

# The influence of fire, fox control and habitat structure on the presence of native mammals in East Gippsland

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**Front cover photo:** Red Fox (*Vulpes vulpes*), Long-nosed Potoroo (*Potorous tridactylus*), Feral Cat (*Felis catus*) (Alan Robley); Fire in the landscape (DEPI).

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## Summary

The 2009 Victorian Bushfires Royal Commission recommended that the Department of Sustainability and Environment (now DEPI) “significantly upgrade its program of long-term data collection to monitor and model the effects of its prescribed burning programs and of bushfires on biodiversity in Victoria”. This project is part of the Department’s long-term biodiversity monitoring and research program.

In addition to the direct effects of fire, indirect effects such as predation may play a significant role in determining what species can survive in an area. This study sought to investigate the broad, landscape-scale effects of planned burning on predation risk. In particular, it aimed to understand whether changes in vegetation density resulting from planned burning may alter the predation risk of prey species. A separate study was initiated to investigate direct predator-prey interactions during and in the years following planned burning.

Planned burning may increase predation risk by changing ground-layer habitat complexity, hence reducing the availability of refugia and therefore decreasing protection from predators. This may be countered through effective red fox (*Vulpes vulpes*) control in areas of highest risk.

This project uses a space-for-time approach to investigate how native species at risk from fox predation are distributed in relation to the landscape patterns created by different fire histories and the presence or absence of fox control. We investigated the relationship between observed patterns in native fauna distributions, habitat structure and fox control to inform management about the possible impact fire might have on biodiversity conservation across the landscape.

In areas with sustained fox control, we predicted that the observed patterns of habitat selection by native mammals that are vulnerable to foxes would reflect resource needs regardless of vegetation growth stage (representing differences in vegetation structural complexity created by different fire histories). In areas without fox control, habitat with complex structure was expected to be a key resource for species at risk from fox predation.

Data on the presence of native species was generated using cameras from 122 randomly located sites across five vegetation growth stage classes in two Ecological Vegetation Divisions in East Gippsland in summer 2010/11. Data on 11 explanatory variables, including time-since-fire (TSF), fire history (defined as burn/no burn in 73 years) and vegetation cover was collected from each camera survey site and binary logistic regression was used to assess the most influential predictor variables for 12 native mammal species.

*Vegetation Cover* was a significant predictor variable for seven of the 12 species included in our models, particularly long-nosed bandicoots (*Perameles nasuta*) and long-nosed potoroo (*Potorous tridactylus*). The presence of fox control was associated significantly with six of the 12 species included in our models. However, for three species this was true only when all other predictor variables had been removed from the model process. This indicates some confounding between predictor variables that may mask the influence of predation when modelled together. *TSF* and *Fire History* were only important for common wombat (*Vombatus ursinus*), and foxes and feral cat (*Felis catus*) respectively. Vegetation growth stage was not included in the models due to co-linearity with *TSF*, which was included in the models.

There was no clear relationship between *TSF* or *Fire History* and the presence of native species detected in this study, making it difficult to prescribe management strategies for predator control in relation to fire management for a set of species or a particular species. This finding is supported by previous research that also found species’ responses to TSF and habitat complexity are variable, and suggests prescriptions for fire regimes may need to be developed for specific areas if species conservation is the aim, rather than the maintenance of broadscale biodiversity.

This study has highlighted a number of areas for future investigation. Further studies should take an experimental approach to determine the relative role of predation, habitat structure and fire. While this would need to be undertaken at a smaller scale than this study, it could be undertaken at a landscape scale relevant

to most native ground-dwelling species at risk from fox predation. It would also provide a more direct measure of the relative importance of predation versus habitat and fire for the management of native species. Effort should be directed to developing and assessing rapid or remote techniques that quantify habitat structural complexity or resources that vary in space and time and how these relate to changes created by the use of planned burning and native species.



# 1 Introduction

The 2009 Victorian Bushfire Royal Commission recommended that the State commit to a long-term program of planned burning through a rolling target of 5 percent of public land (annually), report on the outcomes, and that “the Department of Sustainability and Environment significantly upgrade its program of long-term monitoring and modelling of the effects of its prescribed burning programs and of bushfires on biodiversity in Victoria”. This project is part of the Department’s long-term biodiversity monitoring and research program.

In addition to the direct effects of fire, indirect effects such as predation may play a significant role in determining what species can survive in an area. This study sought to investigate the broad, landscape-scale effects of planned burning on predation risk. In particular, it aimed to understand whether changes in vegetation density resulting from planned burning may alter the predation risk of prey species. A separate study was initiated to investigate direct predator-prey interactions during and in the years following planned burning.

Introduced predators constitute a major threat to natural ecosystems around the world, degrading habitats and eliminating species (Saunders *et al.* 2010, Croll *et al.* 2005). As a result, large areas of land in many parts of the world are treated with some form of predator control in a bid to recover species and habitats (Keedwell *et al.* 2002, Reddiex *et al.* 2006). Introduced predators, especially the red fox (*Vulpes vulpes*), have been implicated as a primary cause in the complete or regional extinction of an array of Australian mammal species, most of which are small to medium-sized and ground dwelling (Burbidge and McKenzie 1989, Short and Turner 1994).

Fire is a naturally occurring ecosystem disturbance (Whelan 1995) and is also used in land management globally through the application of planned burns (Fire Ecology Working Group 2004, Drever *et al.* 2006). The ability of a predator to limit populations of animals depends on both the predators’ ability to find, capture and kill prey and the prey’s ability to avoid predation. Disturbance, such as fire (either planned or bushfire) may increase the rate at which predators can find and kill prey by reducing structural cover (Verdolin 2006) and increasing hunting efficacy. There are also possible indirect effects of predator presence in a disturbed environment. Fox-removal experiments in Australia have revealed some native fauna, such as brushtail possums (*Trichosurus vulpecula*) and eastern grey kangaroos (*Macropus giganteus*), modify their foraging behaviour in response to the risk of predation (Banks 2001, Gresser 1996). Thus, some prey species show the potential population-level effects of predators through reduced foraging and altered foraging patterns (NSW National Parks and Wildlife Service 2001).

