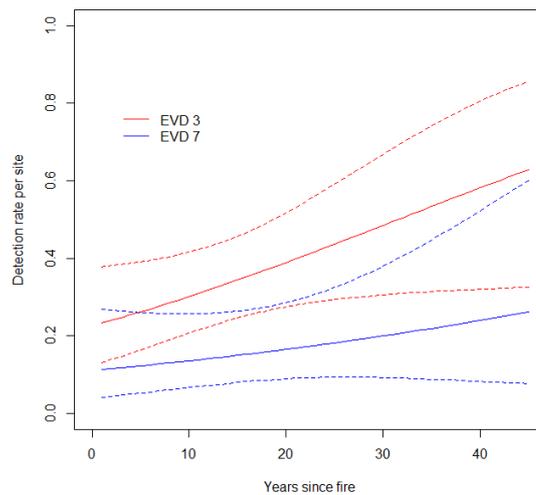

Figure 22: Lichen 'Projecting growth forms on dead fallen wood', occurrence per site and time since fire (with 95% CI) and interaction with EVD

Flat growth forms on dead fallen wood

The time since fire model had the most evidence as a predictor of occurrence for this morphogroup (Figure 23). The analysis showed a similar trend to the previous morphogroup, but with slightly lower presence of lichens. There was a greater detection of these lichens at longer periods after fire, with the highest occurrence at over 40 years since fire, with a positive trajectory appearing to continue. There was also a greater presence of lichens in EVD 3 compared to EVD 7 at any time since fire, but a stronger recovery of lichens in EVD 7 in later years. Once again, wide confidence intervals reflect the lack of site data between 23 and 43 years after fire, with four sites (two for each EVD) sampled after this time.
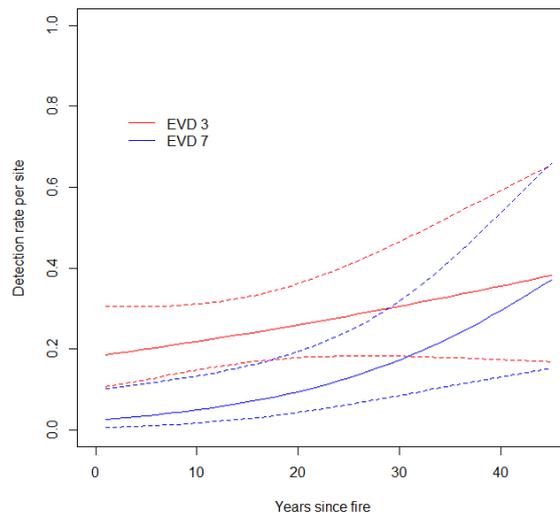
Figure 23: Lichen 'Flat growth forms on dead fallen wood', occurrence per site and time since fire (with 95% CI) and interaction with EVD

Projecting growth forms on living stems/trunks

The time since fire model also had the most evidence as a predictor of occurrence for this morphogroup, with a small increase in occurrence over time. However there were very wide confidence intervals due to an uneven spread of sites across time since fire, and a low occurrence of lichens on these substrates which is likely to be related to insufficient sampling intensity. For planned burns, the wide confidence intervals are due to the lack of data for sites burnt more than 22 years prior to the survey. For bushfires, the wide confidence intervals result from the zero detections in the early years after fire, the lack of data for sites between 15 and 43 years after fire, and the low number of sites overall.

Discussion

Relationships between lichen morphogroups and fire variables

Our results provide support for the prediction that lichens are negatively affected by short fire intervals. Three of the four morphogroups showed trends for highest occurrence of lichens at sites burnt more than 40 years before our surveys. This aligns with other studies that show time since fire is the critical factor in lichen diversity (Pharo and Beattie 1997) and high lichen abundance occurs at sites protected from fire, and low lichen abundance at sites that have experienced frequent fire (Mistry 1998). Reduction in moisture levels following fires may be a factor in lower lichen occurrence at more recently burnt sites (Mistry 1998, Pharo and Beattie 1997).

The impact of fire on the substrates appears to be the strongest factor influencing the recorded presence of lichens. Lichen growth forms occurring on dead fallen wood continued to increase in occurrence at sites greater than 40 years after fire. The availability of fallen wood on the ground may be limited after fires and takes time to develop. Lichen growth forms on living stems and trunks were detected in low numbers at all sites, indicating that sampling intensity appears to be inadequate to discern trends. Other studies overseas have documented lower species richness of lichens on burnt sites compared to older vegetation on shrubs (Davies and Legg 2008) and tree trunks (Hamalainen *et al* 2014, Mistry 1998).

