Author/s:
Wanniarachchi Kankanamalage, Saumya Chinthani

Title:
Resource selection of small mammals in post-fire environments

Date:
2022

Persistent Link:
https://hdl.handle.net/11343/331633

# RESOURCE SELECTION OF SMALL MAMMALS IN POST-FIRE ENVIRONMENTS

SAUMYA CHINTHANI WANNIARACHCHI
KANKANAMALAGE

orcid.org/0000-0003-2784-3334

Doctor of Philosophy

May 2023

School of Agriculture, Food and Ecosystem Sciences

Faculty of Science

University of Melbourne

Submitted in total fulfilment for

the requirements of the degree of Doctor of Philosophy

# ABSTRACT

Fire is an important ecological driver and widely used land management tool that alters habitats across the globe. Animals are often most affected by fire indirectly through its effects on resources. However, the interrelationship between fire, resources and animals is complicated as these phenomena interact at various spatial and temporal scales. This thesis aims to determine the influence of fire, environmental gradients and habitat and food resources on small mammals. I used complementary approaches to achieve this: I investigated occurrence, diet and resource selection, and studied this at multiple spatial scales. An introduction, three data chapters, and a synthesis make up my thesis; summaries of each data chapter are as follows.

In Chapter 2, I investigated the influence of post-fire age, environmental gradients and resources on the occurrence of small mammals. Elliott trapping and habitat surveys were carried out, and Generalised Linear Models (GLMs) were used in analysing the relationship between the variables across different spatial scales. Habitat resources better predicted small mammal occurrence than time since fire or food availability (invertebrate biomass). Strong environmental gradients and the weak relationships between fire and resources likely drove the lack of fire responses. This chapter highlights the importance of habitat resources in facilitating species persistence in fire-prone landscapes.

In Chapter 3, I investigated the diets of small mammals and how the diets changed over time after fire. I analysed small mammal scat using eDNA metabarcoding technology to obtain high-resolution taxonomic information. The results showed a diverse array of small mammal diet items, and overall diets were different for each species. I found out that the diet of one predominantly insectivore focal species (yellow-footed antechinus, *Antechinus flavipes*) also included substantial amounts of plant matter. Overall, the diets of the three focal species changed to different degrees with respect to different post-fire growth stages. This chapter provides insights into the dietary requirements of three native mammal species and changes in resource use over time after a fire, guiding land managers to reduce fire impacts on small mammals across the landscape.

In Chapter 4, I investigated the resources selected by yellow-footed antechinus in foraging events within their home ranges. Individuals were radio tracked and foraging locations compared to random locations in the landscape. Findings suggest that individuals selected locations with denser vegetation for foraging, potentially as a predator avoidance strategy. Further studies, such as experimental manipulations are required to determine how study species use structural resources depending on changes in vegetation cover caused by disturbances such as fires.

An understanding of the different resource requirements of animals is essential for developing successful conservation and land management plans. This thesis emphasizes the importance of acquiring comprehensive ecological information on species resource selection, especially the importance of diet and dietary resources. This thesis highlights the importance of using complimentary approaches such as live trapping, radio tracking and novel eDNA metabarcoding to understand interrelationships between resources and small mammals in post-fire environments at multiple scales. The approaches and findings of this thesis can guide conservation actions in post-fire environments.

DECLARATION

This is to certify that:

i. The thesis comprises my original work towards the PhD unless indicated in the preface
ii. Due acknowledgment has been made in the text to all other material used
iii. The thesis is fewer than 100,000 words in length exclusive of tables, maps bibliographies and appendices.

Saumya Chinthani Wanniarachchi Kankanamalage

May 2023

# PREFACE

## General Introduction

My thesis consists of three data chapters (Chapter 2, Chapter 3 and Chapter 4) an introductory chapter (Chapter 1) and a synthesis chapter (Chapter 5). The three data chapters have been prepared in manuscript format and one of which (Chapter 3) is published in the journal Ecology and Evolution. I am the lead researcher and principal author and I led field work data collection, analysis and writeup. My co-authors on each paper all contributed to designing the study, planning field work, and collecting data, carrying out statistical analysis, interpretation and consolidation and revising the manuscripts (Table 1). Chapter 1 includes the introduction and the conceptual model that binds the three data chapters within the thesis. Chapter 5 provides a synthesis where the three data chapters are summarised and discussed in a broader perspective.

The thesis does not contain an initial chapter explaining the study sites and common methodologies given that the data chapters (Chapter 2, Chapter 3 and Chapter 4) are arranged and written in the manner of standalone papers. This resulted in somewhat of an overlap among the three data chapters specifically regarding the study sites and methodologies. Throughout Chapters 2 to 4 I used the plural pronoun ‘we’ to be aligned with the contribution of co-authors for the three manuscripts. To ensure the stylistic cohesion throughout the rest of the thesis, I used the first person pronounce ‘I’ in Introduction (Chapter 1) and Synthesis (Chapter 5).

The research was carried out under the university of Melbourne Animal Ethics Committee ID 1614071 in compliance with the Australian Code for the Care and Use of Animals for Scientific Purposes. Field work was conducted under the National Parks Act (permit number 10008227).

*Table 1 The contribution to the three data chapters*

| Thesis Chapter | Co-authors and manuscript title | My contribution |
|---|---|---|
| Chapter 2 | Wanniarachchi, S., Smith, A., Sitters, H., Di Stefano, J., York, A. and Swan, M. (In prep). Small mammals respond more strongly to environmental gradients and habitat resources than fire history and foraging resources in a woodland ecosystem.<br>Contributions: SW, AY and MS developed the concept and the study design. AY, JD, HS and MS developed the idea and secured funding for the larger landscape scale project wherein this project was nested. SW and AS led the field work jointly for two separate manuscripts and two data sets with an overlap. SW analysed the data with assistance from MS and AY. SW lead the writing of the manuscript with the editorial guidance from AY and MS. | Wanniarachchi, S. **70**% |
| Chapter 3 | Wanniarachchi, S., Swan, M., Nevil, P., and York, A. (2022) Using eDNA metabarcoding to understand the effect of fire on the diet of | Wanniarachchi, S. **80** % |

| | | |
|---|---|---|
| | small mammals in a woodland ecosystem. *Ecology and Evolution*, 12, e9457. DOI: 10.1002/ece3.9457<br>Contributions: SW, AY and MS developed the concept and the study design. SW led the field work and data collection. SW, MS, PN and AY contributed to funding acquisition for the molecular work and creating the methodology. SW analysed the data with assistance from AY and MS. SW wrote the manuscript with editorial assistance from MS, PN and AY. | |
| Chapter 4 | Wanniarachchi, S., York, A., and Swan, M. (In Prep). Fine-scale resource selection of Yellow-footed Antechinus (*Antechinus flavipes*) in south-west Victorian heathy woodlands.<br>Contributions: SW, MS and AY developed the concept and study design. SW led the fieldwork and data collection. SW analysed the data with assistance from MS and AY. SW led the writing of the manuscript with the editorial guidance from AY and MS. | Wanniarachchi, S. **80**% |

My PhD was funded by a Melbourne Research Scholarship from the University of Melbourne which included full tuition remission, living allowance, relocation allowance and visa-length overseas student health cover. Additionally, I was able to secure the following scholarships and research grants from multiple funding bodies to carry out field work and laboratory work to complete my thesis.

- Parks Victoria Applied Park Management Research Scholarships – Granted by Parks Victoria, State of Victoria (2019)
- Holsworth Wildlife Research Endowment (awarded to Australian postgraduate students who are conducting field work on Australian native plants and animals; conservation biology and biodiversity studies; or wildlife management, Awarded by Ecological Society of Australia partnered with Dr Bill Holsworth.) - (2019 Round 1, 2020 Round 1, 2021 Round 1)

Furthermore, I was able to secure the 2022 Science Abroad Travelling Scholarship (SATS), awarded by the School of Ecosystem and Forest Sciences, The University of Melbourne, to present findings of this thesis at an international conference (INTECOL).

The list of conferences I presented at are as follows.

- Wanniarachchi, S., Swan, M. and York, A., (2019). RESOURCE SELECTION OF SMALL MAMMALS IN POST-FIRE ENVIRONMENTS, SEFS (School of Ecosystem and Forest Sciences) Graduate Student conference, Creswick, Australia (2019).

- Wanniarachchi, S., Swan, M. and York, A., (2019). RESOURCE SELECTION OF SMALL MAMMALS IN POST-FIRE ENVIRONMENTS, Ecological Society of Australia (ESA) Annual Conference: Poster Presentation, Open Forum. Launceston, Australia.
- Wanniarachchi, S., Swan, M., York, A. and Nevil., P., (2020). RESOURCE SELECTION OF SMALL MAMMALS IN POST-FIRE ENVIRONMENTS, Ecological Society of Australia (ESA) Annual Conference (Virtual): Symposium: Speed talk, Perspectives on a changing landscape of fire. Australia.
- Wanniarachchi, S., Swan, M. and York, A., (2021). FIRE AND HABITAT RESOURCES INFLUENCE ON OCCURRENCE OF SMALL MAMMALS IN AN AUSTRALIAN WOODLAND ECOSYSTEM, Ecological Society of Australia (ESA) Annual Conference (Virtual): Open forum: Speed talk, Fire Ecology. Australia.
- Wanniarachchi, S., Swan, M., Nevil, P., York, A., (2022) USING E-DNA TO UNDERSTAND THE EFFECT OF FIRE ON THE DIET OF THREE SMALL MAMMAL SPECIES, International Association for Ecology Conference (INTECOL), Geneva, Switzerland.

# COVID 19 IMPACT STATEMENT

Due to the COVID 19 pandemic, significant disruptions occurred in completing this thesis. In March 2020, restrictions were imposed throughout Victoria (Australia), with travel restrictions and lengthy stay-at-home orders occurring during that time. This resulted in campus closure with restriction on travelling for field work, recruiting volunteers, using laboratory spaces and accessing field equipment. Additionally, one of the most crucial aspects that affected this study was the cancellation of fieldwork permits from Victorian Government authorities, which restricted access to study sites.

These restrictions resulted in major delays and ultimately a change in scope for the final chapter of the thesis. Relevant disruptions and their impacts directly related to each of the three data chapters (Chapter 2, Chapter 3 and Chapter 4) are listed below.

### *Chapter 2*: *Key experiments and data collection delayed*

This chapter included an invertebrate counting, sorting and biomass weighing component. Initially invertebrate counting was to be carried out by a Research Assistant, yet with COVID 19 restrictions and campus closure they were unable to access any facilities at the University, thus I needed to complete this task in my accommodation on campus (setting up a working station/laboratory at home following safety guidance). Having to undertake this task in lieu of a Research Assistant led to delays of two and a half months which impacted the progress of other chapters.

*Chapter 3*: *Major delays in data analysis due to changes of plans for data chapter 2*.

COVID 19 did not directly influence this chapter, as the data had already been collected before the pandemic. However, delays to the other two chapters led to delays in finalising this chapter.

*Chapter 4*: *Unable to undertake essential work due to travel restrictions*. *Key Experiments delayed and analysis and writing delayed due to restrictions. Major changes in the data chapter.*

This chapter was the most significantly impacted chapter by the COVID 19 restrictions. The radiotracking of yellow-footed antechinus was intended to occur in March 2020. I was not able to carry this out due to fieldwork restrictions. I received approval to recommence fieldwork from the University in June 2020. However, I was only allowed to undertake research at a subset of study sites because of the cancellation of Parks Victoria permits.

The late start resulted in a very short window to undertake the research. For ethical and study design reasons I had to avoid spring and summer because,

- All male antechinus in the population die off in mid to late August leaving only lactating females and pouch young.
- Ethics did not permit us to collar lactating females.
- Juvenile antechinus in summer were too small to radio collar as individuals needed to be > 28g.
- Juveniles disperse in summer which would interfere with the results.

University requirements around volunteers were restrictive at this time – they had to be University staff or students and needed additional COVID 19 training. It was a requirement of all fieldwork that I was accompanied; however, the restrictions made it extremely difficult to recruit people. This, plus the frequently changing rules and administrative hurdles, led to delays in multiple field trips. Also, low trapping rates meant that I could not successfully collar sufficient numbers of animals in a timely manner. This did not allow me to offset losses from collar failures which are common in radiotracking studies. Furthermore, some animals were captured later in the season than optimal, with some disappearing (predation, male die-off) before sufficient data could be collected.

All of this resulted in a smaller sample size than I had hoped, and this reduced the possible study scope. Therefore, I could not compare differences among fire treatments. Also, a significant component of the planned research had to be abandoned. Initially, I had two study designs with a correlative approach to identify the exact resources selected within the home range, followed by an experimental design to understand the mechanistic links between activity and resources. The planned experimental study was to use a before-after control-impact (BACI) study, adding or subtracting relevant resource attributes, thus enabling causative relationships between resources and home range to be determined. Some comments on this abandoned research plan are provided in the synthesis as future research ideas. Despite the delays and constraints, I was able to carry out a suitable alternative to the planned analysis for Chapter 4. It was not possible to attempt to redo the study in 2021 due to a limited time window I have as an international student on a visa in Australia.

# ACKNOWLEDGMENTS

As I pursued my PhD, many generous people supported me and guided me throughout, and I am forever grateful for all of them.

My sincere gratitude goes out first and foremost to my supervisors, Prof. Alan York and Dr Matthew Swan; I am endlessly thankful for the guidance and unwavering support you two gave me and believing in me and being extremely patient with me when I was making mistakes and struggling to complete my tasks. As the saying goes, I was able to "stand on the shoulders of giants" and see beyond and be inspired to be a better scientist. Alan, thank you for the knowledgeable insight you've given me and your encouragement to see things from a broader perspective. Matt, my sincere appreciation goes out to you for teaching me all the field skills needed so that I can become a true field ecologist and for dedicating a lot of time to collecting data in the field, discussing and explaining complex theories, as well as for helping me with the analysis of the data.

Thanks to my two advisory committee chairs, Prof. Trent Penman and Prof. Gerd Bossinger, for their advice, guidance, and kind support, as well as for understanding and acknowledging the struggles I had to go through as an international student and for suggesting me numerous alternatives and solutions.

Working with my wonderful colleagues from the Fire Ecology and Biodiversity Group at the Creswick Campus has been very rewarding. Dr Julian Di Stefano, thank you for your insight into statistical analysis, manuscript preparation and guidance in the field and for teaching me to drive in Australia. Dr Holly Sitters, thank you for checking up

on my mental health and discussing Science and Buddhism whenever we had time. Thank you, Amy Smith, for explaining all the Australian ways and being the most excellent fieldwork buddy, an ecologist could ask for. Thank you, Rachel Nalliah, Taylor Reid, Amanda Lo Cascio, Erin Thomas, Ella Pouton, Amber Button, Pip Taylor, Simeon Zylinski, Emma Window, Sandra Penman, Sarah Mulhall and Lilly Wheeler, for your support and encouragement. Last but not least, Julio Najera, for helping me with the laboratory work in invertebrate analysis, which couldn't have been completed without your help.

Thanks to the incredible molecular biologists team at TrEnD Lab Curtin University Western Australia; Dr Paul Nevil, thank you for contributing to experimental work and providing insightful comments and suggestions. Dr Rose Lines, Dr Mahsa Mousavi Derazmahalleh, and Shane Herbert for the technical support in molecular analysis.

There will never be enough thanks I can give to "Creswickets", my chosen family away from home. It means a lot that you all helped me with a million different things, from making sure I don't miss my meals to teaching me complex statistical theories and inside secrets on how to do a PhD: Dr Nadeeshani Karannagoda, Dr Yasika Subasinghe, Sachinthani Karunarathna, Dr Duncan Smith and Mojtaba Khorrami Raad.

Thanks to my "Three Musketeers" for believing in me even when I didn't want to: Dr Subhashi Rajapaksha for the best writing advice; Dr Bhagya Herath- for listening to my endless rants and Sewwandi Wijesuriya for being my writing buddy.