However, it is also possible that prey periodically escape regulation by predation following disturbance. Post-fire increases in short-term food availability (e.g. hypogeous fungi; Verns *et al.* 2004) may induce increased growth rates in mycophagous, ground-dwelling mammals which outstrip the impact of predation, despite a significant decline in structural habitat. Other, more complex interactions are possible as a result of increased habitat heterogeneity created by fire disturbance. For example, short-beaked echidna (*Tachyglossus aculeatus*) is predicted to respond rapidly post-fire and is known to be a prey item of foxes (Coman 1973), while populations of long-nosed potoroo (*Potorous tridactylus*) are predicted to decline and recover more slowly (Catling *et al.* 2001, MacHunter *et al.* 2009) and are restricted to fragmented patches post-fire (Justine Smith, pers comm.). The increase in the prey base may support foxes which in turn increase predation pressure on potoroos. Evidence for this interaction is both theoretically possible and supported by empirical evidence from other systems (Seip 1992, Wittmer *et al.* 2007, Kojola *et al.* 2009). Therefore, understanding the relationship between disturbance created by fire and the role of predation on the persistence of populations of species at risk is crucial to future conservation and fire management.

Species vulnerable to predation by foxes may persist in the landscape in refuge areas (habitat with complex structure) with sometimes small populations. These small populations are at added risk from perturbations in the demography, environmental stability, and genetic movement that may lead to local extinction (Caughley

and Gunn 1996). Removal of habitat complexity and the reduction of refuge areas to isolated patches caused by fire may be sufficient to decrease the threshold of species at risk from predation by allowing predators to exploit refuge habitats that expose native species to increased risks of predation, effectively eroding the resilience of the species and potentially the ecosystem.

There is some evidence of interactions between fire and predation by foxes in Australia. Half of the brush-tailed bettongs (*Bettongia penicillata*) that survived a bushfire in south-west Western Australia were subsequently killed by predators (Christensen 1980). Newsome *et al.* (1983) postulated that modification of habitat structure can increase the impact of predation on native species. They showed that post-fire predation by Dingo (*Canis lupus dingo*) was disproportionately severe on native mammalian prey after an extensive bushfire at a coastal site in New South Wales. Russell *et al.* (2003) found that following the reintroduction of 22 common ringtail possums (*Pseudocheirus peregrinus*) after bushfires in Sydney in 1994, proportional mortality due to predation by lace monitor (*Varanus varius*) and diamond python (*Morelia spilota spilota*) increased. Within 12 months, the population decreased to two animals. The authors concluded that increased predation by native predators, added to continued predation by foxes and feral cats (*Felis catus*), maintained a level of predation beyond a threshold that would allow the ringtail possum population to re-establish to previous levels. The possible flow-on effects of this habitat modification process include reduced herbivory rates that can lead to alterations in floristic community structure and so lead to alterations in water and nutrient flows. For example, Ripple *et al.* (2001) showed that quaking aspen (*Populus tremuloides*) sucker heights were significantly higher in areas of high wolf (*Canis lupus*) use and that elk (*Cervus elaphus*) pellet counts were significantly lower.

There is even less information available about the role of predation by the feral cat in relation to fire. It has been suggested that, in the Kimberley in northern Australia, the combination of fire regimes and predation by feral cats is placing native species at risk (Tony Peacock pers. comm., Invasive Animals CRC, Canberra).

We used a 'space-for-time' approach to investigate how native mammals were distributed in relation to the pattern in the landscape created by different vegetation growth stages (representing differences in vegetation structural complexity created by *TSF* and *Fire History*) in areas with and without sustained fox control. We predicted that native mammals would select habitat to avoid predation. Thus, in areas with sustained fox control, habitat selection would reflect resource needs and native species would rely less on complex structural habitat to avoid or reduce predation risk. In areas without fox control, habitat with complex ground-layer structure would be a key resource for species at risk from predation by providing areas of refuge.

Planned burning may increase predation risk by changing ground-layer habitat complexity and reducing the availability of refugia from predators. We investigated the relationship between observed patterns of native fauna distributions, habitat structure and predator control to inform management about the possible impact the use of fire might have on biodiversity conservation across the landscape.

## 2 Methods

### 2.1 Study Site

The pattern of occurrence of native mammals and predators (red fox and feral cat) was investigated in late spring through to summer 2010/11 using heat-in-motion activated digital cameras in East Gippsland across areas with and without long-term sustained fox control (Figure 1). The Southern Ark fox control project has been in operation since 2003 over a large area of East Gippsland. Fox control is undertaken using 1080 Fox-Off baits spaced at 1 km intervals along roads and tracks. Baits are checked and replaced on a six-week rotation across the operations area.

**Figure 1. Study area showing location of 20 km x 20 km landscape grids, the Southern Ark fox control bait stations (roughly east of the Snowy River) and the location of camera survey sites.**

Across these areas, the two most common Ecological Vegetation Divisions (EVDs; Long *et al.* 2003) are Tall Mixed Forest (EVD 7) and Grassy/Heathy Dry Forest (EVD 3). EVDs are a grouping of Ecological Vegetation Classes into broadly similar communities of vegetation (Cheal 2010). Both these EVDs will be subject to increased rates of planned burning in the coming years in order to meet increased fuel reduction burning targets. Based primarily on time-since-fire, Cheal (2010) divided EVDs into various vegetation growth stage classes. In both Tall Mixed Forest and Grassy/Heathy Dry Forest there are five classes (Table 1) though durations vary.

**Table 1. Vegetation growth stages (Cheal 2010) within EVD 3 and EVD 7 used in this study.**

<b>EVD</b>	<b>Growth Stage</b>	<b>Years After Fire</b>
EVD 3 Grassy/Heathy Dry Forest	Juvenility	0.5–2.5
	Adolescence	2.5–10
	Maturity	10–35
	Waning	35–45
	Senescence	45+
EVD 7 Tall Mixed Forest	Juvenility	0.75–2.75
	Adolescence	2.78–8
	Vigorous Maturity	8–20
	Stasis	20–60
	Waning	60+

## 2.2 Camera Site Selection

Camera site selection followed the method used by Muir *et al.* (2013). A grid of 20 km x 20 km landscapes were located across the study area (Figure 1) inside and outside the Southern Ark fox control area. Landscapes that contained more than 20 ha of each vegetation growth stage (see Table 2) were selected. This landscape layer was used to identify the vegetation growth stage combinations, creating a landscape/vegetation growth stage/fox control, no fox control layer. A spatially random point was located within each of the vegetation growth stage/fox control, no fox control categories within each landscape.