Both EVDs showed the trend for lichens on dead fallen wood to be more common at longer times since fire, although there were some differences in the trajectories. There were generally more lichens observed in EVD 3 compared to EVD 7 at any time since fire, although this may be due to the availability of fallen wood in this vegetation type. Projecting growth forms (foliose and fruticose) were found to have a higher occurrence at sites than flat growth forms (crustose and squamulose), but this is likely to be an artefact of observability.

No direct data was available on the effects of fire severity on lichen occurrence, and so records of planned burns (usually low severity) and bushfires (usually high severity) were used as surrogate measures. The model for projecting growth forms on living stems and trunks showed no lichens recorded from sites up to14 years after bushfires, and low occurrence at sites up to 22 years after planned burns. Other studies have shown that low severity and patchy fires are associated with higher survival of lichens immediately after fires and quicker recovery in the following years (Mistry 1998). Higher severity fires are likely to have a larger effect on lichens because shrubs will have been totally consumed and there is a lag time to replace the shrub layer. Lichens on tree trunks may be affected for shorter periods because of recolonisation from higher up the trees.

Limitations

The site selection process has resulted in some limitations on the models derived from this analysis. The number of sites was restricted and the fire age distribution was uneven (no sites between 23 and 43 year after fire), due to the sites being sampled in the second year of the vascular plant surveys. Fire history records did not include patchiness, which may have effects at the scale of sampling for lichen substrates. The use of 'bushfire' or 'planned burn' records was an inadequate surrogate for fire severity.

The sampling methods also had some limitations. There is likely to have been insufficient intensity of sampling at each site, especially for the substrate consisting of stems and trunks where lichen occurrence was low. Finer scale sampling methods have been used in other studies (e.g. Pharo and Beattie 1997). Although morphogroups are an accepted sampling method, the choice of substrates in this study may have been too coarse. Different bark textures support lichens with different sensitivities to fire (Mistry 1998). The two substrates used in our study could have been subdivided into four (i.e. small sticks, large logs, tree trunks, shrub stems). Unfamiliarity with lichens by field operators may also have led to under-detection of crustose lichens at sites, especially in recently burnt vegetation.

Implications for fire management

Fire management to maintain lichens needs to take into account that lichens are both killed by fire and their habitats altered. Hence the time after fires for lichens to recover their presence at sites is critical, and in future should be considered in assessing minimum Tolerable Fire Intervals. The results from this study do not indicate what this time interval should be for the two EVDs sampled, but the trend in the models suggests that lichens continue to increase in presence beyond 40 years after fires.

Future research

Lichens, which are considered to be sensitive to frequent fire, are rarely studied in relation to fire regimes. Results from the trial of lichen data collected and analysed as part of this project have yielded some insights into data collection methods and relationships to fire. Future project designs would benefit from an even stratification of sites for fire variables, greater replication of plots at each site and finer resolution of lichen substrates. A more detailed and targeted study of lichen morphogroups would test the preliminary evidence that presence of lichens is positively related to time-since-fire.

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Appendix 6: The effect of fire regimes on insectivorous bat activity

Introduction

Information on how microbats respond to fire is limited, especially in Australian environments. Research internationally and in northern Australia has mainly focussed on planned burns and has shown an increase in microbat activity in burnt areas (Buchalski *et al.* 2013; Inkster-Draper *et al.* 2013; Smith and Gehrt 2010) or no difference between burnt and unburnt areas (Loeb and Waldrop 2008). In contrast, recent research in Victoria has shown microbat activity to be lower in areas burnt by bushfire, particularly compared to those that have not been burnt for many years (Jemison *et al.* 2012; Macak *et al.* 2012).

The varied responses of microbats to fire have been attributed to differences in the forest structure between burnt and unburnt sites, and linked to microbat flying characteristics (Inkster-Draper *et al.* 2013; Smith and Gehrt 2010). In general, there appears to be a positive association between microbat activity for large, fast flying species with limited manoeuvrability and a more open vegetation structure (Inkster-Draper *et al.* 2013; Smith and Gehrt 2010).