To my little brother Sanka Wanniarachchi, thank you for being my best friend, my go-to person for everything under the sun and my tech guru. This thesis is dedicated to you, Mom (Ammi) (Evadni Wanigasekara) and Dad (Thaththi) (Dr Sumith Wanniarachchi); you have always been there for me no matter what, and you have always supported me in every way and showered me with unconditional love, thank you for being the pillars of strength in my life.

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# 1. INTRODUCTION

Fire is considered both a natural and an anthropogenic disturbance that is a fundamental part of many ecosystems (Scott *et al.,* 2013; Geary *et al.,* 2020). Apart from natural ignition sources such as lightning strikes creating fires (Yang *et al.,* 2015; Bates *et al.,* 2018), humans have been using fire for managing the landscape for millennia (Gill, 1975; Bates *et al.,* 2018; Gott, 2005). At present, land managers and ecologists are using fire as a tool to reduce wildfires risks and to promote biodiversity (Gill, 1975; Whitehead *et al.,* 2003; Penman *et al.,* 2011). Fire-mediated landscapes are adapted to different fire regimes and retain a suite of fire adapted plants and animals (Whelan, 1995; Burrows, 2008; Pausas & Parr, 2018), yet natural fire patterns are changing due to human induced climate change (Ward *et al.,* 2020; Abram *et al.,* 2021). Future climate models are predicting a continued trend of warm, dry climates with longer fire seasons and more hazardous fire weather for next few decades (Clarke & Evans, 2019; State of the Climate, 2020). Many plant and animal species are nominally threatened by inappropriate fire regimes yet the mechanisms by which fire contributes to population declines are often unclear (Kelly *et al.,* 2020). Therefore, a detailed understanding of how fires are affecting flora and fauna is important for conservation in a rapidly changing world.

## 1.1. Fires, animals and resources

Landscapes that are adapted to frequent fires retain a suite of fire adapted plants and animals; and the habitats will go through successional changes where resources are altered spatially and temporally (Whelan, 1995; Burrows, 2008; Pausas & Parr, 2018; Smith, 2018). Fire can directly affect animals through mortality, reduced reproduction, displacement and emigration (Brown *et al.,* 2013; , Dickman, 2021; Jolly *et al.,* 2022). This will depend on the fire severity, mobility and life-stage of the animal (Whelan, 1995; Kelly *et al.,* 2017a). At the same time, some species can persist within post-fire habitats, although fire could reduce the habitat attributes that provide food and shelter which will increase the predation risk (Swinburn *et al.,* 2007b; Flanagan-Moodie *et al.,* 2018). However, some species are attracted to recently burnt environments due to the newly shaped resources (e.g., certain invertebrates that feed and reproduce in post-fire environments and insectivorous birds that prey on them; Whelan, 1995). Thus, responses to fires vary among species according to their life-history strategies as well as to components of the fire regime.

Spatial and temporal characteristics of fire such as frequency, severity, seasonality, heterogeneity and magnitude that make up the fire regimes will facilitate resource changes; with different regimes affecting the biota in different ways (Gill, 1975; Keeley et al., 2011; York et al., 2012; Kelly et al., 2017a). Low severity fires occurring in the appropriate season can bring short term increase in resource availability such as the growth and regeneration of plants while preserving the canopy vegetation. In a study carried out in a mixed foothill forests low severity spring burning increased the resprouting of plants and autumn burning favoured the recruiting of reseeding plants (Management and Environment, 2003). Therefore, in short-term, recovery will be much more rapid creating renewed resources for animals such as fresh food sources. In contrast a severe fire can result in a large nutrient outflows creating nutrient deficiencies in the landscape and causing mortality by tissue damage or suffocation from smoke (Neary et al., 1999; Whelan, 1995). As examples, *Persoonia hirsuta* (Proteaceae) communities subjected to high severity fires showed a significant increase in seedling dieback and mortality (Andres et al., 2022) and smoke from bushfires caused mortality in a captive population of an endangered Pseudomys fumeus (Smoky Mouse) (Peters et al., 2021). The change of season can alter population dynamics by impacting adult survival, propagule availability, and the establishment of seedlings after a fire (Platt et al., 2015; N'Dri et al., 2018; Miller et al., 2019). For example, fire in spring and early summer can prevent seed production and recruitment of the endangered Rutidosis leptorhynchoides (Button Wrinklewort) and Leucopogon exolasius (Woronora Beard-heath) (Knox and Clarke, 2006; Mark et al., 2007). In environments where fires are occurring at frequencies different to historical cycles, it is possible for subsequent fires to disrupt this recovery process, resulting in population declines or extinctions (Keith, 2012).

Populations respond to individual fire events, whereas species assemblages respond to long-term fire regimes (Whelan, 1995; Kelly *et al.,* 2017a). The Habitat Accommodation Model (HAM) was proposed by Fox (1982), which suggests that species enter succession after a disturbance when the habitat resource conditions are adequate for them; eventually, when the conditions no longer meet the requirements of the species, they are replaced by species that are able to adapt to the changed conditions (Fox & Taylor, 2001). Therefore, in fire-mediated landscapes, change in resources are influential in driving animal occurrence, abundance and diversity (Zylinski *et al.,* 2022). A comprehensive study of both resources and animals in fire-mediated environments is therefore essential in order to understand the effects of fires on animal communities.

## 1.2. Resource selection

Understanding interrelationships between fire, resources and animals is complicated by the various scales at which these phenomena operate and interact. The resource selection process is multi-scale or hierarchical in space and time (Mayor *et al.,* 2009; Pavlacky *et al.,* 2012). These scales can vary from larger areas of landscapes where certain types of resources are present or required in longer timeframes, to small-scale resources that are present and utilized in shorter timeframes (Mayor *et al.,* 2009).

A useful framework in this context is the different *Orders of Resource Selection* introduced by Johnson (1980), whereby different spatial scales of resources are defined geographically

(Figure 1. 1). The *First order* of selection is the geographic range of a species, generally the distribution of species defined by climatic and environmental conditions such as rainfall, temperature, wind and soil conditions. *Second order* of selection is the selection of home range of an individual or a social group (Meyer & Thuiller, 2006) within a landscape. Characteristics of the home range could vary depending on the sex, maturity state and resource requirements in the season (Haris *et al.,* 1990). *Third order* of selection is the specific habitat resources an individual uses within its home range; selection of this order will depend on the resource heterogeneity of the home range patch. *Fourth order* of selection is the actual procurement of a particular resource within the third order resource such as food items or the usage of a hollow in a tree within the home range (Johnson, 1980; Brennan *et al.,* 2019).

For example, the mountain caribou (*Rangifer tarandus caribou*) in British Columbia selects northernly aspects or a northernly distribution at the larger geographical scale - *First order*. Within that geographical range, animals were found in high elevation landscapes with low site productivity - *Second order*. In these landscapes, this species selected the areas with high canopy closure and older cedar and hemlock forests - *Third order* (Apps *et al.,* 2001). Therefore, resource selection of the same species could lead to varying conclusions, an animal could be selecting different resources at different scales. Not all critical resources will be detected when viewed at a specific scale (Johnson, 1980). Ecological relationships cannot be scaled up or down, therefore resource selection should be studied at multiple levels in order to understand the full characteristics of the resource usage of a species (Mayor *et al.,* 2009). It is common in landscapes that are subjected to disturbances that resources are arranged in patches and as a result resources may not be distributed evenly (Mayor *et al.,* 2009; Kolka *et al.,* 2014; Pellegrini *et al.,* 2018; Dorph *et al.,* 2021). As such, an individual must make decisions about how to exploit the resource environment in various situations such as the presence of competitors or predators in order to take advantage of the resources available (Arcis & Desor, 2003; Koike *et al.*, 2008; Donihue, 2016).

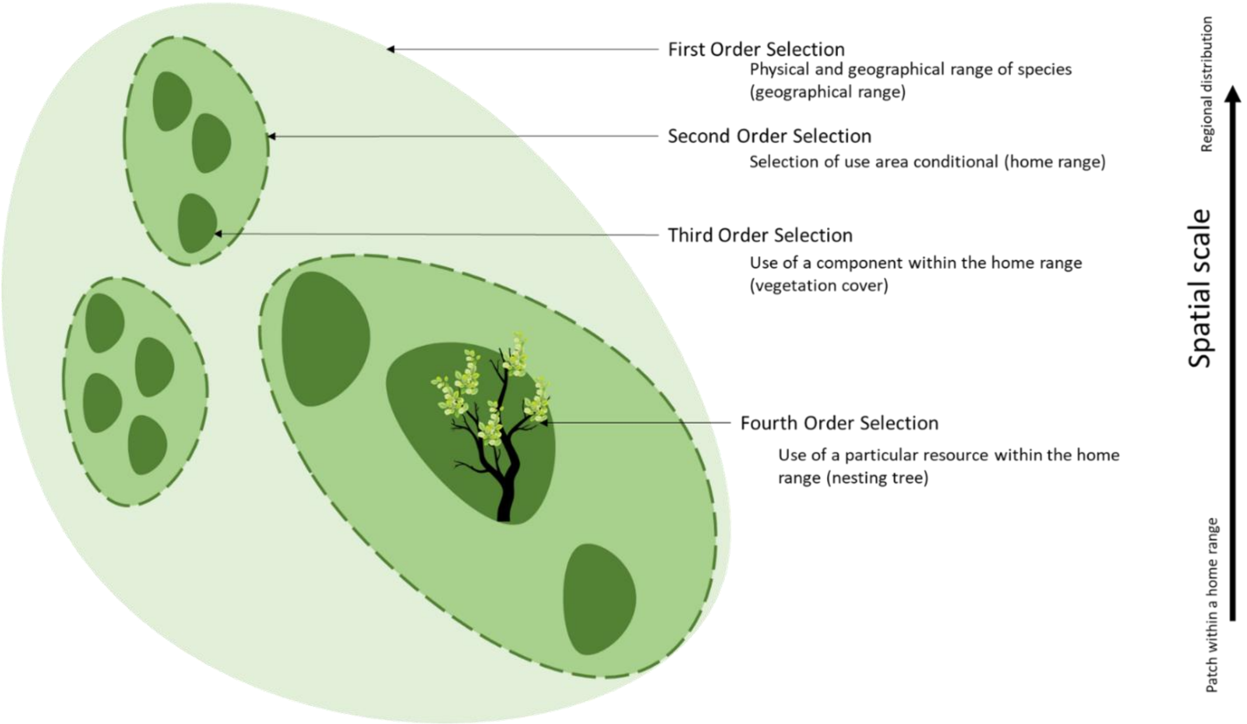


*Figure 1. 1 Graphical representation of the four orders of resource selection; First order of selection is the geographic range of a species, generally the distribution of species in this order is defined by the climatic and environmental conditions such as rainfall, temperature, wind and soil conditions. Second order of selection the selection of home range of an individual or a social group. Third order of selection are the components within the home range that are being selected and Fourth order of selection is the selection of a particular resource within the home range (Johnson, 1980; Mayor et al., 2009).*

## 1.3. Australian context of fire, resources and animals

In Australia, fire has been used as a tool for shaping and manipulating the landscape for millennia by the Indigenous Australians to create resource-rich habitats. Currently, prescribed fires are carried out by many land managers to reduce the risk of wildfires and to promote biodiversity (Gill, 1975; Whitehead *et al.,* 2003; Cheal, 2010). With the adverse effects of climate change, inappropriate fire regimes are an increasing risk (Hughes, 2010; McDonald, 2020), therefore, knowledge on successional processes after fires and how animals are responding to resource changes across landscapes is critical for conservation management (Browning *et al.,* 2010).

Australian small mammals are an excellent group of animals to study changes following a fire, with information on habitat selection revealing complex relationships between species, resource partitioning, and competition between sympatric populations among small mammals after a fire (Dickman, 1991a; Yunger *et al.,* 2002; Menkhorst, 2011; Fordyce *et al.,* 2016; Nalliah *et al.,* 2021). However, there has been changes in the distribution and population size of many species, and niche utilization has been altered (Kelly & Bennett, 2008; Bilney, 2014; Kelly *et al.,* 2020). One key factor recognized as responsible for the decline is inappropriate fire regimes (Converse *et al.,* 2006; Di Virgilio *et al.,* 2020).

Many studies have shown that the composition of animal communities and/or the abundance of animals and their behaviour vary greatly between burned areas, regenerating areas and unburnt areas (Gill *et al.,* 1999; Dawson *et al.,* 2007; Lees *et al.,* 2021), however functional mechanisms/ mechanistic links responsible for these patterns are still not well understood in the context of fire resources (specifically food) and within the context of the hierarchical manner of resource selection (Mayor *et al.,* 2009, McElhinny et al., 2006 Pavlacky *et al.,* 2012, Southgate & Carthew, 2006).

Resource selection hierarchy could be a useful framework for understanding interrelationships between fire, resources and different animal species (Pavlacky *et al.,* 2012, Mayor *et al.,* 2009). Undertaking studies at multiple scales and considering the various resources that animals need is important for generating information that can be used in conservation management.

Many studies have examined the relationships between fire, resources (especially habitat structure) and small mammals (see (Flanagan-Moodie *et al.,* 2018, Nalliah *et al.,* 2021, González *et al.,* 2021)). However, many studies utilise approaches that are consistent with the second and third order of habitat selection. Fewer studies have investigated the fourth order of habitat selection, especially regarding diet and the procurement of food resources.

Recent studies have indicated the importance of patch-scale habitat structure and food resources in driving small mammal fire responses (Di Stefano *et al.,* 2014, Swan *et al.,* 2015, Nalliah *et al.,* 2021). Generally, habitat structure refers to the identity and spatial arrangement of biotic and abiotic components that are important for a species. The selection of habitat structures is an individual choice, but it will eventually be demonstrated in the distribution and abundance of species (Stapp, 1997). Various structural characteristics directly affecting animals will be determined by the forest strata in which the animal lives and the taxonomic group to which it belongs (McElhinny *et al.,* 2006). Similarly, the availability and selection of food directly influences the survival and persistence of animals and, in turn, are reflected in patterns of abundance in animals (Whittaker *et al.,* 1973, Broughton & Dickman, 1991). A diet analysis would provide us with the opportunity to directly identify the food usage of a given animal, which can then be used to examine the fine-scale patterns of resource selection of the species (Southgate & Carthew, 2006). However, very little is known about food acquisition and the usage of structural resources at a fine scale within home ranges and how these resources are utilized in different post-fire ages.

## 1.4. Thesis aims

The overarching aim of this thesis is to determine the influence of fire, environmental gradients and habitat and food resources on small mammals. To accomplish this, a conceptual model was created based on past literature, defining links between major drivers of small mammals at multiple scales (Figure 1. 2). This model was then used to frame a series of questions relevant to the aims.

Specifically in this thesis I address three key questions:

1. What are the links between time since fire, environmental gradients, habitat resources and small mammal occurrence?

2. What are the diets of small in post-fire environments, are there any dietary changes post-fire and what are the nature of these changes?

3. What are the fine-scale structural resources selected by small mammals while foraging?

Collectively the research carried out in this thesis is important in several reasons. Firstly, as the assessment of the usage of resources across multiple scales is an important yet regularly overlooked component, due to the time-consuming field-based data collection involved such as live trapping of individuals and radio-tracking studies. I looked at multiple scales of resource selection staring from the *second order of resource selection* to the *fourth order of resource selection*.

Secondly, although diets are one of the crucial parts of animal ecology and could be a major determinant in the persistence of populations, studies on diets of animals are limited, with few studies on diets in post-fire environments. Studying animals inhabiting landscapes with changing fire regimes require a lot of information about resource use, and one crucial factor to understand is how fire might be influencing the diets. I carried out a novel and effective eDNA metabarcoding study, which demonstrated the potential of incorporating diverse methods to create more comprehensive studies in resource selection adding to the current body of knowledge in ecology.

Focal species of this study belong to the family Muridae (bush rat, heath mouse and house mouse) and Dasyuridae (yellow-footed antechinus) (Smith, 1984, Cockburn et al., 1981, Kemper et al., 2014, Vaughan, 1972). Dasyurid marsupials are native to the Australian continent while Muridae are a family later introduces to Australia (Vaughan, 1972). Therefore, the evolutionary adaptation of these two families may lead them to have different responses to the resource environments posing their differences in physiology (Fisher and Dickman, 1993, Yunger et al., 2002). Furthermore, the response of different resources to fire varies creating variable resource environments for species to navigate (Gill, 1975, Fox, 1982, Santos et al., 2014). Thus, understanding the differences in how these species use resources will further help in advancing the knowledge from an evolutionary perspective.