This resulted in 122 camera sites across the vegetation growth stage classes within EVD 7 and EVD 3. Table 2 shows the allocation of cameras to treatment and vegetation growth stage.

**Table 2. Number of camera sites within each treatment by vegetation growth stage combination.**

<b>Ecological Vegetation Division</b>	<b>Vegetation Growth Stage</b>	<b>No Fox Control</b>	<b>Fox Control</b>	<b>Total</b>
Tall Mixed Forest EVD 7	Juvenility	11	5	16
	Adolescence	1	0	1
	Maturity	10	10	19
	Waning	1	3	4
	Senescence	3	8	11
Grassy/Heathy Dry Forest EVD 3	Juvenility	9	10	19
	Adolescence	7	3	10
	Vigorous Maturity	9	7	16
	Stasis	4	15	18
	Waning	7	1	8
	<b>Total</b>	<b>62</b>	<b>62</b>	<b>122</b>

### 2.2.1 Camera surveys

We set cameras to specifically target native mammals, foxes and feral cats. At 88 sites four cameras were established, two native mammal and two predator cameras. These were located in sites used in an existing program investigating patterns of native species in relation to patterns of fire regime (Muir *et al.* 2013). To balance the predator camera sampling effort across the areas with and without fox control, an additional 34 sites were selected and had two cameras deployed, 17 sites in the baited area and 17 in the non-baited area.

#### Native mammal cameras

Two cameras were placed 50 m to the east and west of the camera survey 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 camera (Reconyx Inc., Wisconsin, USA). We attached the camera to the nearest suitable tree at the 50 m mark.

The bait station contained a lure of rolled oats, peanut butter and golden syrup placed inside a 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 rain by a metal lid. A bait station was placed at each camera location, 2 m from the camera and 20–40 cm from the ground. To maximise the chance of photographing an animal near the bait station, the vegetation was cleared between the camera and bait station as well as 1 m behind and to either side of the bait station.

#### Predator cameras

Two cameras (Reconyx PC900, Reconyx Inc., Wisconsin, USA) were placed 150 m to the east and west of the camera survey centre (measured using hand-held GPS units [Garmin GPSMAP 62s, Garmin Ltd., Olathe, USA]). We attached the cameras to the nearest suitable tree 2 m from the lure and 20–40 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 1 m behind and to either side of the bait station.

The lure comprised of a tea infuser containing a piece of felt doused in tuna oil and a fresh chicken drumstick. These items were attached to the inside of a wire metal cage. The cage was attached to a metal star picket 1.5 m from the ground.

Two cameras were set at a single site to target specific fauna (i.e. native mammals and introduced predators) and as insurance against one camera failing.

#### Camera settings

Cameras were set to take photos 24 hours per day with other settings varying according to camera type. Settings were chosen according to our prior experience with each camera model:

- *PixController* – Medium sensitivity and highest resolution, with one photo 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.

Given the proximity of individual cameras at a single site they were not considered to be independent. Cameras operated from 22–26 days between late autumn and summer 2010/11.

## 2.3 Image Organisation

Images were organised following the method outlined by Harris *et al.* (2010) and using a set of software programs (DataOrganise and OccupancyMatrix) developed by James G. Sanderson (Small Wild Cat Conservation Foundation, Los Altos, USA).

Folders were initially set up with the following structure: Landscape-number/Site\_number/Species\_name/Number-of-individuals (e.g., 01 or 02). Upon retrieval from each camera, all images were renamed into the following format: year | month | day | hour | minute | second. Duplicate images were examined and either manually renamed or deleted. Renaming was undertaken using the freeware Renamer V5.60 (www.den4b.com). For each image we identified the species, counted the number of individuals of each species recorded, and stored the image in the proper location/species/number-of-individuals folder.

We then ran all images through the DataOrganise software, which creates two files – AllPictures.txt and Input.txt. The Input.txt file is edited to ensure the proper start and finish dates of the survey are present. The dates initially produced represent the first and last image dates, not the start and finish survey dates. This is corrected using additional software. The final step is to use the OccupancyMatrix software. OccupancyMatrix reads and processes the AllPictures.txt and edited Input.txt files and creates detection/non-detection matrices for all species and all camera locations.

## 2.4 Data Analysis

### 2.4.1 Explanatory Variables

We collected categorical and numerical data on variables to explain the presence of native species for each camera location. A complete list of explanatory variables used in the analysis is presented in Table 3.

**Table 3. Explanatory variables used to investigate the relationship between foxes, native mammals and vegetation in East Gippsland.**

Variable Name	Variable Type	Description
<i>Fire History</i>	Categorical	Site burnt 'more than' or 'less than or equal to' 73 years ago
<i>EVD_Code</i>	Categorical	Ecological Vegetation Division ('3' or '7')
<i>Fire Type</i>	Categorical	The last fire being wildfire or a planned burn
<i>Treatment</i>	Categorical	Site with or without a fox control program
<i>Camera Number</i>	Categorical	The number of cameras on the site (2 or 4)
<i>Days</i>	Categorical	Number of days cameras active (22, 23 or 26)
<i>Height_100</i>	Numerical	Height above sea level
<i>Since Burnt</i>	Numerical	The time in years since the site was burnt (vegetation growth stage)
<i>TPI_100</i>	Numerical	Topographic position index
<i>TWix1000</i>	Numerical	Terrain wetness index
<i>Mean Cover</i>	Numerical	The average vegetation cover as a proportion of cover board

### Categorical Data

Six categorical variables were used in the analysis: *Fire History*, *Fire Type*, fox control *Treatment*, camera *Days*, the number of cameras at a site (*Camera Number*) and *EVD\_Code* (Appendix 1). For 11 sites, the time since the last burn record was unknown, but greater than 73 years ago. However, for those sites no records were available to estimate the year the burn(s) took place or whether the last burn was a bushfire or a planned fire. For this reason, a new variable (*Fire History*) was derived that grouped the sites into either those that were less than or equal to 73 years (and known) or those that were more than 73 years old. This allowed the 11 sites to be included in the analyses, with the numerical variable *Since Burnt* and the categorical variable *Fire Type* being nested within the variable *Fire History*, meaning that *Fire History* was not considered as an explanatory variable unless both *Since Burnt* and *Fire Type* were excluded. Ecological Vegetation Class (*EVC*) and Ecological Vegetation Division Growth Stage (*EVD-GS*) for each site were also recorded, but not used in the analysis for this report. This was because there were too few sites per *EVC* category, and there was non-independence between *EVD-GS* and *Since Burnt*.