Many of the insectivorous bats (or microbats) that are known to reside within the forests of the current study area forage in the low to mid-storey (tall shrub layer) or in or above the tree canopy. They roost in hollows or under bark (Churchill 2008). Foraging strategies are thought to be influenced by the density and structure of vegetation (Law and Chidel 2002) (often referred to as 'clutter'), which has been related to the morphology of particular bat species, as clutter constrains their manoeuvrability around obstacles, and how fast they can fly (Aldridge and Rautenbach 1987). Fire has the potential to influence habitat quality for microbats via changes in the forest structure and availability of roosting sites or food. Mortality during the fire event itself (Whelan *et al.* 2002), and subsequent population recovery may also be a factor in how microbats' respond to fire.

In this component of the study we report both species level and community responses (all species combined) to time since fire and the number of fires since 1970. We predict that overall microbat activity (all species combined) will be positively associated with time since fire. We also predict that the response to fire history will differ between species, and that this may be related to specific foraging preferences or flying strategies. The limited information available on the responses of microbats to the number of fires is inconclusive (e.g. Jemison *et al.* 2012; Macak *et al.* 2012), so we are unable to make any specific predictions about that aspect of fire regime.

Methods

Site stratification and replication

One bat detector per site was deployed at 27 sites, but one unit malfunctioned resulting in useable data from a total of 26 sites, 16 in EVD 3 and 10 in EVD 7. Table 48 summarises the sites by time since fire and Table 49 summarises the sites by the number of fires since 1970.

Table 48. Number of sites surveyed for microbats by time since last fire

Time Since Last Fire (years)	EVD 3	EVD 7	All sites
0–5	6	3	9
6–20	5	7	12
21–40	2	0	2
41+	3	0	3
All sites	16	10	26

Table 49. Number of sites surveyed for microbats by the number of fires since 1970.

Number of Fires Since 1970	EVD 3	EVD 7	All sites
0	3	0	3
1	6	5	11
2	0	0	0
3+	7	5	12
All sites	16	10	26

Bat survey technique

Surveys for microbats took place from October 2011 to December 2011. We measured microbat activity by recording their echolocation calls on Anabat SD2 bat detector units (Titley Scientific, Ballina, Australia). As microbats use echolocation calls for navigation and foraging, activity levels are indicative of habitat use, allowing a comparison between areas. Note that this method does not measure microbat abundance as it is not possible to determine the number of individuals that are making the calls e.g. one microbat may be producing many calls or many microbats may be producing few calls. Measuring microbat abundance would require trapping and mark-recapture techniques (e.g. Lumsden and Bennett 2005), which are time-consuming and can be restricted by access to sites or lack of appropriate flyways to install traps. Bat detectors in contrast, are an efficient, unobtrusive way to survey microbats, particularly in remote areas, and will record high flying species that are unlikely to be caught in traps.

The detector units were housed in waterproof cases and powered by 12v 7Ah lead-acid batteries. The external microphone and cable was placed in a PVC housing which elevated the microphone (90 cm from the ground), protected it from moisture and angled it towards the canopy. The housing was oriented so that the microphone pointed to a gap in the vegetation, which are known to act as microbat flyways, increasing the likelihood of recording good quality calls. They were programmed to record between 7:00 pm (before dusk) and 7:00 am (after dawn). Detectors were placed at the centre point of sites, which were located using a handheld GPS unit. They were therefore deployed in groups, there were three separate deployments.

Microbat echolocation call identification

Microbat echolocation calls were downloaded from detector units using CFCread software (C. Corben/Titley Electronics). During this process sequences of calls (denoted as 'passes') are converted to an electronic file which can be viewed as a graph of frequency versus time. Good quality calls have a distinctive shape with many, but not all, microbat species able to be distinguished according to a range of call parameters. Call files were viewed using AnalookW software (C. Corben) to filter out extraneous noise (e.g. insect calls, electronic interference) that may also be recorded. Confirmed microbat call files were then processed using AnaScheme software (Adams *et al.* 2010; Gibson and Lumsden 2003), which automatically assigns files to either a species or species complex, or an unknown category. AnaScheme processing is based on microbat call identification keys which are region specific (Adams *et al.* 2010; Lumsden and Bennett 2005). An identification key developed for the south-eastern region of Victoria (L. Lumsden, pers. comm. 2014) was used for the current study sites. The calls of two species of long-eared bat that potentially occur in the study area, Lesser Long-eared Bat, *Nyctophilus geoffroyi* and Gould's Long-eared Bat, *N. gouldi* cannot be distinguished from each other. The identification key is programmed to group these together as long-eared bats, *Nyctophilus* sp. In addition, calls identified as the Large-footed Myotis, *Myotis macropus*, were unable to be distinguished from long-eared bats, and were added to the *Nyctophilus* sp. grouping to form a *Myotis*/*Nyctophilus* species complex post processing. However, the Large-footed Myotis is strongly associated with water bodies for foraging (Thompson and Fenton 1982), e.g. streams, dams or lakes, and as none of the study sites were near such features it is very unlikely that this species was recorded by the bat detectors. It is therefore assumed that calls identified by the key as the Large-footed Myotis were those of Long-eared Bats.