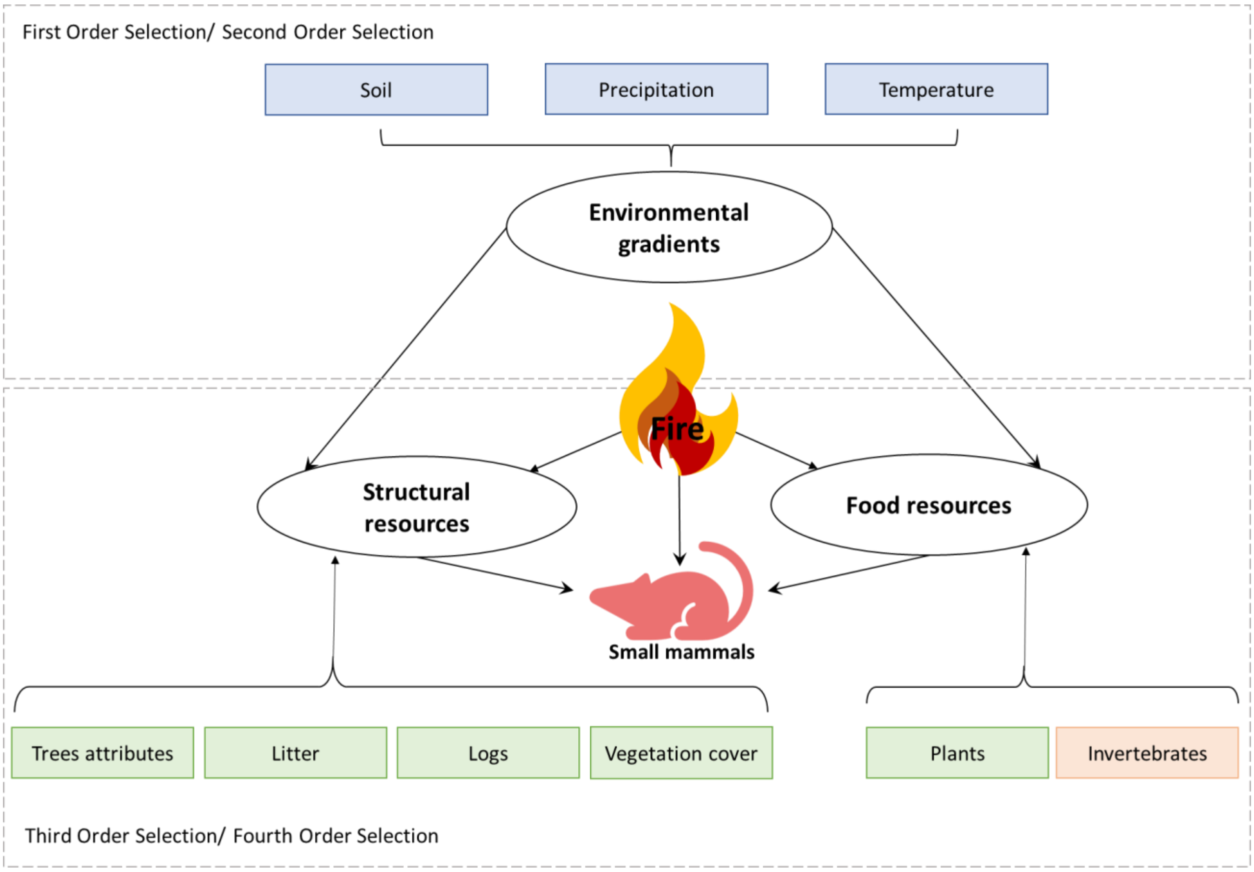


*Figure 1. 2 Conceptual diagram showing the possible interactions between the small mammals in the study area for food, structural resources, fire, and environment variables*

## 1.5. Thesis structure

This thesis does not contain an initial chapter explaining the study sites and common methodologies, as the data chapters (Chapter 2, Chapter 3 and Chapter 4) are arranged and written in a manner to be submitted to peer reviewed journals as stand-alone papers. This resulted in somewhat of an overlap among the three data chapters specifically regarding the study sites and methodologies. Within the three data chapters, Chapter 2 focusses on the landscape scale (*second and third order of resource selection*) resource selection while Chapter 3 and Chapter 4 are focusing on the fine scale (*fourth order of resource selection*) resource selection in the study area.

The focus of each data chapter is outlined below,

Chapter 2:

Chapter Title*: Small mammals respond more strongly to environmental gradients and habitat resources than fire history and foraging resources in a woodland ecosystem*

In this chapter I determine the interrelationships between fire, resources, and small mammals at a range of spatial scales from the larger landscape scale to the smaller scale relevant to the home ranges of small mammals. The four Australian small mammal species selected for this chapter were: yellow-footed antechinus (*Antechinus flavipes*), heath mouse (*Pseudomys shortridgei*), bush rat (*Rattus fuscipes*) and house mouse (*Mus musculus*). I looked at small mammal occurrences and how they are influenced by environmental gradients, structural resources, food resources and fire. Both environmental variables and habitat structural resources were considered, with invertebrate biomass as a proxy of food resources. Time since fire was used as the variable regarding fire history. Generalized linear models (GLMs) were developed to determine the relationship between environmental variables, habitat resources, fire and small mammals.

The key predictions for this chapter are,

i. At the landscape scale the distribution of the small mammal species will respond to the environment gradients.
ii. At smaller local spatial scale, the occurrence of the small mammals will respond to the patch scale resource availability, with the different species responding differently.
iii. Time since fire will be a poor predictor compared to the other variables in explaining the occurrence of small mammals

Chapter 3:

Chapter Title*: Using eDNA metabarcoding to understand the effect of fire on the diet of small mammals in a woodland ecosystem*

In this chapter I utilized eDNA metabarcoding to obtain an improved understanding of the diet of three native Australian small mammal species: yellow-footed antechinus, heath mouse and bush rat in the study area. Additionally, I investigated how diets are changing over time after fire.

The key predictions for this chapter are,

i. eDNA metabarcoding will result in disclosing cryptic food taxa in the diets of the three species.
ii. The diets of the three small mammals will be fundamentally different.
iii. Diets of each species will change over time after fire.

This chapter has been published in Ecology and Evolution:

- Wanniarachchi, S., Swan, M., Nevil, P. & York, A. 2022. Using eDNA metabarcoding to understand the effect of fire on the diet of small mammals in a woodland ecosystem. *Ecology and Evolution*, 12, e9457.

The author-accepted version of the manuscript is presented here with some modifications to match the style and formatting of this thesis. The content remains unchanged from the published article.

Chapter 4:

Chapter Title*: Fine-scale resource selection of yellow-footed antechinus (Antechinus flavipes) in south-west Victorian heathy woodlands*

In this chapter I examined how structural resources are being utilized by yellow-footed antechinus in their home ranges while foraging. Yellow-footed antechinus were radio-tracked while foraging, and the relationship between animal movement and habitat resources investigated.

Due to the COVID 19 restrictions data collection for this chapter was severely constrained, resulting in only a small set of radio-tracking data as a consequence of the small-time window that was available for fieldwork.

The key predictions for this chapter are:

i. Individuals will select some variables disproportionately to their availability within their home range.

ii. Individuals will select coarse woody debris as a foraging substrate and will select areas associated more understorey and hollow bearing trees in preference to more open areas.

## Chapter 5:

## Synthesis

In this chapter the results of the three chapters are summarised and discussed in a broader perspective. Limitations and potential areas of future research are discussed.

# 2. SMALL MAMMALS RESPOND MORE STRONGLY TO ENVIRONMENTAL GRADIENTS AND HABITAT RESOURCES THAN FIRE HISTORY AND FORAGING RESOURCES IN A WOODLAND ECOSYSTEM

## 2.1. ABSTRACT

Insufficient knowledge of species' resource use after fire limits effective fire management planning, especially as fires become more frequent and intense under climate change. There is a complex three-way relationship between fire, resources, and fauna; these are further complicated by broad-scale environmental gradients such as rainfall and temperature. This study aims to determine the interrelationships between fire, resources, and small mammals at a range of spatial scales. Elliott trapping was used to capture four species: yellow-footed antechinus (*Antechinus flavipes*), bush rat (*Rattus fuscipes*), heath mouse (*Pseudomys shortridgei*) and house mouse (*Mus musculus*) across a time since fire gradient at 111 sites. We quantified habitat (vegetation structure) and foraging resources (invertebrates) at each site. Generalized linear models (GLMs) were used to determine relationships between fire, resources, and small mammal occurrence. Habitat resources were better predictors of small mammal occurrence than time since fire, and there was no relationship between invertebrate biomass and any of the four species. Each species showed preferences for specific habitat resources such as tree hollows for yellow-footed antechinus and dense low vegetation cover for heath mouse. The lack of fire responses was likely driven by the strong environmental gradients and the weak relationships between fire and resources. Our work highlights the

importance of resources in facilitating species persistence in fire-prone landscapes. Fire management will be improved by developing a greater understanding of the resources that species rely on and ensuring that fire management protects and improves these resources.

## 2.2. Introduction

Fire can be considered both a natural and an anthropogenic disturbance which is an integral part of many terrestrial biomes (Scott *et al.*, 2013, He *et al.*, 2019, Geary *et al.*, 2020); yet natural fire patterns are changing due to human-induced climate change (Prichard *et al.*, 2017, Ward *et al.*, 2020, Abram *et al.*, 2021). Prolonged high temperatures coupled with irregularities in rainfalls are producing climate extremes and anomalies, resulting in severe droughts and bouts of sudden heavy rainfall, leading to changes in vegetation and fuel loads which are precursors of fire (Flannigan *et al.*, 2006, Di Virgilio *et al.*, 2020, Abram *et al.*, 2021). Thus, spatial and temporal characteristics of fire regimes, such as heterogeneity, magnitude, frequency, severity and seasonality (Whelan, 1995) are changing with severe wildfires becoming more common in many parts of the world, disrupting natural cycles (Neary *et al.*, 1999, Johnson, 2007, Heinrichs *et al.*, 2016, Di Virgilio *et al.*, 2020, Wilson & Garkaklis, 2020). Nevertheless, fire can be used as a successful tool to modify and manage landscapes to reduce the risk from wildfires and promote biodiversity (Gill, 1975, Whitehead *et al.*, 2003, Penman *et al.*, 2011).

Many animals are closely dependent upon plant communities that reflect past fire regimes rather than responding to fire itself, creating a complex three-way interaction between fire, resources, and animals.  Following a fire, plant communities change over time in terms of productivity, composition and structure, with animal communities responding to these changes (Fox, 1982, Smith, 2018). Alterations to historical fire regimes can become threatening to some plant communities, as tree mortality could promote habitat loss (Fairman *et al.*, 2016), furthermore changes to soil seed banks could create shifts in plant community composition and structure (Cary and Morrison, 1995, Chick *et al.,* 2016, Gallagher *et al.,* 2021). Plant-derived old-growth elements such as logs, hollows and leaf litter layers require time to develop and accumulate; repeated fires can significantly deplete these resources on the forest floor (Miehs *et al.,* 2010, Aponte *et al.,* 2014, Flanagan-Moodie *et al.,* 2018). Ultimately, many animals rely on these resources to complete their life cycles; yet time for these elements to develop will depend on the past fire regimes in the landscape (Fox *et al.,* 1979, Garden *et al.,* 2007, Miehs *et al.,* 2010, Seibold *et al.,* 2015).

Furthermore, species' fire responses are complicated by environmental gradients such as rainfall and temperature that are primary drivers of the distribution and abundance of many animal species through their effects on vegetation structure and function (Masters, 1993, Lada *et al.,* 2013, Sitters *et al.,* 2014). Additionally, species' responses to fire can change depending on varying environmental conditions in space and time. For example, a study of small mammal relationships with time since fire found vastly different responses in dry versus wet years (Hale *et al.,* 2016). Similarly, the properties of fire regimes can interact with environmental conditions to influence resources. For example, carbon pools are higher in unburnt forest soils, promoting soil moisture retention and soil structure, affecting habitat productivity and suitability (Kolka *et al.,* 2014: Pellegrini *et al.,* 2018).

Altered fire regimes have played a key role in mammal decline in Australia, which is well established as the country with the highest mammalian extinction rate globally (Woinarski *et al.,* 2015, Hradsky, 2020). Small mammals, defined as species weighing less than 5 kg (Stoddart, 1979), within this group the species in the intermediate weigh range 35 g to 5500 g are one of the most extensively threatened yet widely studied groups (Chishlom & Taylor, 2007; Bilney *et al.,* 2010: Woinarski *et al.,* 2010: Burns, 2020).

are particularly vulnerable to extinction according to the critical weight range hypothesis for Australian terrestrial mammals.

They have been used widely as a suitable group of model organisms in ecological studies due to their short life cycles, high reproductive rates, and traceable responses to successional changes (Fox, 1982, Abramsky and Rosenzweig, 1984, Burt, 1943, Sutherland and Dickman, 1999). Recent studies on small mammals in post-fire environments in Australia have given insight into how large landscape-scale characteristics such as pyrodiversity, habitat mosaics, habitat complexity, and fuel loads are influencing mammal populations (Letnic *et al.,* 2004, Nimmo *et al.,* 2013, Bowman and Legge, 2016, Kelly *et al.,* 2017b). However, mechanistic links between patch-scale resources and small mammals in post-fire environments are less well known or based on broad-scale assumptions from more extensive landscape-scale studies (Jorgenson, 2004, Clarke, 2008). Recent studies have indicated the importance of patch-scale habitat structure and food resources in driving small mammal fire responses (Di Stefano *et al.,* 2014, Swan *et al.,* 2015).

Habitat structure is defined as the identity and spatial arrangement of components in a landscape or a patch and can be considered a resource unit that is being repeatedly used by an animal (Manly *et al.,* 2004). The selection of habitat structures is a decision made by an individual, yet this will be eventually transferred to patterns of species distribution and abundance (Stapp, 1997). Key structural features directly affecting the animal will depend on the forest strata the animal occupies (McElhinny *et al.,* 2006). Essential structural resources identified as important features for small mammals include shrub cover, coarse woody debris, and litter (Swinburn *et al.,* 2007a, Flanagan-Moodie *et al.,* 2018, Fox and Monamy, 1999, Monamy and Fox, 2010, Morris *et al.,* 2000).

Food availability and selection similarly directly influence the survival and persistence of animals (Whittaker *et al.,* 1973, Broughton and Dickman, 1991, Manly *et al.,* 2004). Food resources of small mammals vary from plant material such as seeds, flowers, nectar, leaves, bark and roots to other vertebrates and invertebrates (Carron *et al.*, 1990, Kelly, 2006, Lada *et al.*, 2008, Di Stefano *et al.*, 2014). Among these resources, invertebrates are a crucial component in food webs, having complex links with plants and vertebrates and make up a large proportion of ecosystem diversity (DiCarlo *et al.,* 2019). Although relationships between invertebrates and fire have been well studied in a number of post-fire environments (e.g. Gill *et al.,* 1999, Driessen and Kirkpatrick, 2017, Robson *et al.,* 2018, DiCarlo *et al.,* 2019, New *et al.,* 2010), only few studies have focused on interactions between fire, small mammals and invertebrates (Day *et al.,* 2019).

To accomplish successful management strategies, a thorough understanding of how fauna respond to post-fire environments is required. It is therefore essential to further investigate links between fire, resources, and small mammals at a range of spatial scales in fire-mediated environments to evaluate future risks and potentially manipulate habitats to better conserve small mammals (Kelly *et al.,* 2011, Kelly *et al.,* 2017b, Ward *et al.,* 2020, Wilson and Garkaklis, 2020).