### Numerical Data

#### *Mean Vegetation Cover (Mean Cover)*

At each camera site, four images were taken using a hand-held digital camera. These images were of a small cover board (290 mm x 420 mm; Figure 2). The board was placed standing upright at a random location, no more than 10 m from the survey cameras, and an image of the board, and the vegetation cover in front of the board, was recorded. Images were processed using an R-script (The R Foundation for Statistical Computing ISBN 3-900051-07-0, version 2.15.1) that read-in the image and calculated the difference between the background board and vegetation in the image. This gave a measure of the mean vegetation cover at each camera site.



**Figure 2.** Cover board used to assess horizontal, ground-layer, vegetation density.

#### *Topographic Position Index (TPI\_100)*

Topographic Position Index is the mean difference between a cell and a neighbourhood of surrounding cells in a digital elevation model (DEM). The method involves finding the difference in elevation for each DEM cell and the eight cells surrounding it (using a 3×3 neighbourhood). Difference values are converted to absolute values and averaged to obtain a single value. This value was applied to the 3×3 neighbourhood's center cell in the output raster. The square root of this value was taken to create the index values.

#### *Terrain Wetness Index (TWI\_1000)*

Terrain Wetness Index is defined as  $\ln(a/\tan\beta)$  where 'a' is the local upslope area draining through a certain cell per unit contour length in a DEM, and ' $\tan\beta$ ' is the local slope.

Summaries of this explanatory variable showed that it was negatively skewed, with 11 values lower than  $Q_1 - 3 \times 1QR$  including four values lower than  $Q_1 - 30 \times 1QR$  and four values higher than  $Q_3 + 3 \times 1QR$ . To improve the spread of this variable, a cube root transformation was applied to allow for finer discrimination between values inside the inter-quartile range in the modelling process.

Summary statistics for numerical variables are shown in Appendix 2. There were seven sites that had some missing data in *Fire Type* and *Mean Cover* (not recorded by contractors) and were excluded from all analyses.

#### *Bivariate variable association*

When investigating whether any categorical variables are confounded with other explanatory variables, or if any numerical variables are highly correlated with one another, bivariate associations between the explanatory variables are important to consider. A variable may be overshadowed by its confounding variable, affecting the modelling procedure. In this data set there were some instances of categorical variables being confounded:

- There were only two sites that had cameras active for 26 days. Both sites were burnt by bushfire less than 73 years ago, were in EVD 7, had no fox control and had two cameras.
- All 11 sites with a time-since-last-burn of more than 73 years were in EVD 3 and had four cameras.
- All 34 sites that had two cameras were in EVD 7.

The number of cameras (*Camera Number*) and number of days the cameras are active (*Days*) are expected to affect the likelihood of detecting animal presence, assuming that an increase of either will increase detection. For this reason, the two variables were included in all models. This may be problematic for the variables partially confounded with them (i.e. *Fire History*, *EVD\_Code*, *Treatment* and *Fire Type*) as the true effect of these explanatory variables may be lost.

### **2.4.2 Modelling**

Since the response variable is a binary presence/absence measurement at independent sites, a binary logistic regression approach was used. Given that the variables relating to fire were nested in the model, a backward stepwise selection method was used. Backward stepwise selection includes placing all possible explanatory variables into a model and dropping the least significant term before the model is run again and the process continues until all remaining terms are significant.

The cut-off *P*-value for terms to be kept in the model was chosen as a more conservative 0.1 compared to the usual 0.05. Observational studies are usually less controlled, which often leads to larger variability and therefore larger *P*-values. Modelling binary response variables also requires larger sample sizes than general linear regression to detect small effect sizes. Setting a slightly higher *P*-value allows terms with smaller effect sizes to be included in the model.

For each species for which there was sufficient data, one model was derived using the 11 explanatory variables (Table 3). The variables *Camera Number* and *Days* were included in all models to account for any bias in animal detection, regardless of their *P*-values. *Since Burnt* and *Fire Type* were nested within the variable *Fire History*, meaning that *Fire History* was not considered as an explanatory variable unless both *Since Burnt* and *Fire Type* were excluded. Additionally, the main effects of *EVD\_Code* and *Mean Cover* were not considered unless the interaction between *EVD\_Code* and *Mean Cover* was excluded.



### *Odds ratio*

The Odds Ratio (OR) is a measure of effect size, describing the strength of association or non-independence between two binary data values. The OR compares the odds of at least one animal being present at a site, when either comparing levels of categorical explanatory variables or when increasing the value of a numerical explanatory variable.

The 95% confidence interval around the OR indicates a range of plausible values for the true OR. Categorical variables are arranged so that the factor level with the highest odds is first, meaning the OR is always greater than 1. The OR for a categorical variable with two levels can be interpreted in such a way that if an OR for EVD 3 to 7 is 2, then EVD 3 has twice the odds of an animal being present at a site than EVD 7, whatever the levels or values of the other variables in the model. The OR for a numerical variable denotes the change in the odds of species' presence when the numerical variable increases by one unit. For example, if the OR for *Mean Cover* is 1.5 then as *Mean Cover* increases by one unit the odds of an animal being present increases by 50%.

### 3 Results

#### 3.1 Camera Trapping

A total of 45,864 images of 52 species from 122 sites were recorded during this study from 2,759 camera trap nights. Twenty-five mammal species, including 10 considered at risk from fox predation, 25 bird species and two reptile species were detected. A full list of all species detected, the number of sites occupied and their naïve estimate of occupancy is presented in Appendix 3.

The most commonly detected species were black wallaby, common brushtail possum and common wombat. Feral cats were detected more often than the red fox indicating that they were relatively more common across the entire study area than foxes (Table 4).