Data analyses

To enable a consistent level of survey effort among and within the three deployments, we made an *a priori* decision to analyse data from a subset of nights based on a maximum number of overlapping consecutive dates. Dates for which detectors were operational were compared among sites within each deployment. The range of dates which were consecutive and common for all sites within a deployment were identified, and the maximum number of consecutive dates that matched across the three deployments was chosen as the survey period for analysis. Eight consecutive nights of data were analysed for each site.

For species with sufficient detections (defined as being detected at detected at more than 50% of the 26) sites we created an activity index by dividing the total calls for that site by the number of nights (eight). This procedure was repeated to generate an activity index for all species combined by pooling the call data from individual species to explore community level responses. The activity index for each species and for all species combined was then transformed (log(x+1)) to reduce skewness in the response variable. We modelled the transformed activity indexes as a function of fire and vegetation variables (Table 50) to test each of our statistical hypotheses (Table 51) using generalised linear models in the R statistical language (R Core Team 2014). These hypotheses were designed to evaluate our predictions about bat responses to fire. To determine which of the candidate models had the most support we used the corrected Akaike information criterion (AICc) (Burnham and Andersen 2010) in the R package "AICmodavg" (Mazerolle 2013). Models with an AICc < 2 of the "best" model were determined to have sufficient support for further investigation of the influence of modelled predictor variables on bat activity (α < 0.05).

Table 50. Variables included in microbat analyses

Variable	Abbreviation	Possible values	Variable type
EVD	EVD	EVD3, EVD7	Categorical
Years since last fire	TSF	1 to 72 years	Numeric
Number of fires since 1970	Fires	0 to 5 fires	Numeric

Table 51. Hypotheses tested for microbat activity

Hypothesis	Model
Activity is different between EVD 3 and EVD 7	EVD
Activity is affected by time since fire	TSF
Activity is affected by the number of fires since 1970	Fires
Activity is affected by time since fire and is different between EVD 3 and 7	EVD*TSF
Activity is affected by the number of fires and is different between EVD 3 and 7	EVD*Fires
Activity is affected by the number of fires and is different depending on the time since fire	Fires*TSF
Activity is equal for all sites, vegetation types and fire histories	Null

Results

We identified ten microbat species and one species complex in this study, eight of which were of a sufficient quantity for further analyses. (Table 52). Over half of the microbat passes recorded were unable to be identified to species level. The Little Forest Bat (*Vespadelus vulturnus*) was the only single species detected at every site, and also had the highest level of overall activity, with the Eastern Bent-wing Bat (*Miniopterus oceanensis*) detected at 25 sites. The least commonly recorded species were the Eastern Broad-nosed Bat (*Scotorepens orion*), the Eastern Horseshoe Bat (*Rhinolophus megaphyllus*), and the Eastern False Pipestrelle (*Falsistrellus tasmaniensis)*; from two, four and eight sites respectively.

Table 52. Summary of microbat species detected from the 26 sites in this study

*Indicates that this species was not included in further analyses due to too few detections. [#] A complex of Lesser Long-eared Bat, Gould's Long-eared Bat and Large-footed Myotis (see methods for explanation).