## 2.3. Aims

The aim of this study is to identify patch-scale resource requirements of small mammals in post-fire environments, specifically to determine species responses to variation in habitat and foraging resources after fire across environmental gradients. We predicted that at the landscape scale, the distribution of species will be in part, a response to environmental gradients. At smaller spatial scale, we expect the occurrence/abundance of species will response to the patch-scale resource availability with the species responding differently due to their varying life history strategies.

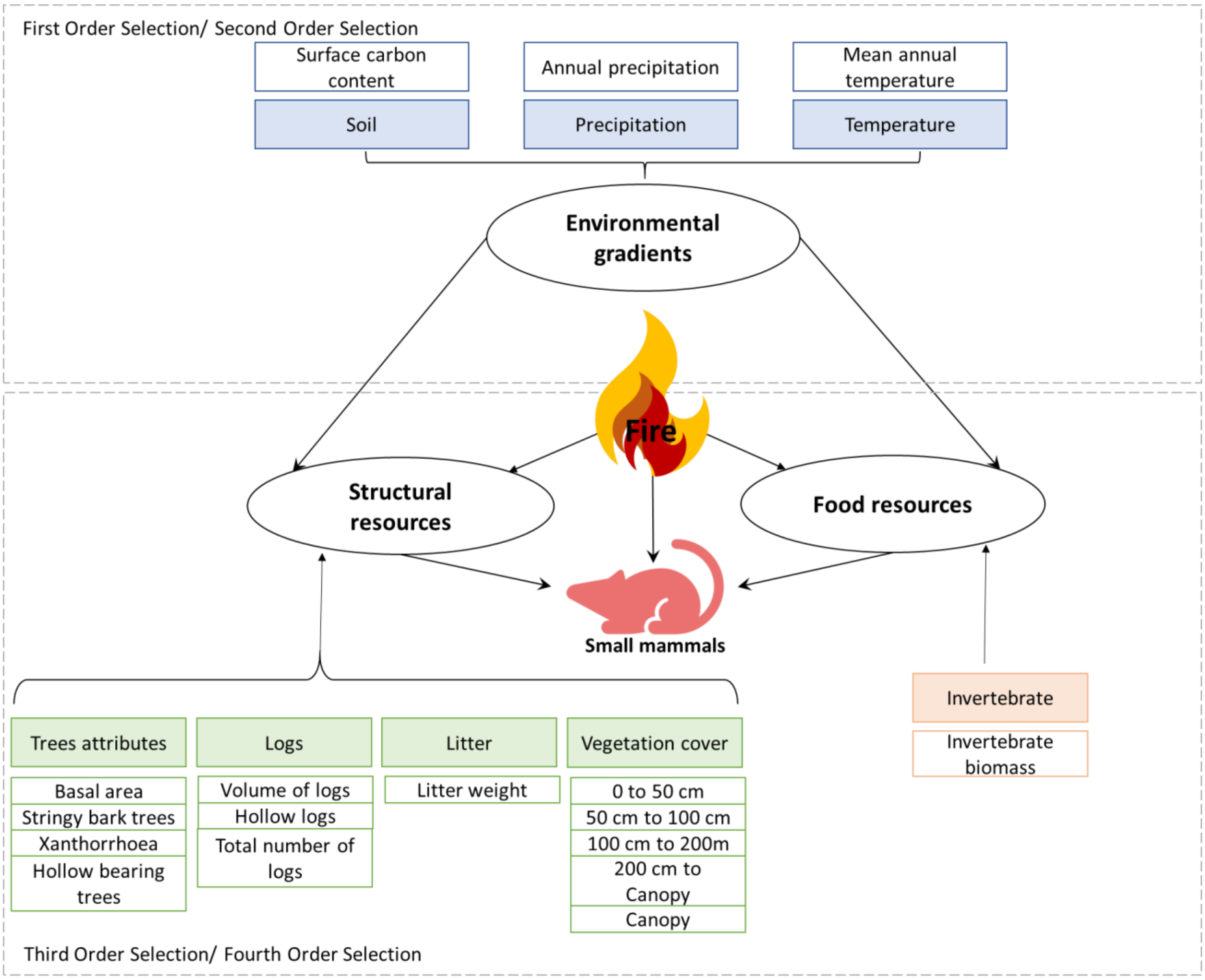


*Figure 2. 1 Conceptual diagram showing the possible interactions between the small mammals in the study area for food, structural resources, fire, and environment variables used in the analysis*

## 2.4. Methodology

### 2.4.1. Study area

The study area is located in south-western Victoria to the west of the town of Casterton, across an area of ~50000 ha. It lies within a roughly rectangular region bordered by the towns of Edenhope (37°02’24” S, 141°17’20” E) and Dartmoor (37°55’41” S, 141°16’21” E) in Victoria, and Naracoorte (36°57’21” S, 140°44’23” E) and Mount Gambier (37°49’23” S, 140°46’54” E) in South Australia (Figure 2. 2). This area includes lands managed by Parks Victoria, the Department of Environment, Land, Water and Planning (DELWP), plantation companies and private landholders. This study forms a component of a larger, landscape-scale project studying the effects of fire and fragmentation on biodiversity (Delaney *et al.,* 2021, Nalliah *et al.,* 2021). The project team previously established 28 circular “landscapes”, each with an area of 19.6 km$^2$ (5 km diameter). The landscapes are positioned across the study area to sample variation in the time since fire and native vegetation cover.

The predominant vegetation type is open heathy stringybark woodland (Cheal, 2010). The basic forest structure can be described as open woodland where the canopy is dominated by *Eucalyptus* species such as brown stringybark (*Eucalyptus baxteri*) and desert stringybark (*E. arenacea*), with a sparse understorey dominated by grass trees (*Xanthorrhoea australis* and *X. caespitosa*), *Acacia* spp., *Banksia* spp., grasses, heath shrubs, sedges and forbs (Duff *et al.,* 2013b). These woodlands occur on sandy nutrient-poor soils, displaying very low growth and decomposition rates (Cheal, 2010). The elevation above sea level varies between 75-131 m. The climate of the region is cool temperate with warm summers and cool to cold winters with a mean annual rainfall of 647.9 mm and mean annual maximum and minimum temperatures of 20.2 °C and 8.3 °C respectively (Bureau of Meteorology, 2022). The area is an ideal location for studying the effects of fire and resource availability on fauna as the native vegetation is highly flammable and has been subjected to planned and unplanned burns in the past, creating a range of habitats varying in respect to time since last fire.

### 2.4.2. Site selection

Five sites were established in each landscape using a restricted random protocol to sample a range of post-fire growth stages. These included sites that are 0.5 to 79 years post-fire, within three vegetation types representing the three EVDs. Following Cheal (2010), post-fire age classes were defined as: Renewal/Juvenility 0-2.5 years, Adolescence 2.5-10 years, Maturity 10-35 years, Waning/Senescence 35+ years after fire. For this study, we selected a subset of the established sites (111 sites in total) using Arc Map 10.5.1. In each site, a 200 m transect was established on a random bearing with a distance of 50-200 m away from access tracks within the study area. Each site was well away from each other with a minimal distance of 1.5 km.

### 2.4.3. Mammal surveys

Twenty-five small Elliott traps (33cm × 10cm × 10cm) were placed approximately 8 m apart along the transect within each site (Figure 2. 3: A). A piece of unbleached cotton was placed in the trap as insulating material and the trap was covered with a plastic bag to protect trapped animals from moisture.  Traps were baited with a mixture of oats, peanut butter, golden syrup, and pistachio essence and checked between sunrise and 10 am then closed during the middle of the day to reduce stress and by-catch. Trapping was carried out for five consecutive nights between November 2018 and March 2019 (Austral summer/autumn). Individuals caught were identified to species level, weighed, head-body and tail length measured, sexed, and identified as juveniles or adults. Individuals were given a unique identifiable mark (correction fluid) on the base of the tail to identify recaptures. After processing, individuals were released at the site of capture.

### 2.4.4. Environmental variables and Fire

Annual mean temperature (BIO 1) and annual precipitation (BIO 12) data were extracted from BIOCLIM–World climate database (spatial resolution of 30 seconds) (~1 $km^2$), using data averaged over 1970-2000 (Fick and Hijmans, 2017). Annual mean temperature denotes the total energy inputs for an ecosystem while annual total precipitation approximates the total water inputs and is a useful indicator of species' distributions (O'Donnell and Ignizio, 2012). Soil carbon content data was extracted from ISRIC world soil information database SoilGrids 250 m 2.0 and topmost soil carbon stock layer (0.0 to 0.05 m depth) was used in the analysis (Hengl *et al.*, 2017). Time since fire (TSF) which is the number of years since the last fire recorded at a site in years was extracted from the Spatial fire history data sets dating from 1939 obtained from the Victorian Government Data directory (Data. Vic, 2018).

### 2.4.5. Habitat variables

Habitat structure attributes (Table 1) were measured at five 5×5 $m^2$ plots for all 111 sites, spaced at 50 m intervals along the 200 m transect; 5 m right of the Elliott trapping transect setups (to avoid trampled vegetation) (Figure 2. 3: B). In each plot, vegetation structure was measured using the point intercept method at 16 sampling points positioned at 2 m intervals on a cross-section, starting from the centre of the plot and extending out 8 m. A 2-metre structure pole was held vertically at each sampling point and the presence or absence of 10 vegetation functional groups was recorded within five height classes (Table 1). Leaf litter (leaves and soft woody debris <20mm in diameter) was collected using three 35 cm diameter circular quadrats positioned within the plot (Figure 2. 3: B), one metre from each corner of the plot. Collected litter was stored in paper bags and tagged within the detailed location, then samples were transported to the laboratory where they were oven-dried at 70°C (for 48 hours) and weighed to obtain dry biomass. The presence and the diameter of logs (≥5cm diameter and ≥50cm long) were measured along the four log assessment arms within the plot (Figure 2. 3: B). The decay state of the logs was assessed based on the ability to support weight, resistance to a kick, presence-absence of the bark, twigs, cracks, fungi, and state of the sapwood using a 3–point scale: 1–non-decayed to 3–substantially decayed. Information on presence/absence of hollows, fissures and charring of logs was collected. The basal area of live and dead trees (minimum diameter 10 cm) was calculated using a Kramer's dendrometer and distance to the closest hollows bearing tree within each quarter of the 5×5 $m^2$ plot was measured. All variables were chosen a priori based on known requirements of small mammals and previously defined resources in the region (Williams and Faunt, 1997, Di Stefano *et al.,* 2011, Nalliah *et al.,* 2021).

### 2.4.6. Invertebrate sampling

Terrestrial invertebrates were sampled using pitfall traps at the same time as small mammal trapping was carried out, with five traps set up on each site (111 sites), 10 m parallel to the marked 200 m transects (Figure 2. 3). Traps consisted of plastic jars with a diameter of 6.5 cm and a depth of 10 cm containing 150 ml of propylene glycol and ethylene glycol solution (1:1) and sunk flush with the ground surface. A roof was created for each trap using metal spikes and plastic plates to reduce contamination and evaporation. Traps were left open for 5 days. Samples were collected and transported to the laboratory, then stored in 90% ethanol. Material was sorted and quantified at different taxonomic levels (Invertebrate Orders) using a binocular microscope and invertebrate identification keys (Lawrence and Britton, 1994, Shattuck, 1999, Stevens *et al.,* 2007). To obtain the biomass of invertebrate taxa, samples were initially air-dried for 24 - 48 hours and then oven-dried in 70°C for 12 - 24 hours and weighed using an electronic balance. For this component of the overall project, data for all taxa were bulked across the 5 traps at each site to provide an index of invertebrate food availability.

### 2.4.7. Data analysis

Data analysis was carried out within the R 3.6.3 (R Core Team, 2018) statistical environment, and using “Minitab 17” (Minitab Inc., 2010) and “IBM SPSS” Statistics 26 statistical software (IBM Corp, 2019). Environmental data (derived spatial data), habitat and food resource data (obtained by habitat and invertebrate surveys) and small mammal data (from live trapping) were used in the analyses. Time since fire (in years) at each site was included as the fire variable. An exploratory data analysis was carried out for environmental and habitat data to investigate the distribution of the data, and to identify trends and outliers. Relationships between variables were examined; where there were groups of correlated variables (Pearson’s r >0.6), a single representative variable from each group was selected for subsequent analyses. Three environmental variables and 15 habitat variables were selected (Table 2). Selected environmental variables and the spatial distribution of the small mammal species were mapped to understand landscape-scale patterns using R package “ggplot 2” (Wickham, 2016).

We used Generalized Additive Models (GAMs) to investigate relationship between time since fire and resources using the R package “mgcv” (Wood, 2011). We used either gaussian or negative binomial distributions. We checked for overdispersions and gaussian assumptions using the R package “DHARMa” (Hartig, 2017) and found no departure from assumptions. To understand the relationship between small mammal occurrence, habitat and foraging resources, environmental variables, and fire we initially constructed GAMs but found no evidence of nonlinear relationships. We instead used Generalized Linear Models (GLMs) as this allowed us to incorporate models more easily with interactions between continuous variables.

Presence or absence of each small mammal species was used as the response variable. We calculated daily detection probabilities to determine the rate of false absence and tested if detection probability varied with time since fire by comparing a model with no detection covariates to a model with time since fire using AIC. For this analysis package unmarked (Fiske and Chandler, 2011). Overall detection ranged from 0.80 to 0.65 (Appendix A, a-2) however it did not vary with the covariates of the interest thus it is unlikely to have substantially biased our results (Hutto, 2016).

### 2.4.8. Model building

We built models including response variables (probability of occurrence of yellow-footed antechinus, heath mouse, house mouse and bush rat) and predictor variables (time since fire, habitat resources and environmental variables). We included single variable models and models with predictors in additive and interactive combinations. We only investigated pairs of variables and not more complex models in model building to avoid overfitting (Binomial error distributions were used in the analysis).

The model set included 96 models for each species including null models. Akaike information criterion corrected for small samples (AICc) was used to compare the GLMs, model ranking was completed using the R package “MuMIn” (Bartoń, 2020). Models were ranked from most parsimonious to the least using delta AICc and Akaike weight (Burnham and Anderson, 2016). We used the models within 2 AICc units of the best models for inference and created graphs of these using the “ggplot2” (Wickham, 2016). We checked if spatial clustering of sites had an effect on the variance structure by including landscape as a random effect and found that there was no influence of spatial clustering on the response (Appendix A, a-1) thus models were built without random error terms.