**Table 4. Species detected, the number of sites where they were detected and the naïve estimate of occupancy of 12 species used in the modelling process.**

Common name	Species name	Number Sites Occupied	Naïve Estimate
Black Wallaby	<i>Wallabia bicolor</i>	110	0.87
Common Brushtail Possum	<i>Trichosurus vulpecula</i>	96	0.76
Common Wombat	<i>Vombatus ursinus</i>	86	0.68
Wonga Pigeon	<i>Leucosarcia melanoleuca</i>	67	0.53
Bush Rat	<i>Rattus fuscipes</i>	65	0.52
<sup>a</sup> Lace Monitor	<i>Varanus varius</i>	57	0.45
Superb Lyrebird	<i>Menura novaehollandiae</i>	57	0.45
Short-beaked Echidna	<i>Tachyglossus aculeatus</i>	47	0.37
Feral Cat	<i>Felis catus</i>	43	0.34
Long-nosed Bandicoot	<i>Perameles nasuta</i>	26	0.21
Red Fox	<i>Vulpes vulpes</i>	12	0.10
Long-nosed Potoroo	<i>Potorous tridactylus</i>	8	0.06

<sup>a</sup> at risk from fox predation when juvenile

#### 3.2 Modelling the influence of fire, predators and habitat on native species

There were varied results across the species' models. The variable *Mean Cover* was included in the most models (seven), though the direction of the relationship varied (Figure 3 a–g). Common brushtail possum and Wonga pigeon both had increased occupancy with decreasing *Mean Cover* (on average 30% and 16% less cover respectively), while bush rat, echidna, lace monitor, long-nosed bandicoot and, particularly, long-nosed potoroo had an increased probability of presence with an increase of *Mean Cover*. Sites at which Long-nosed Potoroo were recorded had on average 43% more lateral vegetation cover.

Summaries of each species model are given in Table 5, and a full table of odds ratios and their 95% confidence intervals is given in Appendix 4. All terms were also included in each model alone to determine their individual contribution without *Camera Number* or *Days* to the species' presence, and are also summarised in Appendix 4.

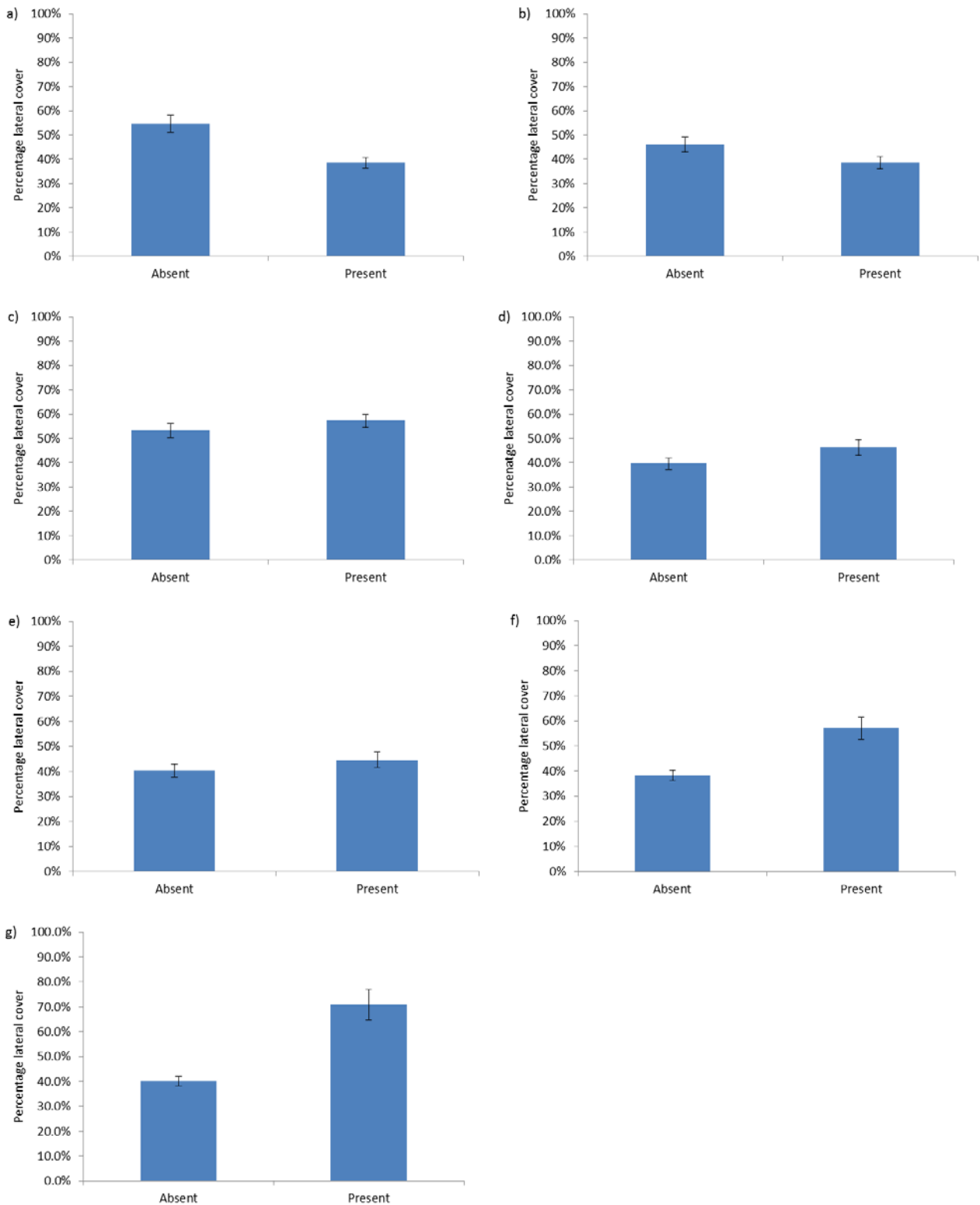
*EVD\_Code* was the next most common term, being included in four models. The direction of the effect was different for different species. Long-nosed Bandicoots were four times more likely to be present at sites in Tall Mixed Forest, while common brushtail possum, lace monitor and superb lyrebird (marginally), were twice as likely to be present in Grassy/Heathy Dry Forest. When modelled alone Tall Mixed Forest became important for long-nosed potoroos.

*Treatment* was only significant when modelled alone, despite the fact that this term represented the presence or absence of a fox control program. *Treatment* was included in the black wallaby (wallabies were nearly 10 times more likely to be present at sites without fox control), Wonga pigeon (three times more likely at sites with fox control) and common wombat (twice as likely to be present at fox control sites) models.