Common name	Scientific name	Number of sites	Number of call sequences
Eastern Horseshoe Bat*	Rhinolophus megaphyllus	4	18
White-striped Freetail Bat	Tadarida australis	19	93
Gould's Wattled Bat	Chalinolobus gouldii	22	561
Chocolate Wattled Bat	Chalinolobus morio	22	731
Large Forest Bat	Vespadelus darlingtoni	22	3005
Southern Forest Bat	Vespadelus regulus	15	129
Little Forest Bat	Vespadelus vulturnus	26	10089
Eastern False Pipistrelle*	Falsistrellus tasmaniensis	8	133
Eastern Bread-nosed Bat*	Scotorepens orion	2	8
Eastern Bent-wing Bat	Miniopterus oceanensis	25	1484
Long-eared Bats#	Nyctophilus sp.	26	1934
Unidentified		26	23591
All bats		26	41776

The element of fire regime most often associated with microbat activity was the number of recorded fires at a site (Table 53). There was a significant negative relationship between the number of fires and the activity of Chocolate Wattled Bat and Little Forest Bat. This relationship was positive for White-striped Freetail Bat activity and positive in EVD 7 for Gould's Wattled Bat. EVD predicted activity in Chocolate Wattled Bat (lower in EVD 7 than EVD 3) (Figure 24). There were no significant relationships between the predictor variables and total bat activity (Table 54).

Table 53. Models with the most evidence for predicting microbat activity

Species	Model with lowest AICc	Other models with ΔAICc < 2
White-striped Freetail Bat	Fires	EVD* Fires, EVD, Null, EVD* Fires
Gould's Wattled Bat	Null	EVD* Fires, Fires
Chocolate Wattled Bat	EVD*Fires	
Large Forest Bat	EVD	Null, EVD*TSF
Southern Forest Bat	Null	
Little Forest Bat	Fires	
Eastern Bent-wing Bat	Null	Fires, EVD
Long-eared Bats	Null	Fires, TSF
All bats	Null	Fires, EVD, TSF

Table 54. Summary of variables predicting microbat activity

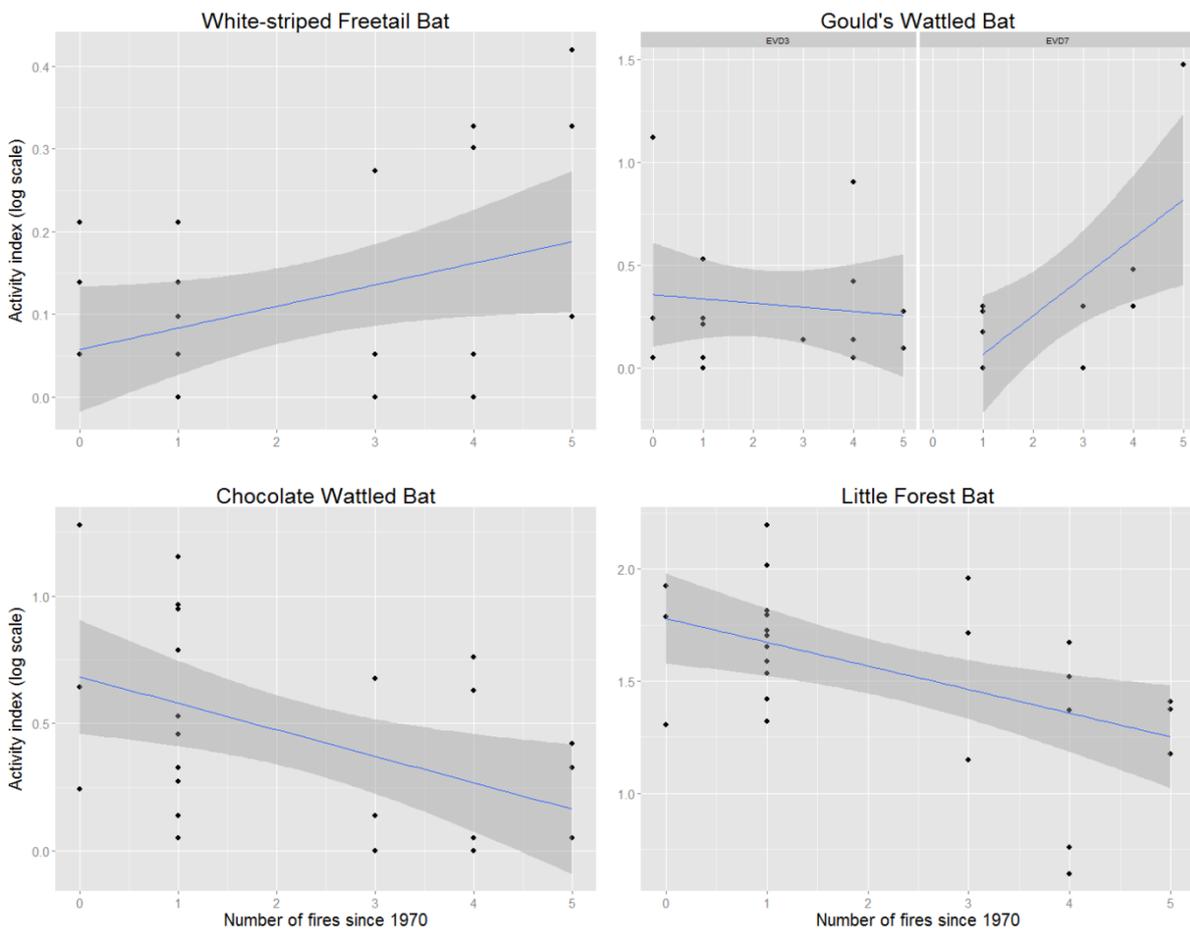| Species	EVD 7	TSF	Fires	EVD 7 x TSF	EVD 7 x Fires	Fires x TSF
White-striped Freetail Bat			↑			
Gould's Wattled Bat					↑	
Chocolate Wattled Bat	↓		↓			
Large Forest Bat						
Southern Forest Bat						
Little Forest Bat			↓			
Eastern Bent-wing Bat						
Long-eared Bats						
All bats						