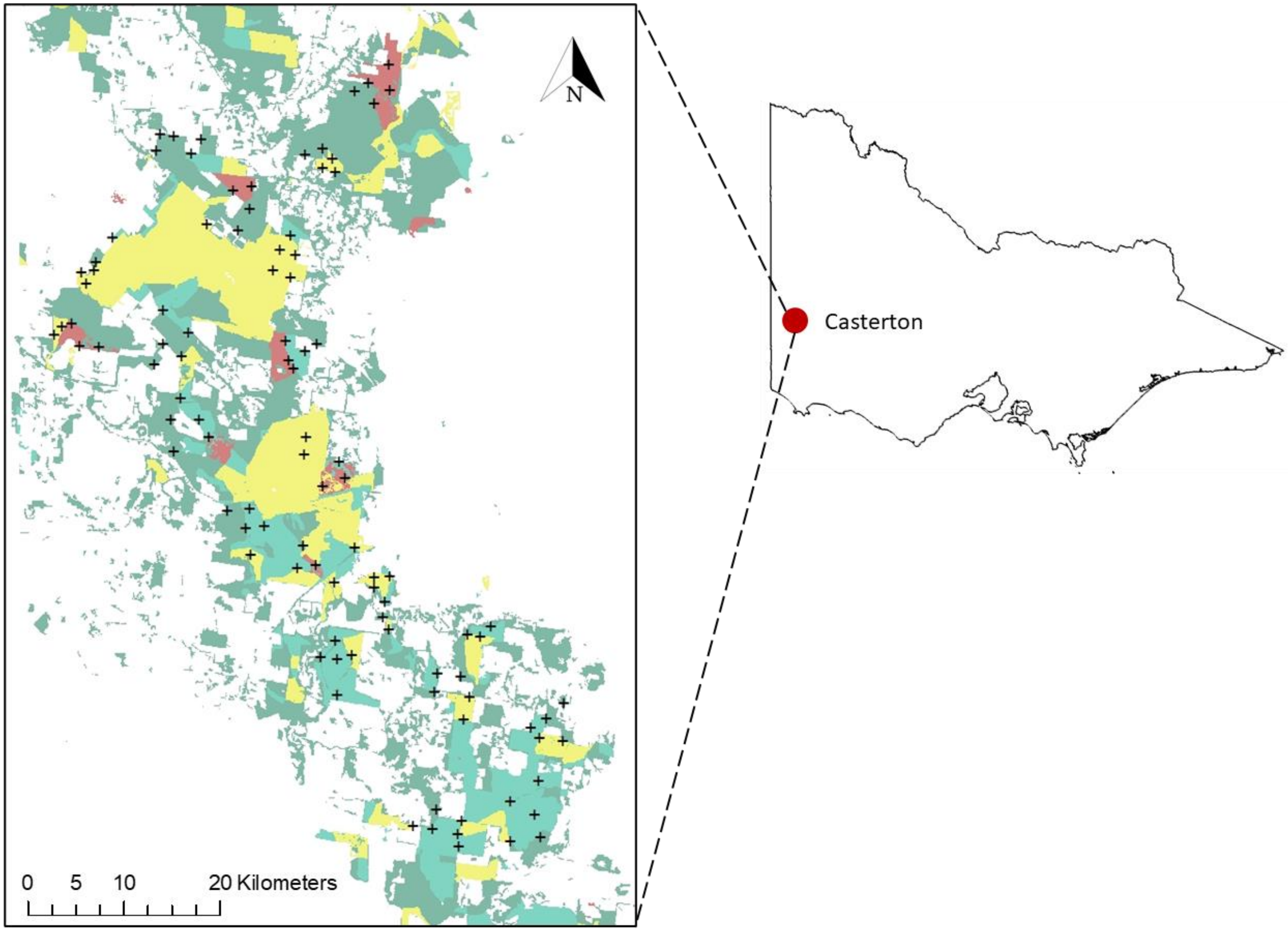


*Figure 2. 2 Map of the study area, crosses indicates the study sites.*

*Table 2. 1  Habitat attributes measured within the 200 m transect of each site*

| **Habitat Attribute** | **Description** | **Measurement** |
|---|---|---|
| Vegetation height class | Five height classes, 0-0.5m, 0.5-1.0 m, 1.0 m-2.0 m, 2.0 m-canopy and canopy | Presence/Absence |
| Vegetation functional groups | Sedge, Grass, Herb, Fern, Shrub, Rush, *Xanthorrhoea australis* (live and dead), *Xanthorrhoea caespitosa* (live and dead), Stringybark eucalypt (live, dead and resprouting), Ribbonbark eucalypt (live, dead and resprouting) | Presence/Absence |
| Basal area of trees (dead and live) | Basal area calculated using factor 1, 2 and 4 in the Kramer's dendrometer | $m^2$ $ha^{-1}$ |
| Tree hollows | Distance to the closest hollow-bearing tree | M |
| Log diameter | Fallen logs not attached to roots that are >5 cm diameter and >50 cm length | Cm |
| Decay classes | Decay class 1- resistance to a kick, bark present | Presence/Absence |
| | Decay Class 2- Soft to kick, retains shape, degrading bark | Presence/Absence |
| | Decay Class 3- Soft to kick, loses shape | Presence/Absence |
| Charring | Evidence of the log being burnt, charred surface | Presence/Absence |
| Hollows | Presence of hollows >2 cm in diameter, >6 cm in depth | Presence/Absence |

| | | |
|---|---|---|
| Litter weight | Leaves, bark, soft woody material < 2cm diameter | G |

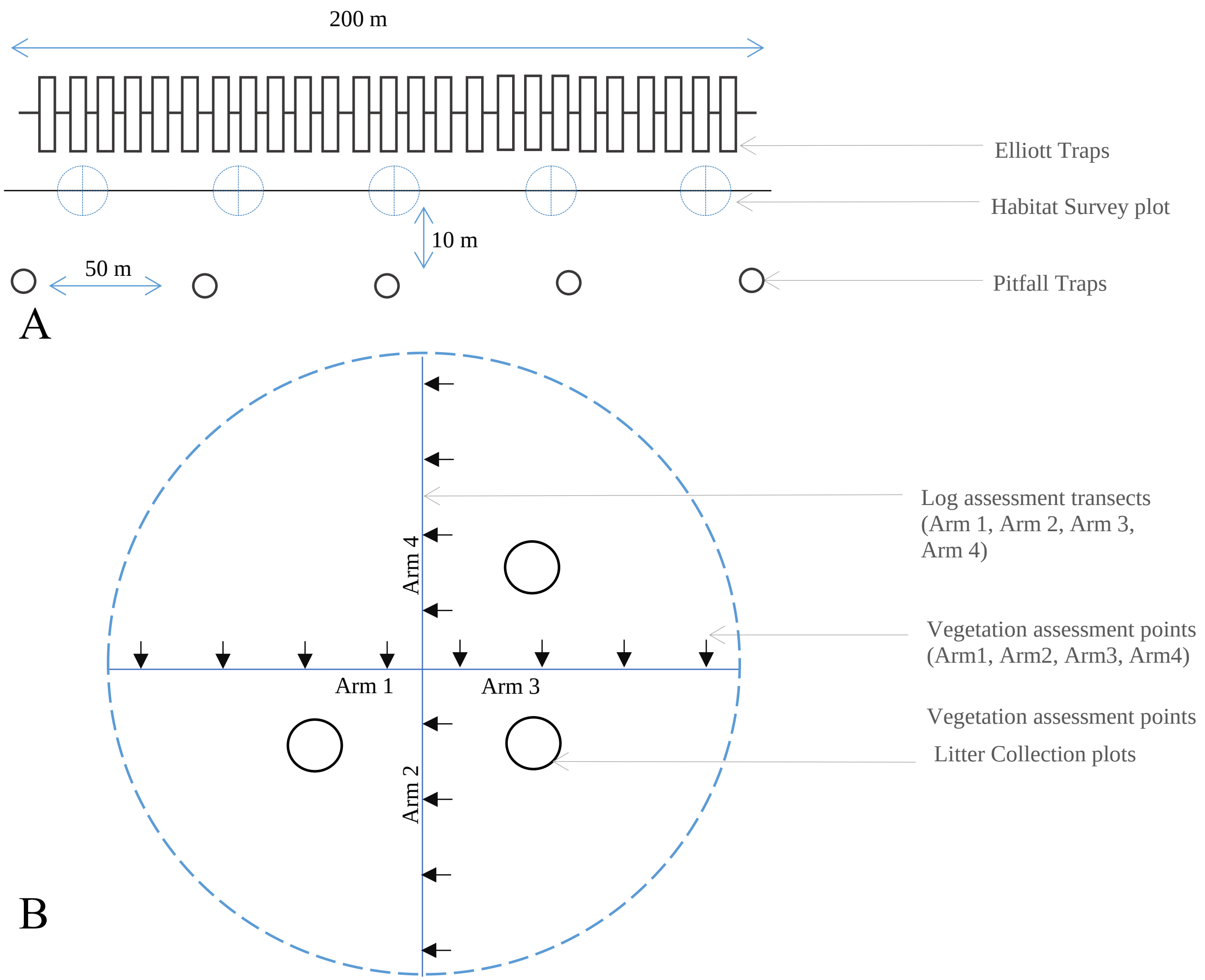


*Figure 2. 3 Trap setup for Elliott traps, invertebrate pitfall traps and habitat measurement plots within the 200 m transect of each site. A-Twenty-five small Elliott Traps (33cm × 10cm × 10cm) were placed approximately 8 m apart along the transect while five pitfall traps were set up every 50 m and 10 m parallel to the transect, b-Habitat structure attributes were measured using five 5×5 m2 plots, spaced at 50 m intervals, 5 m right and parallel to the transect that was used for mammal trapping, in each habitat plot vegetation structure and logs were measured using the point intercept method within 16 points along each arm. Litter was collected 1 m away from the central point of three quarters within the plot.*

*Table 2. 2 Variables selected to create models for selected species. These variables were selected from an initial set of variables by creating a correlation matrix with all the candidate variables and examining Pearson's correlation coefficients. Variables with a correlation coefficient of ≤ 0.6 were selected for constructing models, where there were groups of correlated variables, a single representative variable was selected for further analysis*

| **Variable Type** | **Variable** | **Description** | **Mean (min - max)** | **Units** | **Abbreviation** |
|---|---|---|---|---|---|
| Fire | Time since fire | Fire chronosequence age from 0.5 to 79 years after a fire | 30 (0.5-79) | years | Tsf |
| Environmental | Annual precipitation | Sum of all total monthly precipitation values | 684 (644-772) | mm | App |
| | Carbon content | Soil surface carbon content | 62 (38-94) | g $Kg^{-1}$ | CC |
| | Temperature | Average temperature for each month is averaged across the year | 13.5 (13.0-14.0) | $^{O}$C | AMT |
| Vegetation cover | 0 to 50 cm vegetation cover (Ground cover) | Frequency of vegetation (out of 80 points) | 0.86 (0.3 – 1.0) | Proportion | Veg 0-50 |
| | 50 cm to 100 cm vegetation cover | Frequency of vegetation (out of 80 points) | 0.4(0.11-1.0) | Proportion | Veg 50-100 |

| | | | | | |
|---|---|---|---|---|---|
| | (Small shrub layer) | | | | |
| | 100 cm to 200 cm vegetation cover | Frequency of vegetation (out of 80 points) | 0.12 (0-0.58) | Proportion | Veg 100-200 |
| | (Medium shrub layer) | | | | |
| | 200 cm to Canopy vegetation cover | Frequency of vegetation (out of 80 points) | 0.21 (0-0.57) | Proportion | Veg 200-Can |
| | (Understory layer) | | | | |
| | Canopy vegetation cover | Frequency of vegetation (out of 80 points) | 0.29 (0-0.71) | Proportion | Veg Can |
| | (Canopy) | | | | |
| Tree attributes | Basal area of trees | Basal area of all the trees (dead and live) | 15.52 (0-36.80) | $m^2ha^{-1}$ | BA |
| | Xanthorrhoea | Total counts of *Xanthorrhoea spp.* in each vegetation height class | 46 (0-169) | Counts | Xanth |
| | Stringybark trees | Total counts of stringybarks in each vegetation height class | 6 (0-14) | Counts | STR |

| | | | | | |
|---|---|---|---|---|---|
| | Hollow bearing tree density | Number of hollow-bearing trees per a unit area | 0.002(0-0.008) | $m^{-1}$ | Tree hollows |
| Logs | Volume of logs | Log volume per unit area calculated using the diameter of the logs and the length of the transect | 0.24 (0-1.4) | $m^{3}ha^{-1}$ | Log_vol |
| | Total number of logs | Total counts of logs along the transect | 14 (0-57) | Counts | Log total |
| | Hollow logs | Total counts of hollow-bearing logs along the transect | 4 (0-17) | Counts | Log-h |
| | Decay class 3 logs | Total counts of decay class 3 logs along the transect | 3 (0-19) | Counts | Dc3 |
| Litter | Litter weight | Dry biomass of the litter averaged across the transect | 4.36 (0.72-10.20) | $Mgha^{-1}$ | Litter_w |
| Invertebrates | Invertebrate biomass | Dry biomass of the invertebrate samples collected from pitfall traps | 0.30 (0.02-1.48) | g | Invert_bm |

## 2.5. Results

### 2.5.1. Small mammals

Elliott trapping was carried out for 13,865 trap nights, resulting in 110 captures of small mammals belonging to 10 species from three Orders (Rodentia, Diprotodontia and Dasyuromorphia) (Table 2.1). Among the detected species, yellow-footed antechinus, bush rat, heath mouse and house mouse were captured in sufficient numbers to analyse reliably.

### 2.5.2. Responses of habitat and foraging resources to time since fire

There were relationships detected between time since fire and seven habitat variables (Table 3). For six of these, vegetation cover of the 100 to 200 cm layer (medium shrub layer), vegetation cover of 200 cm to canopy layer, total number of logs, total number of logs in decay class 3, and total number of log hollows and tree basal area the relationship was positive, or hump-shaped (Figure 2. 4). The remaining variable, *Xanthorrhoea* cover, had a U-shaped relationship (Figure 2. 4).

### 2.5.3. Response of small mammals to environment variables, habitat and foraging resources and time since fire

The spatial patterning of the occurrence of small mammals indicated that species were not evenly distributed across the landscape; *A. flavipes* showed a more northern distribution while *R. fuscipes* showed a more southern distribution, with *P. shortridgei* found in both northern most and southern most ends of the study area. *M. musculus* showed no spatial trend (Appendix A, a-3).

Compared to time since fire, habitat and environmental variables were better predictors of the probability of occurrence for yellow-footed antechinus, bush rat, heath mouse and house mouse. For all four species, null models ranked higher than the time since fire variable (Table 5). Although it was expected that invertebrate biomass would have a significant effect on the occurrence of small mammals there was no significant effect detected for yellow-footed antechinus, bush rat, heath mouse; however, there was a negative, statistically significant correlation for house mouse, yet the model was not among the top models.

For the yellow-footed antechinus, hollow-bearing tree density, 50 to 100 cm vegetation cover and annual precipitation were significantly better predictors than time since fire (Table 5). The best model included number of hollow bearing trees and annual precipitation in additive combination; the second-best model was the 50 to 100 cm vegetation cover with annual precipitation in additive combination (Figure 2. 5). Hollow-bearing tree density and 50 to 100 cm vegetation cover showed a positive correlation with yellow-footed antechinus occurrence, while annual precipitation had a negative correlation (Figure 2. 5).

The best model for bush rat included 100 to 200 cm vegetation cover and annual precipitation in interactive combination (Table 5). The second-best model was 100 to 200 cm vegetation cover in a single variable model, which showed a positive correlation. Additionally, 100 to 200 cm vegetation cover with soil carbon content in additive combination and 50 to 100 cm vegetation layer with annual precipitation in additive combination (Figure 2. 6).

The best models for heath mouse included single variable models, and the top model was 100 to 200 cm vegetation cover. Other top-ranked models included litter weight, 200 cm to canopy vegetation cover (Table 5), 100 to 200 cm vegetation cover. All the variables showed a positive correlation with the probability of occurrence of heath mouse. Although there were some statistically significant models for heath mice, the variance explained was very low for all models, indicating the variables we have used are not predicting the species well. Furthermore, the null model with just over 2 AIC units higher than the top-ranked model indicating that all models did not fit this species well.

The best model predicting the probability of occurrence for house mouse was the litter weight in interactive combination with the soil carbon content (Table 5) and the second-best model was the number of stringy bark trees at each site (Figure 2. 6), both models showed a negative correlation with the probability of occurrence of house mouse.