When considering the variables alone, there were many similar patterns (Appendix 5). However, the term *Treatment* became significant in a further three species' models (echidna, lace monitor and long-nosed bandicoot). This could be due to confounding with *Days* or other variables in the full models. As expected, when the variable representing the number of cameras (*Camera Number*) was significant alone (bush rat, echidna and common wombat presence models), there was a tendency for sites with four cameras to have a higher odds of species' presence than for sites with two cameras. The only species where *Days* was a significant factor was the lace monitor, where 22 days had the lowest presence followed by 26 then 23, however, there was only a significant difference between sites with 22 and 23 days of operational cameras ( $P$ -value = 0.010).

*Fire History* was retained in only two models, with red fox and feral cat nearly four times more likely to be present at sites with a fire history of no fires for 73 years. The only species to be associated with time-since-last-fire was the common wombat, which was more likely to be present at sites that were burnt 18 year ago. For all other species, there was no detectable relationship with time-since-fire. Long-nosed bandicoots were three times more likely to be present at sites that were burnt less than 73 years ago by a bushfire than a planned burn.

The variables *TW1x1000*, *Height \_100* and the interaction between *Mean Cover* and *EVD\_Code* were not included in any models.



**Figure 3. Percentage lateral cover at sites with species present and absent: a) Common Brushtail Possum, b) Wonga Pigeon, c) Bush Rat, d) Echidna, e) Lace Monitor, f) Long-nosed Bandicoot, and g) Long-nosed Potoroo.**

**Table 5: The final 12 species' presence models investigating relationships between fire, predator control and habitat structure.**

For numerical variables, a positive or negative relationship denotes the direction of the relationship between the explanatory variable and the proportion of species' presence. The bottom row 'No. of Models' shows the number of species' models that each of the variable was used in. The *P*-value (in brackets) shown is that of each variable in the final model, which includes *Camera Number* and *Days*. Two models, red fox and superb lyrebird, have terms with *P*-values slightly larger than 0.1 due to having only one variable close to this cut-off. <sup>a</sup> – species more likely to be at risk from fox predation after Robley and Choquenot (2002).

Species Model	FireHist ( $\leq 73$ or $> 73$ )	FireHist. Time since burnt	FireHist. Fire Type (W/P)	Treatment +/- Fox Control	Terrain wetness Index	Terrain Position Index	Height ASL	EVD Code	Mean Cover	Mean Cover EVD Code
Red Fox	>73 higher (0.102)									
Feral Cat	>73 higher (0.039)									
<sup>a</sup> Common Brushtail Possum								3 > 7 (0.096)	negative (0.003)	
Black Wallaby				none > control (0.009)						
Bush Rat						negative (<0.001)			positive (0.016)	
Echidna									positive (0.030)	
<sup>a</sup> Lace Monitor								3 > 7 (0.015)	positive (0.034)	
<sup>a</sup> Long-nosed Bandicoot	required due to interaction term		bushfire > burn (0.092)					7 > 3 (0.058)	positive (0.010)	
<sup>a</sup> Long-nosed Potoroo									positive (0.002)	
Superb Lyrebird								3 > 7 (0.113)		
Wonga Pigeon				control > none (0.011)					negative (0.003)	
Common Wombat	required due to interaction term	positive (0.058)		control > none (0.062)		positive (0.082)				
<i>No. of Models:</i>	<i>2</i>	<i>1</i>	<i>1</i>	<i>3</i>	<i>0</i>	<i>2</i>	<i>0</i>	<i>4</i>	<i>7</i>	<i>0</i>

## 4 Discussion

This study aimed to investigate the influence of long-term fox control and vegetation growth stages on the presence of native fauna to help land managers understand the possible impact the use of planned fire might have on biodiversity conservation. Due to non-independence between vegetation growth stage and time-since-fire (TSF), we excluded vegetation growth stage from the analysis in preference for the numerical variable time-since-fire. The result was six categorical and five numerical predictor variables describing predator control, fire and habitat structure. TSF and habitat structural complexity have been shown to be useful surrogates for predicting the distribution of ground-dwelling mammals (Fox and Fox 1981, Catling and Burt 1995, Di Stefano *et al.* 2011, Arthur *et al.* 2012).

Vegetation cover was important for seven of the 12 species included in our models, with five of these species more likely to occur at sites with higher levels of lateral vegetation cover, particularly long-nosed bandicoots and long-nosed potoroos. Not all relationships were positive, with common brushtail possum and Wonga pigeon associated with sites with less lateral cover. The relationship between vegetation cover and the variables used to describe the impact of fire (TSF and fire history) on habitat were not reflected in our models. Only red fox and feral cats had positive association with fire history. This is in contrast to Payne (2012) who found no association with fire history and the presence of foxes in semi-arid north western Victoria. Echidna were associated with sites with a TSF of 11 years. Long-nosed bandicoots were also associated with sites that were subjected to bushfires with a TSF of less than 73 years in Tall Mixed Forest.

Our results reflect the mixed response native ground dwelling species have to vegetation structural complexity and TSF. Di Stefano *et al.* (2011) found that habitat structural complexity was not well explained by TSF and that TSF was a poor predictor of habitat selection by silky mouse (*Pseudomys apodemoides*) and heath rat (*Pseudomys shorridgei*) and that habitat structural variables were better at explaining habitat selection by these species. In contrast, Catling *et al.* (2001) found that TSF and habitat complexity were significant for long-nosed potoroos, common wombats, black wallaby and feral cat, while habitat complexity only was important for bandicoots (Long-nosed and Southern Brown combined), common brushtail possum and common ringtail possum in predicting presence.

The presence of fox control was associated with six of the 12 species in our models. However, for three species the presence of fox control was only significant when all other predictor variables had been removed from the model process. This indicates some confounding between predictor variables influencing the independence of potential explanatory variables and hence may mask the influence of predation when modelled together. For example, long-nosed potoroo were found to be associated with sites that had increased mean vegetation cover (43% more than at absent sites), at sites nine years since the last fire, in Tall Mixed Forest (EVD 7), while the presence of fox control was only significant for this species when modelled alone. Hence the true relationship between habitat, fire and predation appears to be confounded. This was also true for lace monitor and echidna. Confounding is an issue not unique to our study. Lindenmayer *et al.* (2008) report on the same issue affecting their study on mammal response, vegetation type and fire. They note that confounding is a difficult issue to resolve due to the complicated nature of the interactions and the spatial and temporal scales at which they operate.