Figure 24. The relationship between the number of fires since 1970 and microbat activity for selected species with 95% confidence intervals. Points are the activity indices for each site.

Discussion

Relationships between microbats and fire and vegetation variables

Contrary to predictions, activity levels of the microbat community as a whole were not strongly influenced by the number of years since its forest habitat was last burnt. Furthermore, the number of fires that have occurred in the last 40 years and the EVD also appear not to have detectable effects on overall activity levels of all species combined. These latter two variables, either separately or combined, did however, explain differences in activity levels of four single species. These four species may be divided into two broad groupings of larger, fast flying bats with low manoeuvrability, and smaller, moderately slow flying bats with high manoeuvrability (Churchill 2008; O'Neill and Taylor 1986), which corresponds to their respective responses to time since last fire and forest type. Although the responses by single species appear to be split along the lines of morphological and flying characteristics, as predicted by other research, the mechanisms of these relationships are unclear.

While both the activity levels of the larger-bodied White-striped Freetail Bat and Gould's Wattled Bat were higher at sites with more fires since 1970. These two species exhibit differences in foraging preferences, with the former foraging above the canopy, and the latter within the canopy itself (Churchill 2008). Due to its foraging habit, it seems unlikely that White-striped Freetail Bat activity would be directly affected by changes in clutter. For this species, the observed increase in activity may be due to other, indirect effects of fire such as changes in the availability of insect prey, which has been shown to increase after fire (Lacki *et al.* 2009). The response to the number of fires shown by Gould's Wattled Bat was only significant in EVD 7, but given the small number of sites within this EVD, further investigation is required to confirm this result.

While both the smaller Chocolate Wattled Bat and Little Forest Bat forage beneath the canopy, they have slightly different foraging preferences (between the canopy and understorey, and within the upper understorey respectively, Churchill 2008). Their high manoeuvrability suggests that they are relatively tolerant to increases in vegetation clutter (Aldridge and Rautenbach 1987). However, it is unclear whether this explains lower activity levels for these species at sites that have experienced more fires, as the relative differences in vegetation density has not been analysed.

Differences in vegetation structure between the two forest types studied is also a possible factor in the observed positive relationship for Gould's Wattled Bat activity in EVD 7, noting that EVDs also capture geographical gradients and management histories that may have an influence on local populations. The design of this study does not allow for the untangling of these factors, nevertheless, differences in responses to fire between EVDs may have implications for how fire is managed in these vegetation communities.

Differences in post-fire microbat activity could also be related to population recovery after fire-related mortality (Whelan *et al.* 2002), availability of roosts (Boyles and Aubrey 2006) and the availability of insect prey (Lacki *et al.* 2009); the specific effects of fire on these factors within the study area is unknown.

Limitations

Although the use of the automated echolocation call software increases the efficiency of processing microbat calls compared to manual identification, a proportion of calls will remain unidentified (56% in this study) due to the requirements of the system for high quality calls. This reduces the volume of data that is available for species specific analysis. There were three species with too few calls that could be positively identified and therefore we are unable to draw any inference about their responses to fire.