*Table 2. 3 Elliott trap captures, and modelling information and error distributions used in modelling*

| **Order** | **Species** | **Number of sites** | **Number of individuals** | **Used in modelling Y/N** | **Error distribution used in Modelling** | **Daily detection probability** | **Overall detection** |
|---|---|---|---|---|---|---|---|
| Dasyuromorphia | Agile antechinus (*Antechinus agilis*) | 1 | 3 | N | NA | NA | NA |
| | Swamp antechinus (*Antechinus minimus*) | 1 | 1 | N | NA | NA | NA |
| | Yellow-footed antechinus (*Antechinus flavipes*) | 25 | 35 | Y | Binomial | 0.278 | 0.80 |
| Diprotodontia | Eastern pigmy possum (*Cercartetus nanus*) | 2 | 2 | N | NA | NA | NA |
| | Ringtail possum (*Pseudocheirus peregrinus*) | 1 | 1 | N | NA | NA | NA |
| Rodentia | Bush rat (*Rattus fuscipes*) | 13 | 31 | Y | Binomial | 0.204 | 0.68 |
| | Heath mouse (*Pseudomys shortridgei)* | 9 | 7 | Y | Binomial | 0.193 | 0.65 |
| | House mouse (*Mus musculus*) | 13 | 20 | Y | Binomial | 0.190 | 0.65 |
| | Silky mouse (*Pseudomys apodemoides)* | 7 | 13 | N | NA | NA | NA |
| | Swamp rat (*Rattus lutreolus*) | 1 | 1 | N | NA | NA | NA |

*Table 2. 4 Results of Generalized Additive Models for relationships between time since fire and resource variables.*

| Predictor Variable | Response Variable | Distribution | Estimated degrees of Freedom | p | Proportion deviance explained |
|---|---|---|---|---|---|
| Time Since Fire | 0 to 50 cm vegetation cover | Gaussian | 3.71 | 0.38 | 0.06 |
| | 50 to 100 cm vegetation cover | Gaussian | 6.94 | 0.06 | 0.16 |
| | 100 to 200 cm vegetation cover | Gaussian | 1.00 | 0.02* | 0.05 |
| | 200 cm to canopy vegetation cover | Gaussian | 2.27 | 0.05* | 0.08 |
| | Canopy vegetation cover | Gaussian | 1.86 | 0.26 | 0.04 |
| | Volume of logs | Gaussian | 6.18 | 0.07 | 0.14 |
| | Total number of logs | Negative Binomial | 1.63 | 0.05* | 0.05 |
| | Decay class 3 logs | Negative Binomial | 1.56 | 0.02* | 0.07 |
| | Hollow logs | Negative Binomial | 1.00 | 0.04* | 0.03 |
| | Litter weight | Gaussian | 1.76 | 0.11 | 0.05 |
| | Invertebrate biomass | Gaussian | 1.00 | 0.71 | 0.00 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  | Basal area of trees | Gaussian | 2.42 | 0.00** | 0.14 |
|  | Hollow bearing tree density | Gaussian | 1.00 | 0.78 | 0.00 |
|  | Stringybark trees | Negative Binomial | 1.00 | 0.89 | 0.00 |
|  | *Xanthorrhoea* | Gaussian | 2.58 | 0.04* | 0.09 |

*Table 2. 5 Linear Models built for 4 species and responses. Models were ranked using Akaike's Information Criterion (AICc) and selected the top ranked models that are within 2 delta AICc units. Null models are included for each species, resource, and environment variables (Annual precipitation, Annual Mean Temperature and Soil Surface Organic Carbon content) as predictor variables. Additionally, environment variables were combined with resource and fire variables using interactive and additive terms*

| **Response Variable (Species)** | **Predictor variable/s** | **Δ AICc** | **Akaike Weight** | **R²** | **Term** | **Estimate** | **CI 95%** | **p** |
|---|---|---|---|---|---|---|---|---|
| Yellow-footed antechinus (*Antechinus flavipes*) | Tree hollows + App | 0 | 0.32 | 0.18 | | | | |
| | | | | | Tree hollows | 0.84 | 0.34, 1.44 | 0.00** |
| | | | | | App | -1.06 | -1.85, -0.45 | 0.00** |
| | Veg 50-100 + App | 0.08 | 0.21 | 0.18 | | | | |
| | | | | | Veg 50-100 | 0.84 | 0.033, 1.41 | 0.00** |
| | | | | | App | -1.22 | -2.05, -0.56 | 0.00** |
| | Tree hollows × App | 0.19 | 0.12 | 0.18 | Tree hollows × App | -0.20 | -0.95, 0.55 | 0.61 |
| | | | | | Tree hollows | 0.78 | 0.22, 1.42 | 0.01 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | App | -0.96 | -1.86, -0.35 | 0.00** |
| | Null model | 18.59 | 2.89e-05 | 0 | | | | |
| | Tsf | 35.28 | 4.28e-09 | 0.00 | | -0.14 | -0.58, 0.26 | 0.49 |
| | Invert_bm | 29.85 | 6.46e-08 | 0.04 | | -0.02 | -0.46, 0.37 | 0.91 |
| Bush rat | Veg 100-200 × App | 0 | 0.17 | 0.27 | Veg 100-200 × App | -0.45 | -0.98, 0.07 | 0.09 |
| (*Rattus fuscipes*) | | | | | | | | |
| | | | | | Veg 100-200 | 1.32 | 0.40, 2.22 | 0.00** |
| | | | | | App | 0.62 | 0.01, 1.23 | 0.04* |
| | Veg 100-200 | 0.39 | 0.14 | 0.10 | | 0.92 | 0.35, 1.48 | 0.00* |
| | Veg 100-200 + App | 0.84 | 0.11 | 0.11 | | | | |
| | | | | | Veg 100-200 | 0.75 | 0.16, 1.33 | 0.01* |
| | | | | | App | 0.40 | -0.19, 0.99 | 0.18 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Veg 100-200 + CC | 1.71 | 0.08 | 0.11 | | | | |
| | | | | | Veg 100-200 | 0.96 | 0.38, 1.54 | 0.00** |
| | | | | | CC | -0.29 | -0.95, 0.36 | 0.38 |
| | Veg 50-100+ App | 1.97 | 0.07 | 0.11 | Veg 50-100 | 0.75 | 0.14, 1.36 | 0.16 |
| | | | | | App | 0.50 | -0.03, 1.04 | 0.064 |
| | Null model | 10.27 | 0.00 | 0.00 | | | | |
| | Invert_bm | 10.89 | 0.00 | 0.01 | | -0.45 | -1.38, 0.23 | 0.27 |
| | Tsf | 11.62 | 0.00 | 0.01 | | 0.24 | -0.33, 0.79 | 0.39 |
| Heath mouse | Veg 100-200 | 0.00 | 0.05 | 0.03 | | 0.64 | 0.02, 1.27 | 0.03* |
| (*Pseudomys shortridgei*) | | | | | | | | |
| | litter weight | 0.33 | 0.05 | 0.03 | | 0.72 | 2.8e-04, 1.49 | 0.05 |
| | Veg 200-can | 0.40 | 0.04 | 0.03 | | 0.74 | 6.9e-03, 1.57 | 0.05 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | litter weight + App | 0.68 | 0.04 | 0.04 | | | | |
| | | | | | litter weight | 0.64 | -0.08, 1.40 | 0.08 |
| | | | | | App | 0.47 | -0.24, 1.15 | 0.17 |
| | Null model | 2.09 | 0.01 | 0 | | | | |
| | Tsf | 1.99 | 0.02 | 0.02 | | 0.54 | -0.18, 1.31 | 0.14 |
| | Invert_bm | 3.74 | 0.01 | 0.00 | | -0.30 | -1.52, 0.47 | 0.54 |
| House mouse (*Mus musculus*) | Litterw × CC | 0 | 0.24 | 0.13 | Litterw × CC | 0.91 | 0.31, 1.56 | 0.00 ** |
| | | | | | Litterw | -1.37 | -2.50, -0.49 | 0.00 ** |
| | | | | | CC | 0.42 | -0.28, 1.19 | 0.25 |
| | STR | 0.75 | 0.17 | 0.09 | | -1.06 | -1.84, -0.40 | 0.00 ** |
| | Tsf | 5.50 | 0.02 | 0.00 | | -0.05 | -0.69, 0.51 | 0.85 |
| | Null model | 9.48 | 0.00 | 0 | | | | |
| | Invert_bm | 11.52 | 0.00 | 0.05 | | -1.17 | -2.51, -0.19 | 0.04* |

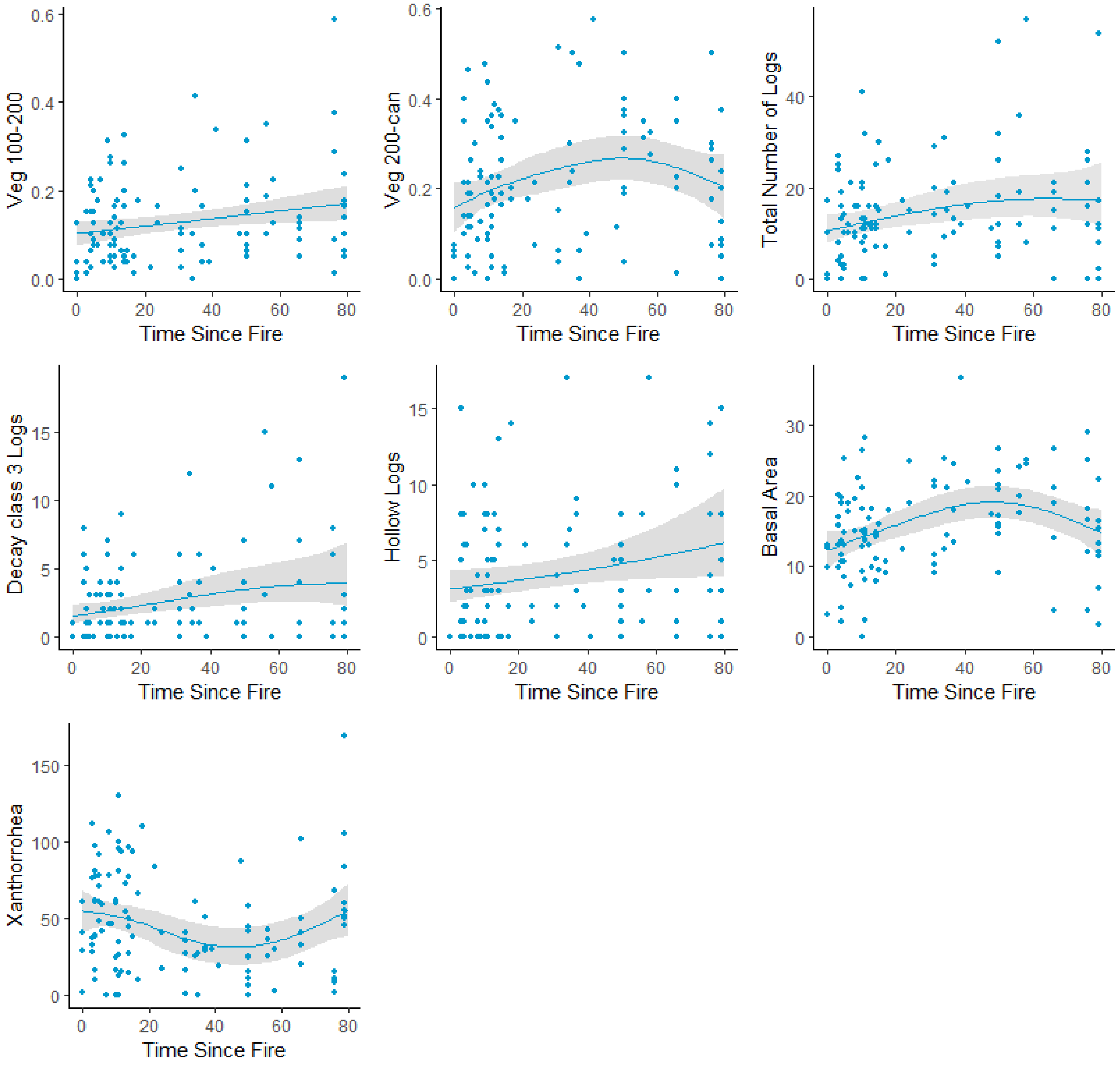


*Figure 2. 5 Relationships between time since fire and habitat variables from Generalized Additive Models. Only models that were statistically significant at the 0.05 level are shown. The Solid line indicates the predicted values, grey ribbon indicates the CI 95%. Raw data are indicated by the blue dots.*

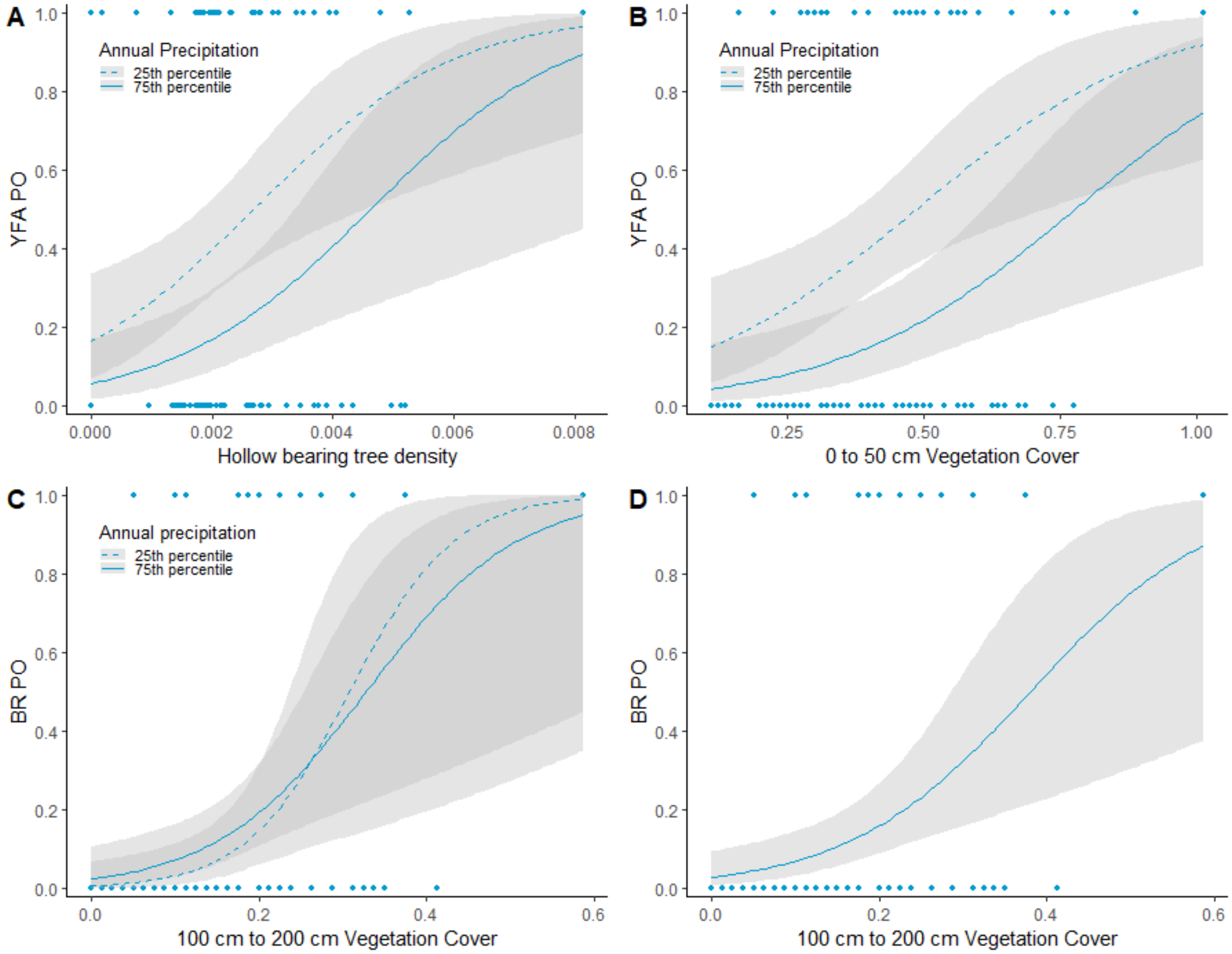


*Figure 2. 6 Responses of top two Generalized Linear Models for yellow-footed antechinus and bush rat. A and B = yellow-footed antechinus (YFA) top two models, C and D = bush rat (BR) top two models (YFA PO – yellow-footed antechinus probability of occurrence, BR PO – bush rat probability of occurrence). Solid lines and dotted lines are generated from the GLMs, responses are presented at high in solid blue lines (75th percentile) and low in dotted lines for (25th percentile) for annual precipitation for A, B and C, gey ribbons indicate the 95% upper and lower confidence intervals. Blue dots represent the presence and absence of each species.*