Some species had more complex interactions with the variables, for example, common wombats were more likely to be present at sites 18 years post fire in mature (EVD 3) or vigorously mature (EVD 7) vegetation, lower in the landscape (low terrain position index) and at sites with fox control. Wonga pigeons were more likely to be present at sites with low levels of lateral vegetation cover and at sites with fox control. The complex nature of predator–prey and habitat dynamics is

evident by the varied and uncertain outcomes in our results. Generally, animal populations trade-off selection of habitat to maximise resources (primarily food which drives growth rates) and risk, such as risk of predation. This is essentially a bottom-up process of population limitation, however, this process can be overridden by three secondary processes: predation (a top-down process), social interactions and environmental disturbance. A complex set of interactions between these factors can produce variable prey population responses (Sinclair and Krebs 2002, Arthur *et al.* 2012, Catling *et al.* 2001) like those seen in our study. Further complicating native species response are non-consumptive effects of the presence of foxes. Non-consumptive effects can include suppression of the immune-response system and increases in parasite loads (Anson *et al.* 2013).

Using surrogates of habitat structural complexity such as TSF, fire frequency and vegetation growth stage are unlikely to capture the appropriate structural and spatial variability in habitat characteristics required to explain patterns in distribution of native species, particularly when trying to relate these to the presence or absence of a single predator species. The long-nosed potoroo is a species considered at risk from fox predation (Robley *et al.* 2012) that was expected to show a positive association with fox control. This species was much more likely to be found at sites with high levels of vegetation cover, with no influence of fox control, TSF or fire history evident from our data. Our results are also supported by previous findings for this species that the relationship with habitat structure is important (Di Stefano *et al.* 2011, Arthur *et al.* 2012) and that habitat for this species is not well characterised by TSF and fire frequency.

In contrast Catling *et al.* (2001) found that both TSF and habitat complexity were important predictors for the presence of long-nosed potoroos. While in south-eastern New South Wales, TSF was found to be a significant predictor of southern brown bandicoot diggings (an indicator of bandicoot occurrence), whereas recently burned habitats (0–20 years since fire) seemed to be less favoured by this species (Newsome and Catling 1979). Possingham and Gepp (1996) modelled the prescribed burn interval of southern brown bandicoot habitat for a population in south-eastern South Australia and arrived at a strategy, with caveats, to burn at 15-year intervals. Our results and these examples reflect the complex response species have to habitat heterogeneity, fire and the presence of native and introduced predators. Only our study has attempted to include the role of predation in predicting patterns in species occurrence, which adds an additional layer of complexity.

We assumed that the presence of fox control meant a significant difference in foxes existed between the baited and unbaited areas; that fox predation rates were sufficiently reduced to allow a numerical response in native mammals that could be detected; and that if fox control was successful, that feral cats had not replaced foxes as an alternative predator, thus masking the effect of fox control. However, notwithstanding issues related to confounding between variables, our results did not clearly support this as *Treatment* was not a significant factor in our models. Gibson (2011) noted that particularly in broadscale, multi-species surveys, in which survey locations are widely dispersed across the landscape, rare species tend to have sparse presence records. The broadscale survey approach we used may have underestimated the occurrence of foxes and feral cats in the landscape, thus further confounding the results. The low-density nature of foxes and feral cats combined with the regional-scale sampling regime, may have contributed to the lack of any clear relationships.

We detected no uniform driver for the occurrence of all 12 native species in this study, making it difficult to prescribe management strategies for predator control in relation to fire management for a set of species or a particular species. This finding is supported by previous studies (Lindenmayer *et al.* 2008, Sutherland and Dickman 1999 and Whelan 1995) which suggest that prescriptions for

fire regimes may need to be developed for specific areas if species conservation is the aim, rather than the maintenance of broadscale biodiversity.

This study has highlighted a number of areas for future investigation. Further studies should take an experimental approach to determine the relative role of predation, habitat structure and fire regime (Arthur *et al.* 2012). While this would necessarily need to be undertaken at a relatively smaller scale than this study, it could still be undertaken at a landscape scale relevant to most native ground-dwelling species at risk from fox predation. It would also have the benefit of providing a more direct measure of the relative importance of predation versus habitat and fire in the management of native species. Effort should be directed to developing and accessing rapid or remote assessment techniques to quantify the habitat structural complexity/resources that vary in space and time and how these relate to changes created by the use of planned burning.



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## Appendix 1: Summary of categorical variables from 122 sites

Variable Name	Levels	Count	Percentage
Fire History	≤73	106	90.6%
	>73	11	9.4%
	Total	117	100.0%
Fire Type	burn	28	26.4%
	wildfire	78	73.6%
	Total	106	100.0%
Treatment	fox control	56	47.9%
	no fox control	61	52.1%
	Total	117	100.0%
Days	22	99	84.6%
	23	16	13.7%
	26	2	1.7%
	Total	117	100.0%
Camera Number	2	34	29.1%
	4	83	70.9%
	Total	117	100.0%
EVD_Code	3	49	41.9%
	7	68	58.1%
	Total	117	100.0%

## Appendix 2: Descriptive statistics for numerical variables from 122 sites.

Variable Name	Mean	Median	Minimum	Maximum	Standard Deviation	N
<i>Since Burnt</i>	17.8	14	1	73	19.6	106
<i>Mean Cover</i>	0.42	0.38	0.07	0.98	0.21	117
<i>TWix1000</i>	8409.9	8566.6	5852.1	9772.2	799.5	117
<i>TPI_100</i>	-3.82	-0.27	-100.00	31.50	17.79	117
<i>TPI_100_cuberoot</i>	-0.35	-0.65	-4.64	3.16	1.43	117
<i>Height_100</i>	242.4	235.3	39.0	694.0	109.5	117

### Appendix 3: Species detected, the number of sites where they were detected and the naïve estimate of occupancy of all species detected during the camera surveys from 122 sites.

Species highlighted with yellow indicates those used in logistic modelling, red text indicates species that are considered likely to be at high risk from fox predation.