Measurements of clutter in the forest understorey, in relation to microbat movement were not included in this study, so testing predictions relating to differences in vegetation structure or density between forest types and fire history and how this may influence the response of microbats based on particular flying strategies was not possible at this time.

Implications for fire management

The significant relationships between fire, and select species found in this study indicate contrasting responses across microbat species, combined with some differences in activity across forest types. Many of the species identified from the study sites use hollows for roosting; a resource whose availability can be affected by fire events (Inions *et al.* 1989), and have subsequent impacts on particular species.

Obtaining bat data is a complex process which requires specialist expertise in using bat detectors, particularly in processing the data via a combination of automated and manual systems. Whilst that may reduce the practicality of obtaining information on bats, their ecological preferences are unlikely to be captured using more cost effective taxonomic groups as surrogates. Some efficiencies could be achieved by selecting an integrated set of sites across the state as part of a longer term program such as the Forest and Parks Monitoring and Reporting Information System or the Landscape Mosaic Burn sites (hence reducing costs associated with setting up new sites). Structural data is already being collected at those sites so would provide an opportunity to examine possible drivers of changes in activity arising from changes in the vegetation.

Future research

There is much in the literature that suggests that the density and structure of vegetation influences how microbats will respond to fire; measuring these variables against fire histories in studies that record corresponding microbat activity may help elucidate these relationships. For example, exploring vegetation attributes at multiple sub-canopy strata levels would allow comparisons between the response of microbat species with particular flying characteristics and foraging preferences. There is potential to examine components of other information collected during this project in conjunction with microbat responses to gain a better understanding of structural attributes of study sites. For example, fuel hazard assessments included coarse measurements of shrub and understorey cover, while photographs of site transects may allow visual evaluation of structural characteristics.

Like most ecological relationships, those between microbats and forest fires are likely to be complex. However, given the paucity of information on these relationships in Victorian forests, this area of research has exciting potential.

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Appendix 7: Fuel hazard assessments

Methods

Field assessments

The Overall Fuel Hazard Assessment Guide (Hines *et al.* 2010) was used to assess fuel hazard at each survey site. This guide is used as the standard DSE method for assessing fuel hazard posed by fine fuels that burn in the continuous flaming zone at the edge of a bushfire. Fine fuels are a key driver of flame height and the rate of spread of a fire; therefore hazard assessments are important when considering the impact of fuel arrangement on fire suppression (Hines *et al.* 2010). Futhermore, there is a large body of data collected using this method for other purposes, enabling broad applicability of results. Similar rapid visual assessment methods are used elsewhere in Australia (Gould *et al.* 2011).

Fuel hazard assessments were carried out for each of the three floristic survey transects from each site. The assessment took place at the end of each transect (0°, 120° and 240°) and encompassed a 20 m radius for canopy and bark assessments and a 10 m radius for elevated, near-surface and surface fuel assessments. At each assessment plot, measurements were taken for each of the fuel layers: canopy, elevated fuel, near-surface fuel, and surface fuel. For the canopy layer the average height to canopy top and average height to canopy bottom as well as bark type was recorded. In the elevated fuel layer the cover and height of elevated fine fuel and cover of dead elevated fine fuel was recorded. In the near-surface fuel layer cover and height of near-surface fine fuel and cover of dead near-surface fine fuel were recorded. Finally, for the surface fuel layer the cover and depth of litter (based on an average of five measurements) was recorded.

Hazard ratings (low, moderate, high, very high, extreme) were than calculated for bark, elevated fine fuel, near-surface fine fuel and surface fine fuel, based on these measurements. An overall fuel hazard rating was determined by using the matrices in the Overall Fuel Hazard Assessment Guide (Hines *et al.* 2010), which combined hazard ratings of near-surface fine fuel, surface fine fuel, elevated fuel and bark. Hazard ratings were converted to numerical rankings (low=1, moderate=2, high=3, very high=4, extreme=5).

Analysis

The two fire history variables 'time since fire' and 'fire frequency' were treated as ordinal variables. Accordingly, the original values for these variables were changed to 1 – 5 for 'time since fire' and to 0 – 4 for 'fire frequency', to maintain their ranks. The three sampling points in each of the sites were not independent of each other, so they were combined into one data point in each site. The resultant combined data were used to build a logistic regression model using the function polr in R package MASS for the ordinal response variable 'fuel hazard'. The explanatory variables included EVD, 'time since fire' and 'fire frequency' as well as the interaction term of the last two variables.