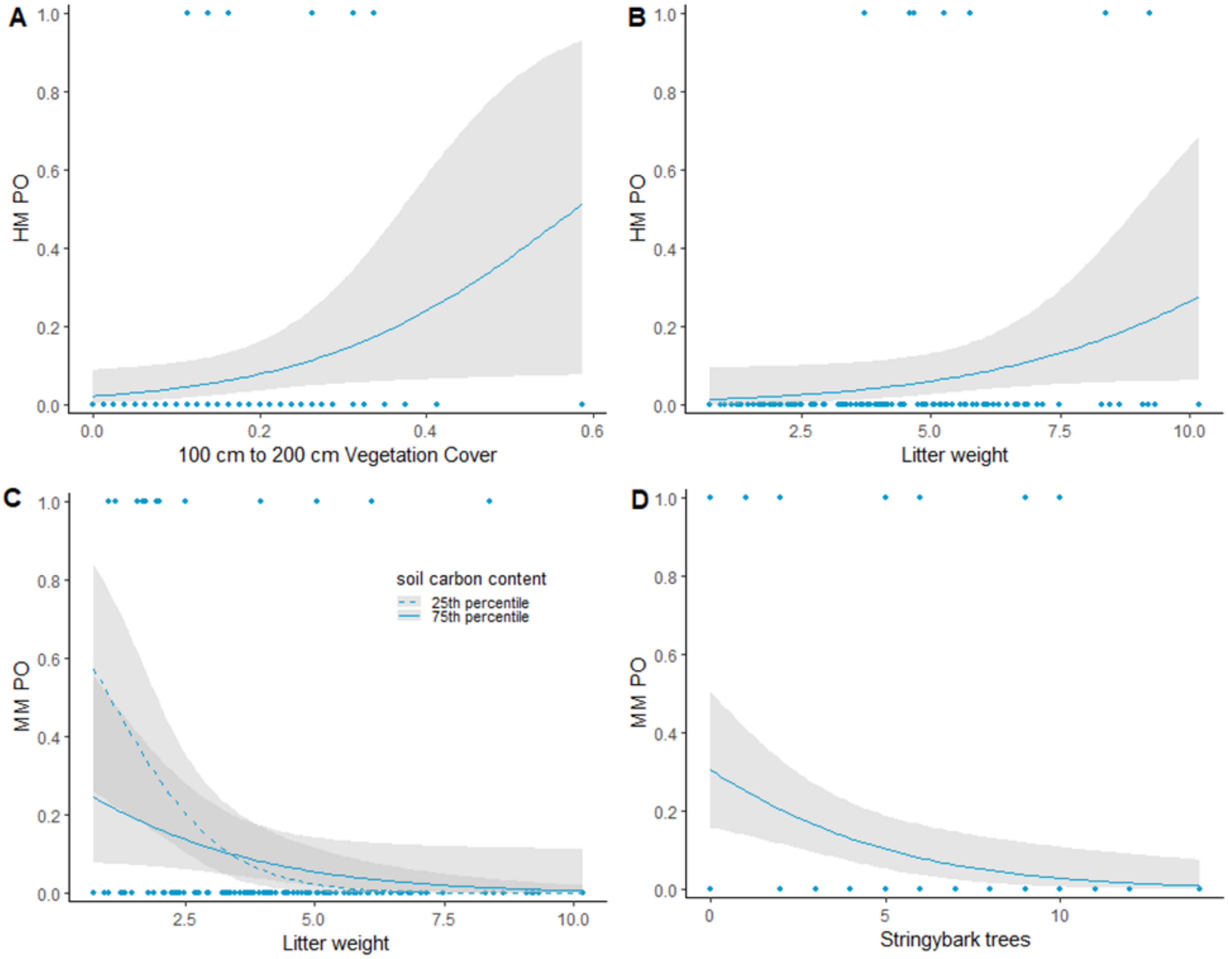


*Figure 2. 7 Responses of top two Generalized Linear Models for heath mouse and house mouse. A and B – heath mouse (HM) top two models, C and D – House mouse (MM) top two models. (HM PO – heath mouse probability of occurrence, MM PO – house mouse probability of occurrence). Solid lines and dotted lines are generated from the GLMs, responses are presented at high in solid blue lines (75th percentile) and low in dotted lines for (25th percentile) for soil carbon content for D, gey ribbons indicate the 95% upper and lower confidence intervals. Blue dots represent the presence and absence of each species.*

## 2.6. Discussion

Understanding both landscape- and patch-scale resource requirements in post-fire environments is an essential component in protecting areas containing critical resources for different small mammals and ensuring their persistence (Kelly *et al.*, 2015, Wilson and Garkaklis, 2020). In this study we identified links between habitat resources that are important for foraging and shelter for small mammals in post-fire environments. We found that time since fire was a poor predictor of habitat and foraging resources, with only a small subset of habitat variables related to time since fire as we predicted, small mammal species responded better to resources than time since fire. At a larger landscape scale, rainfall influenced species occurrence, while at the small scale, species responded to different habitat resources.

### 2.6.1. Responses of habitat and foraging resources to time since fire

Models containing logs and their characteristics showed a significant positive relationship with time since fire, particularly log decay class 3, the total number of logs and the presence of hollows. Fires can affect the formation of coarse woody debris by partially burning root systems and branch attachments. Additionally, fires can burn already decomposing tissues creating fissures and hollows that will further disintegrate the log (Harmon *et al.*, 1986). Thus, fire can act as a precursor for log formation in post-fire environments as well as augmenting the availability of hollows in logs (Mac Nally *et al.*, 2001). Thus, we can assume that time since fire is moderately important in understanding relationships with coarse woody debris such as logs and log attributes. The 100-200 cm vegetation layer showed a significant positive relationship with time since fire; in the study area this layer consisted of plants such as *Acacia*, *Banksia*, and *Leptospermum* species. Additionally, the *Xanthorrhoea* sp. cover showed a decrease and a subsequent increase over time.

Immediately after a fire the vegetation structure can become simplified due to the burning of much of the structural attributes and vegetation structure doesn't show a linear response to time since fire (Swan *et al.,* 2015, Bassett *et al.,* 2017).

Overall, very few resources were predicted strongly by time since fire in our study. Other elements in fire regimes such the extent and patchiness of fires could play a role in creating resource dissimilarities that are not reflected through time (Cheal, 2010, Hollis *et al.,* 2011). The overstory eucalypts in this system resprout after fire so the effect of fire on many habitat features is transient (Rainsford *et al.,* 2020b) and the dominant overstory resprouts after fire, thus succession is not reset as strongly as it is in other systems. The lack of strong relationships between time since fire and habitat and foraging resources may help to explain the poor performance of time since fire in predicting small mammal occurrence (Dorph *et al.,* 2020, Kelly *et al.,* 2017b).

### 2.6.2. The response of small mammals to variation in habitat and foraging resources after fire across environmental gradients

As we expected time since fire was a poor predictor in explaining the distribution and abundance of small mammals consistent with the literature (Di Stefano *et al.*, 2011, Swan *et al.*, 2015, Burns *et al.,* 2019). At a landscape scale, broad patterns in vegetation communities and associated resources that are a response to environmental variability would appear to be primary drivers of individual mammal species' distributions. Vegetation communities in this landscape is primarily a response to environmental variability, rather than fire history (Duff *et al.,* 2014). At landscape scales, small mammal communities have previously been shown to respond to gradients of temperature and rainfall (Catling and Burt, 1995); influenced by plant community composition (Braithwaite *et al.,* 1978, Fox, 1982). However, it should be noted that this analysis resulted in models with low explanatory power and predictive models cannot be always used for (Arif and MacNeil, 2022).

In this study, broad-scale distribution patterns varied between the four focal species. The probability of occurrence of the yellow-footed antechinus showed a negative correlation with annual precipitation, which exhibits a north-south trend (Appendix A, a-3). These results are consistent with previous literature, where they tend to be found in localities with lower precipitation (Dickman *et al.*, 1998, Crowther, 2002). Bush rats were more commonly found in the southern end of the study area, reflecting a preference for moister parts of the landscape. This, and a positive relationship with soil carbon levels, suggest a preference for areas of higher productivity with associated denser understorey vegetation. Heath mice were quite localised in their distribution, being found only in the very north and south of the study area.

At the patch scale, habitat resources that are related to structure such as vegetation cover, tree hollows and dry litter biomass, were found to be better predictors for small mammals than time since fire itself. At the local scale, yellow-footed antechinus showed a positive correlation with the number of hollow bearing trees, consistent with earlier findings (Dickman, 1991b, Kelly, 2006), with this species utilizing hollows as communal nesting sites, as places for rearing young and avoiding predators (Marchesan, 2002). The vegetation cover 50 cm to 100 cm was another important resource that had a positive correlation with the presence of yellow-footed antechinus. This feature is likely to be used for multiple reasons; for foraging as small shrubs are likely to be host plants of food species and shelter, with dense low shrubs providing a lower predation risk (Stokes *et al.*, 2004). Our results for this species are consistent with the known habitat responses of yellow-footed antechinus, but also highlights the diversity of habitats that this species can utilise. For example, several studies have shown that yellow-footed antechinus has a positive response for coarse litter, rock cover, hollow tree density, coarse woody debris and other microhabitat tree conditions like tree leaf litter, and grass trees (Marchesan and Carthew, 2004, Swinburn *et al.,* 2007b, Kelly and Bennett, 2008, Lada *et al.,* 2008, Moore *et al.,* 2014).

The best predictor of occurrence of the bush rat was the 100-200 cm vegetation cover which is the medium shrub layer. These results are consistent with past literature where bush rats preferring complex vegetation structure with dense undergrowth (Braithwaite *et al.,* 1978, Fox *et al.,* 1979, Swan *et al.*, 2015, Fordyce *et al.,* 2016, Swan *et al.*, 2018). Preference of a denser understory could be related to avoiding predators while moving and foraging. Studies have indicated that bush rats use shelter structures and ground cover more often in the presence of predators in the habitat (Strauß *et al.*, 2008). Although time since fire was not a successful predictor in explaining the bush rat abundance, some studies have shown a correlation of the resources that are related to fire (Swan *et al.*, 2015). Similarly, the 100 to 200 cm vegetation cover indicated a significant positive relationship suggesting the three-way interactions between small mammals resources and fire.

The occurrence of heath mouse was strongly positively correlated to the amount of vegetation in the 100 to 200 cm shrub layer, which is consistent with other studies where it was shown that heath mice are generally confined to vegetation with a dense understorey, such as wet heaths, which are floristically diverse, with a dense understorey of *Leptospermum* sp. and *Melaleuca* sp. (Cockburn, 1981, Nalliah *et al.*, 2021, Di Stefano *et al.*, 2011).

The house mouse is an introduced species that is considered invasive in some situations. Similar to the other species, house mouse did not show a direct relationship with the time since fire, and preference was for sites with low litter biomass and lower number of stringybark trees. These findings are consistent with the literature; many previous studies have found the house mouse to prefer early post-disturbance habitats (Williams and Bradstock, 1996, Wilson and Garkaklis, 2020) and are associated with recently burnt or cleared areas where vegetation and litter cover is sparse (Chambers *et al.*, 2000, Kelly *et al.*, 2011).

We investigated interactions between all four species and invertebrate biomass as a potential food source. Populations of small mammals are potentially limited by food supply (Dickman *et al.*, 1999). With yellow-footed antechinus being considered predominantly an insectivore we expected a strong positive correlation with invertebrate biomass since the diet mainly consists of spiders, cockroaches and small vertebrates (Menkhorst, 2011). Yet there was no significant correlation, with the model ranked below the null model. This suggests that either the invertebrate biomass as a coarse measurement does not sensitively capture the relationship between the diets of yellow-footed antechinus or the functional group represented in its diet of has not been effectively sampled by the data collecting method. Although the bush rat is considered an omnivore consuming plant material, invertebrates, and fungi (Braithwaite *et al.*, 1978, Strauß *et al.*, 2008), bush rat occurrence did now show any relationship with the invertebrate biomass. As the house mouse is an omnivore, we expected invertebrate biomass to have a positive correlation with the occurrence, yet models showed a weak negative correlation, this needs to be further investigated to understand the mechanistic reasons behind this interaction. After a fire event generally, there is an invertebrate population decline initially, however post-fire adapted species will colonize and species composition will change with the recovery of the habitat (Wikars, 1997, New et al., 2010, Robson et al., 2018). As the data in this study was collected at a single point of time, seasonal variations of the invertebrate communities could be influencing the occurrence of small mammals in diverse yet unknown ways.

Habitat resources such as vegetation, leaf litter, logs, and other factors may predict the occupation of small mammals differently after a fire event due to factors such as fire severity, post-fire precipitation, topography, and fire history specifically with different legacies being left behind. These factors can significantly impact post-fire recovery and the availability of resources for small mammals. Therefore, an all-inclusive approach considering multiple factors will inform effective management strategies and promote the long-term ecosystem resilience of the ecosystems and species.

## 2.7. Conclusion

This study showed that time since fire does not predict mechanistic links between resources and animals in post-fire environments because it is only weakly correlated with the resources that species rely upon.  Furthermore, both landscape- and patch-scale resource requirements can vary between species. It is therefore important to understand the particular resources that individual species rely upon in fire-prone landscapes and tailor management actions towards individual species where they occur in the landscape. It is unlikely that a single approach will benefit all species equally. Fire management will be improved by developing a greater understanding of the resources that drive species persistence and ensuring that fire management protects and improves these resources. Understanding how aspects of fire regimes can be manipulated to positively affect resources for particular species should be a key focus of research and management.

# 3. USING eDNA METABARCODING TO UNDERSTAND THE EFFECT OF FIRE ON THE DIET OF SMALL MAMMALS IN A WOODLAND ECOSYSTEM

## 3.1. Abstract

Food acquisition is a fundamental process that drives animal distribution and abundance, influencing how species respond to changing environments. Disturbances such as fire create significant shifts in available dietary resources, yet, for many species, we lack basic information about what they eat, let alone how they respond to a changing resource base. In order to create effective management strategies, faunal conservation in flammable landscapes requires a greater understanding of what animals eat and how this change following a fire. What animals eat in post-fire environments has received little attention due to the time-consuming methodologies and low-resolution identification of food taxa. Recently, molecular techniques have been developed to identify food DNA in scats, making it possible to identify animal diets with enhanced resolution. The primary aim of this study was to utilise eDNA metabarcoding to obtain an improved understanding of the diet of three native Australian small mammal species: yellow-footed antechinus (*Antechinus flavipes*), heath mouse (*Pseudomys shortridgei*) and bush rat (*Rattus fuscipes*). Specifically, we sought to understand the difference in overall diet of the three species and how diet changed over time after fire. Yellow-footed antechinus diets mostly consisted of moths, and plants belonging to myrtles and legume families while bush rat consumed legumes,

myrtles, rushes, and beetles. Heath mouse diet was dominated by rushes. All three species shifted their diets over time after fire, with most pronounced shifts in the bush rats and least for heath mice. Identifying critical food resources for native animals will allow conservation managers to consider the effect of fire management actions on these resources and help conserve the species that use them.

## 3.2. Introduction

Understanding how animals utilise resources in different ecosystems is essential to ensure effective conservation practices. Food is a direct resource utilised by an animal in real-time, making diet a robust indicator of resource usage; furthermore, food availability and selection directly influence the survival and persistence of animals which subsequently will be reflected in patterns of co-occurrence (Whittaker *et al.*, 1973, Broughton and Dickman, 1991, Di Stefano *et al.*, 2014). Variations in diet will depend on food availability, species dietary preferences and life-history strategies (Ozaki *et al.*, 2018). Thus, accurate information on diet helps identify how species interact with their environment and persist under changing conditions (Clare, 2014, Monterroso *et al.*, 2018).

Fire is a disturbance that can change food availability in time and space by altering nutrient cycles, community assemblage and habitat structure (Gill, 1975, Bowman *et al.*, 2016). Fires consume above-ground vegetation, but in fire-adapted ecosystems, most organisms survive or recolonize when resource requirements are met, responding to different successional stages as habitat suitability changes (Whelan, 1995, Brown *et al.*, 2013). In many fire-prone environments, fire is used as a land management tool to promote biodiversity and to lower wildfire risk (Gill, 1975, Whitehead *et al.*, 2003). Several studies have indicated the importance of understanding the influence of fire on food resources of animals as fire can alter or limit critical food reserves (Valentine *et al.*, 2014, Stojanovic *et al.*, 2020, Lashley *et al.*, 2015). However, insufficient knowledge on what food resources animals consume in post-fire environments limits the effective usage of fire for faunal conservation in flammable landscapes (Kelly *et al.*, 2017a, Driscoll *et al.*, 2010). Notably, as managers strive to maintain a diversity of post-fire habitats across the landscape ('pyrodiversity'), we need to better understand how resource use changes over time.