Common name	Species name	Number Sites Occupied	Naïve Estimate
Black Wallaby	<i>Wallabia bicolor</i>	110	0.87
Common Brushtail possum	<i>Trichosurus vulpecula</i>	96	0.76
Common Wombat	<i>Vombatus ursinus</i>	86	0.68
Wonga Pigeon	<i>Leucosarcia melanoleuca</i>	67	0.53
Bush Rat	<i>Rattus fuscipes</i>	65	0.52
<sup>a</sup> Lace Monitor	<i>Varanus varius</i>	57	0.45
Superb Lyrebird	<i>Menura novaehollandiae</i>	57	0.45
Short-beaked Echidna	<i>Tachyglossus aculeatus</i>	47	0.37
Feral Cat	<i>Felis catus</i>	43	0.34
Spotted Quail Thrush	<i>Cinclosoma punctatum</i>	42	0.33
Antechinus spp.	<i>A. agilis</i> or <i>A. swainsonii</i>	35	0.28
Long-nosed Bandicoot	<i>Perameles nasuta</i>	26	0.21
Laughing Kookaburra	<i>Dacelo novaeguineae</i>	17	0.13
Grey Shrike Thrush	<i>Colluricincla harmonica</i>	16	0.13
Koala	<i>Phascolarctos cinereus</i>	13	0.10
Painted Button Quail	<i>Turnix varia</i>	12	0.10
Red Fox	<i>Vulpes vulpes</i>	12	0.10
Eastern Grey Kangaroo	<i>Macropus giganteus</i>	9	0.07
Long-nosed Potoroo	<i>Potorous tridactylus</i>	8	0.06
Bassian Thrush	<i>Zoothera lunulata</i>	6	0.05
Common Bronzewing Pigeon	<i>Phaps chalcoptera</i>	6	0.05
Common Ringtail Possum	<i>Pseudocheirus peregrinus</i>	6	0.05
Long-footed Potoroo	<i>Potorous longipes</i>	6	0.05
Wild Dog/Dingo	<i>Canis lupus familiaris/dingo</i>	6	0.05
Red-necked Wallaby	<i>Macropus rufogriseus</i>	5	0.04
Eastern Yellow Robin	<i>Eopsaltria australis</i>	4	0.03
Sambar Deer	<i>Cervus unicolor</i>	4	0.03
White-footed Dunnart	<i>Sminthopsis leucopus</i>	4	0.03
Eastern Pygmy Possum	<i>Cercartetus nanus</i>	3	0.02
Red Wattlebird	<i>Anthochaera carunculata</i>	3	0.02
Satin Bower Bird	<i>Chlamydera violaceus</i>	3	0.02
Southern Brown Bandicoot	<i>Isoodon obesulus</i>	3	0.02
Emu	<i>Dromaius novaehollandiae</i>	2	0.02
European Rabbit	<i>Oryctolagus cuniculus</i>	2	0.02
<sup>a</sup> Red-bellied Black Snake	<i>Pseudechis porphyriacus</i>	2	0.02
Brown Goshawk	<i>Accipiter fasciatus</i>	1	0.01
Crimson Rosella	<i>Platycercus elegans</i>	1	0.01
Eastern Whipbird	<i>Psophodes olivaceus</i>	1	0.01
Fallow Deer	<i>Dama dama</i>	1	0.01
Mountain Brushtail possum	<i>Trichosurus caninus</i>	1	0.01
Red-browed Treecreeper	<i>Climacteris erythroptera</i>	1	0.01
Rufous Fantail	<i>Rhipidura rufifrons</i>	1	0.01

Common name	Species name	Number Sites Occupied	Naïve Estimate
Southern Boobook Owl	<i>Ninox novaeseelandiae</i>	1	0.01
Sugar Glider	<i>Petaurus breviceps</i>	1	0.01
Superb Fairy Wren	<i>Malurus cyaneus</i>	1	0.01
Tawny Frogmouth	<i>Podargus strigoides</i>	1	0.01
White-throated Treecreeper	<i>Cormobates leucophaeus</i>	1	0.01
White-browed Scrub Wren	<i>Sericornis frontalis</i>	1	0.01
Yellow-faced Honeyeater	<i>Lichenostomus chrysops</i>	1	0.01
Yellow-tailed Black Cockatoo	<i>Calyptorhynchus funereus</i>	1	0.01

<sup>a</sup> – at risk from fox predation when juvenile



## Appendix 4. The odds ratios for the final 12 species' presence models investigating relationships between fire, predator control and habitat structure.

Odds ratios and their 95% confidence intervals. Colours signify whether the variable's *p*-value was less than 0.1 either alone (yellow), in the final backward selection model (blue), or in both cases (purple). In addition, a column for *Camera Number* or *Days* with *p*-values less than 0.1 when modelled alone is also included.

Species Model	Fire History (≤73 or >73)	Fire History (≤73). Since Burnt	Fire History (≤73). Fire Type	Treatment +/- Fox control	TPI 100 cube root	Height 100	EVD Code	Mean Cover	Camera Number or Days
Red Fox	'>73' to '≤73' 3.79 (0.77, 18.64)								
Feral Cat	'>73' to '≤73' 4.11 (1.07, 15.72)								
Common Brushtail Possum							'3' to '7' 3.03 (0.82, 11.21)	0.0176 (0.0012, 0.2606)	
Black Wallaby				'none' to 'control' 9.64 (1.76, 52.90)					
Bush Rat					'0.577 (0.416, 0.799)			13.4 (1.6, 111.6)	Camera Number 4 > 2
Echidna		negative		control > none				9.84 (1.24, 77.91)	Camera Number 4 > 2
Lace Monitor				control > none			'3' to '7' 4.03 (1.31, 12.33)	10.62 (1.20, 93.91)	Days 23 > 26 > 22
Long-nosed Bandicoot	required due to interaction term		'wildfire' to 'burn' 3.14 (0.83, 11.85)	control > none			'7' to '3' 4.16 (0.95, 18.19)	32.8 (2.3, 468.6)	
Long-nosed Potoroo							7 > 3	65.6 (10, 43228)	
Superb Lyrebird							'3' to '7' 2.09 (0.84, 5.22)		
Wonga Pigeon				'control' to 'none' 3.21 (1.31, 7.85)				0.045 (0.006, 0.359)	
Common Wombat	required due to interaction term	1.025 (0.999, 1.051)		'control' to 'none' 2.37 (0.96, 5.88)	1.31 (0.97, 1.78)	positive			Camera Number 4 > 2



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