Results

Overall fuel hazard

Overall hazard results were skewed towards the 'Very High' to 'Extreme' end of the scale, with 66% of sites having these ratings (Table 55). There were very few sites with 'Low' to 'Moderate' ratings, accounting for only 10% of sites (Table 55). Figure 25 shows an example from EVD 7 of 'Extreme' fire hazard.

Table 55: Percentage of sites with each fuel hazard rating and EVD

Fuel hazard	Low	Moderate	High	Very High	Extreme
EVD 3	2	7	25	36	30
EVD 7	2	9	19	30	39
All sites	2	8	23	33	33

Figure 25: EVD 7 Site with Extreme fire hazard rating.

The response variable time since fire was statistically significant, but EVD and fire frequency were not. The coefficient for time since fire was positive, which means that the longer the time since last fire, the higher the probability of being higher fuel hazard.

Table **56** has outputs from the model which used categorical fire variables.

Table 56: Effect of fire history variables and EVD on fuel hazard

	Coefficients	Std Error	t value
EVD	0.2499	0.3433	0.7279
Time since fire	0.5759	0.2137	2.6947**
Fire frequency	0.2823	0.4283	0.6591
Time:Fire frequency	0.1041	0.1225	0.8502

The probability of each level of fuel hazard at different time periods after fire is shown in Figure 26. 'Extreme' hazard levels rose sharply in the years following fire, but showed a downward trend after 40 years. 'High' hazard ratings showed a downward trend in the early years following fire, reaching a plateau in the 20-40 year period post-fire. There was a low probability of 'Low' fuel hazard at any time since fire.
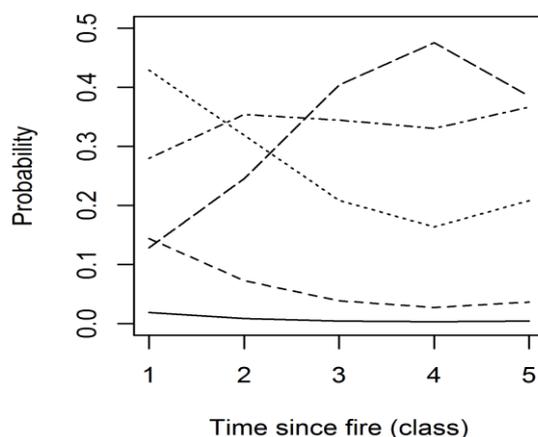

Figure 26. Probability of fuel hazard at five levels in relation to time since fire class

Time since fire class: 1 = 0-5 years; 2 = 6-10 years; 3 = 11-20 years; 4 = 21-40 years; 5 = 41+ years

Fuel hazard rating: Low = solid line; Moderate = dashed line; High = dotted line; Very High = dash-dotted line; Extreme = long-dashed line

Discussion

Relationships between overall fuel hazard and fire variables

The overall fuel hazard ratings were mostly in the 'very high' to 'extreme' range regardless of time since fire, and the analyses showed fuel hazard having a significant positive relationship to time since fire, up to 40 years post-fire. This result is likely to be a function of the rapid build-up of fuel after fires, and is supported by other studies which show that three to six years after fire, fuel hazard has returned to pre-fire levels (McCarthy and Tolhurst 2001, Boer *et al.* 2009, Penman and York 2010). The result may also be partially an artefact of the method of calculating the overall hazard rating, which combines hazard ratings for the individual components (near-surface fine fuel, surface fine fuel, elevated fuel and bark) using a matrix in the Overall Fuel Hazard Assessment Guide (Hines *et al.* 2010). In addition, the surface fuel hazard ratings did not fit well into any one rating because sites often had high litter cover percentages and shallow litter layers. The rating system may be tailored to conditions in more productive forests where leaf litter depth can be considerably greater than that examined in this study.

The indication of a decreased probability of extreme fire hazard over 40 years after fire (compared with the preceding 20 years) may reflect a more open forest structure at older age classes. Further examination of this trend by collecting additional fuel hazard data may be limited by the low availability of sites with verified histories of over 50 years since fire.

Future research

The fuel hazard assessment data collected during this project could be combined with other fuel hazard data from Gippsland which has been collected using the same method. Analysis of this combined data could strengthen results from our study.

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