What animals eat in post-fire environments has been given little attention compared to studies of their responses to other resources such as vegetation structure and shelter (Southgate and Carthew, 2006, Dawson *et al.,* 2007, Di Stefano *et al.,* 2014, Anderson *et al.,* 2018, Geary *et al.,* 2020). This lack of information could be attributed to the time-consuming identification of food items or ethical concerns related to methodologies (Klare *et al.,* 2011). Traditional methods of assessing diets include direct observations, analysis of prey remains, stomach content or scat (Stoddart, 1979). Scat analysis is an extensively used, non-invasive method to assess animal diet (Dickman and Huang, 1988). For animals caught in traps, food items present in scat are likely to express foraging events close to an animal's capture time, making scat analysis an effective method to disclose information on diets (Dickman and Huang, 1988, Di Stefano *et al.,* 2014). A well-established method of analysing scat involves macro and micro-histological identification (Storr, 1961); however, physical digestion through mastication and chemical digestion in the gut can result in diet items that are difficult to differentiate using histological methods. Thus, histological samples cannot be identified to a finer taxonomic resolution in many cases (Storr, 1961, Klare *et al.,* 2011, Zeale *et al.,* 2011). Furthermore, soft tissue and liquid food items (e.g., nectar) can remain unnoticed in histological analysis (Taberlet *et al.,* 2018). Methods such as stable isotope identification, macromolecule analysis, and DNA-based identifications can address this disparity (Nielsen *et al.,* 2017). Animal scat is a combination of different diet items or, more clearly, a partially digested mixture of DNA from different food species; thus, investigating the DNA in scat samples could result in a higher resolution of taxonomic information than histological methods. Modern molecular tools have facilitated the analysis of mixed samples, typically from the environment, for the identification of species present via their DNA. Trace amounts of DNA isolated and characterised from biological substrates including scats, soil, water, or air, are collectively referred to as environmental DNA (eDNA) (Taberlet *et al.*, 2012a). When combined with Next Generation Sequencing (NGS) technologies, eDNA metabarcoding (Taberlet *et al.*, 2012b). can provide information on, for example, community composition, food web dynamics, animal diet, and invasive or pest species presence/absence (Ruppert *et al.*, 2019, Taberlet *et al.*, 2012b). Thus, eDNA metabarcoding is an ideal method to identify what animals eat in post-fire environments with high resolution and precision. From the handful of studies investigating animal diets post-fire, metabarcoding work is rare (Anderson *et al.*, 2018). Nevertheless, metabarcoding technology is rapidly developing with a wide range of molecular databases and can be used to better understand the role of fire in determining resource use.

The aim of this study is to utilise eDNA metabarcoding to obtain an improved understanding of the food resources and effects of fire on diets of three native Australian small mammal species: yellow-footed antechinus (*Antechinus flavipes*), heath mouse (*Pseudomys shortridgei*) and bush rat (*Rattus fuscipes*). Previous work on the diets of these species is limited but in general yellow-footed antechinus diet predominantly consists of invertebrates gleaned from ground litter, logs, tree trunks and stumps (Hindmarsh and Majer, 1977, Kelly, 2006, Lada *et al.*, 2008). Individuals are also reported to consume nectar from the flowers of a range of shrubs and trees (Menkhorst *et al.*, 1995). The heath mouse is a generalist herbivore, feeding predominantly on plant stems, flowers, and seeds, although some insect and fungal material are also consumed (Watts, 1977, Braithwaite *et al.*, 1978). The bush rat is an opportunistic omnivore, eating arthropods, seeds, fruits and other plant tissue stems and leaves, and fungi (Carron *et al.*, 1990). The diets of these species vary seasonally (Cheal, 1987, Carron *et al.*, 1990, Di Stefano *et al.*, 2014), however, little is known about how disturbance such as fire affects their diets. Here we use an emerging methodology, eDNA metabarcoding, to determine: (i) How do the overall diets of the three small mammal species differ? (ii) Does diet change over time after fire? An improved understanding of resource requirements will assist land managers to better conserve these species at a landscape scale.

## 3.3. Methodology

### 3.3.1. Study area and site selection

The study area is located in south-western Victoria, Australia, across ~150,000 ha. It lies within a roughly rectangular region marked by the towns of Edenhope (37°02'24" S, 141°17'20" E) and Dartmoor (37°55'41" S, 141°16'21" E) in Victoria and Naracoorte (36°57'21" S, 140°44'23" E) and Mount Gambier (37°49'23" S, 140°46'54" E) in South Australia. Area includes parks and reserves containing native vegetation, extensive tracts of pasture, and privately managed eucalypt and pine plantations. This study forms a component of a larger project studying the responses of animals to fire in a fragmented landscape (Delaney *et al.*, 2021, Nalliah *et al.*, 2021). In parks and reserves, the predominant vegetation type is open heathy woodland where the canopy is dominated by *Eucalyptus* species such as Brown Stringybark (*Eucalyptus baxteri*) and Desert Stringybark (*E. arenacea*), with a sparse understory dominated by Grass Trees (*Xanthorrhoea australis* and *X. caespitosa*), *Acacia* spp., *Banksia* spp., shrubs, sedges and forbs (Duff *et al.*, 2013a). These woodlands occur on sandy, nutrient-poor soils, displaying deficient growth and decomposition rates (Cheal, 2010). The elevation above sea level lies between 75-131 m. The region's climate is cool temperate with warm summers and cool to cold winters with a mean annual rainfall of 647.9 mm and mean annual maximum and minimum temperatures of 20.2 °C and 8.3 °C, respectively (Bureau of Meteorology, 2018). The area is ideal for studying the effects of fire and resource use on fauna as the native vegetation is highly flammable and has been subjected to prescribed burns and wildfires in the past, creating a range of habitats varying in time since the last fire.

We used a GIS layer accessed from the local land management agency to define four temporal categories representing time since the last fire: Renewal/Juvenility 0–2.5 years, Adolescence 2.5–10 years, Maturity 10–35 years, Waning/Senescence 35+ years after fire. Within these areas we used a number of criteria to define specific locations for study: (a) to remove the potentially confounding effect of vegetation type, we only considered areas of stringybark woodlands, (b) to reduce edge effects, we only used patches >20 ha, (c) whenever possible we only used areas that had been burnt once during the last 40 years (the extent of accurate records) to reduce the potentially confounding effect of fire frequency, and (d) we selected sites across the study area using a restricted random protocol across the range of post-fire growth-stages. Each site was set up to be 1 km apart to promote independence and 200-500 m away from vehicle tracks to reduce the disturbances. A 200 m transect was established on a random bearing for small mammal trapping.

### 3.3.2. Mammal surveys and scat collection

Trapping was carried out in the Austral summer (December 2018 to February 2019) with sites selected haphazardly during this period to reduce temporal bias. Twenty-five small Elliott traps (33 cm × 10 cm × 10 cm) were placed approximately 8 m apart along the transect. A piece of unbleached cotton was placed in the trap as an insulation, and the trap was covered with a plastic bag to protect animals from moisture. Traps were baited with a mixture of oats, peanut butter, golden syrup, and pistachio essence which has been shown to be useful for capturing a wide range of small mammals (Paull *et al.*, 2011). Traps were checked between sunrise and 10 am and closed during the middle of the day to reduce stress and by-catch. Trapping was carried out over five consecutive nights except when interrupted by adverse weather. Individuals caught were identified to species level, weighed, head-body and tail length measured, sexed, and identified as juveniles or adults. Individuals were given a unique identifiable mark on the base of the tail using liquid paper to identify recaptures, then individuals were released at the site of capture. Occupied traps were replaced with clean traps.

Elliott traps were checked for scats each morning, with scats collected on the first capture of each individual of the target species using a pair of sterilized tweezers and stored in 5 ml vials containing ~ 99% ethanol. The driest pellets were selected (as an indication of the earliest defecation upon capture and least likely to contain digested bait), scats with visible bait contamination were avoided. Each vial was given an identifier tag corresponding to the animal and was stored below 4 °C until analysed.

### 3.3.3. Sample processing

Scat samples were analysed by eDNA Frontiers, Curtin University, Western Australia. Initially the ethanol was removed from each vial and samples were left overnight, packed in ice in a fume cabinet allowing to evaporate the remaining ethanol. Following the evaporation scats were cut in half and weighed. Half of each scat was processed to extract DNA and remainder was stored at -20°C. DNA was extracted using a Qiagen Powerfecal Pro kit, following the manufacturer's instructions and eDNA frontiers laboratory standard operating procedures, and extraction controls (n=6) were included to detect the presence of cross contamination. Quantitative PCR (qPCR) was done at three concentrations for all extractions (neat,1/10 dilution, and 1/100 dilution) to see if samples exhibited inhibition, and to determine optimal DNA input for PCR, for each sample to maximize input relative to any inhibitors (Murray *et al.*, 2015). Two assays were used in this study to target invertebrates and plants. For the detection of arthropods (in this study defined as Insecta and Arachnida), the assay ZBJ-ArtF1c/R2c was used; this assay targets a highly variable region in the cytochrome c oxidase I (COI) gene from the mitochondria DNA 16S rRNA gene (Zeale *et al.*, 2011). For plants we used the trnlg/h primers (Taberlet *et al.*, 2007) which targets the chloroplast trnL (UAA) intron. We did not include an assay for fungi as scat samples were collected in summer when the likelihood of feeding on sporocarps is low (Braithwaite *et al.*, 1978, Cheal, 1987, Di Stefano *et al.*, 2014, York *et al.*, 2022).

The qPCRs were run on a StepOne Plus (Applied BioSystems) real-time qPCR instrument with the following conditions: 5 min at 95°C, 40 cycles of 95°C for 30 s, 30 s at 52°C, and 45 s at 72°C, a melt curve stage of 15 s at 95°C, 1 min at 60°C, and 15 s at 95°C, ending with 10 min elongation at 72°C. The PCR mix for quantitation had a 25 µl volume and contained: 2 mM MgCl2 (Applied Biosystems), 1× PCR Gold buffer (Applied Biosystems), 0.25 mM dNTPs (Astral Scientific), 0.4 mg/ml bovine serum albumin (Fisher Biotec), 0.4 µmol/l forward and reverse primer, 1 U AmpliTaq Gold DNA polymerase (Applied Biosystems), 0.6 µl of a 1:10,000 solution of SYBR Green dye (Life Technologies), and 2 µl of DNA template. Extraction controls, non-template controls, and positive controls were included for all PCR runs.

After optimal DNA input was determined by qPCR, each sample was assigned a unique combination of multiplex identifier (MID) tags for each primer assay. These MID tags were incorporated into fusion tagged primers, and none of the primer-MID tag combinations had been used previously in the laboratory to prevent cross contamination. Fusion PCRs were done in duplicate and to minimize PCR stochasticity, the mixes were prepared in a dedicated clean room before DNA was added. The PCRs were done with the same conditions as the standard qPCRs described above, although with 50 cycles performed and the melt curve analysis omitted. Samples were then pooled into approximately equimolar concentrations to produce a PCR amplicon library that was size-selected to remove any primer-dimer that may have accumulated during fusion PCR. Size selection was performed (160-400 bp) using a PippinPrep 2% ethidium bromide cassette (Sage Science). Libraries were cleaned using a QIAquick PCR Purification Kit (Qiagen) and quantified using Qubit Fluorometric Quantitation (Thermo Fisher Scientific). Single-end sequencing was performed on the Illumina MiSeq platform using the 300 cycle V2 as per manufacturer's instructions.

Bioinformatic tools were used to analyse raw sequence data. Results were demultiplexed and trimmed using Obitools and quality filtered with USEARCH v11 for sequencing errors; (maxee = 1) and minimum length (COI minlength = 135, trnl minlength = 30). Sequences were then dereplicated and unique sequences were transformed into zero radius operational taxonomic units (ZOTUs) to provide sensitive taxonomic resolution (USEARCH v11) (Edgar, 2018). ZOTUs, in contrast to operational taxonomic units (OTUs) are a more exact sequence variant. Generated ZOTUs were queried against the nucleotide database NCBI (GenBank) and assigned to the species level. The taxonomic assignment was based on an eDNA Frontiers in–house python script (Mousavi-Derazmahalleh *et al.*, 2021); which further filter of NCBI Blast results (evalue ≤ 1e-5, %identity ≥ 90 and qCov ≥ 100), combines it with ZOTU table results and produces a table containing the taxonomic information available from the Blast taxonomy database (accessed February 2020). The final table was curated to remove singleton assignments, duplicate taxa, non-target taxa (not targeted by assay) and taxa found in the bait and cotton in Elliott traps (*Avena sp*. and *Gossypium* sp.). Three non-arthropod taxa were detected by the COI insect assay (yellow-footed antechinus, a slug *Ambigolimax valentinanus* and a nematode *Rhabditda* sp.) and they were removed from the results. The COI insect assay was developed to detect specific arthropod taxa, thus any detections of non-insect taxa using this assay are possibly caused by errors in the NCBI database or misassignment of tag sequences (tag jumping). The PCR controls were not opened in the laboratory where DNA was added, so the presence of sequence reads may be due to tag jumping. Tag jumping can occur during the sequencing step as a result of mixed cluster on the flow cell (Kircher *et al.,* 2012, Schnell *et al.*, 2015). The presence of misassigned tags to the extraction controls and one of the PCR controls was very low compared with the overall number of sequence reads obtained, and it is not considered to have affected the results of the study. In eDNA metabarcoding results, the number of sequence reads obtained do not represent the abundance of particular ZOTUs present in the sample (Deagle *et al.*, 2018, Verkuil *et al.*, 2020) thus all data were converted to presence/absence before further analysis and ZOTUs that were present in the extraction controls were removed from the dataset.

### 3.3.4. Data analysis

We first created a dissimilarity matrix (Jaccard index) using the ZOTU presence/absence and individual mammal data and analysed the matrix using nonmetric multidimensional scaling (NMDS) in the R package "vegan" (Oksanen *et al.,* 2020). NMDS results were graphically represented as biplots, showing the placement of major groups (species/growth stages) relative to each other in ordination space. Due to small sample size in the youngest age class (5 sites), we combined the 0.5–2.5 years and 2.5–10 years post-fire categories, resulting in three post-fire growth stages changing the terminology to: recent (0.5 to 10 years post-fire), mid (11 to 35 years post-fire) and late (35+ years post-fire) for further analysis. Diet data were then analysed using two-way permutational analysis of variance, PERMANOVA (Anderson *et al.*, 2008), with species and growth stage as fixed factors, to test for differences in composition and any interaction between the factors. To further explore the potential effect of growth stage, separate one-way PERMANOVAs were then undertaken for each species independently. If significant effects were detected, then pairwise tests were carried out between levels of each factor. ZOTUs contributing to observed patterns of similarity/dissimilarity between groups were identified using Similarity Percentages, SIMPER (Clarke, 1993) analysis in “PRIMER 7” (Clarke and Gorley, 2016). Results for these analyses are presented and analysed as the sum of frequency of occurrence across individuals within each mammal species (hereafter denoted as frequency).

## 3.4. Results

From the Elliott trapping carried out over 15,750 trap nights (126 sites × 25 traps × 5 nights), we captured 153small mammals (in 57 sites out of 126 sites) belonging to 10 species from three Orders (Rodentia, Diprotodontia and Dasyuromorphia). We collected 122 scat samples (yellow-footed antechinus; n = 42, bush rat; n = 49 and heath mouse; n = 31) (Appendix B, b-1). The plant assay trnLg/h detected 102 plant taxa belonging to 5 Classes, 34 Orders and 55 Families. Only 27 named species could be identified due to the poor taxonomic resolution of trnLg/h and/or incomplete barcode database. There were 62 arthropod taxa detected using the ZBJ-ArtF1c/R2c assay comprising of 3 Classes, 7 Orders, 26 Families and 44 Genera. Forty-five taxa could be reliably assigned to recognized species.

For the yellow-footed antechinus, 92 food items were detected (38 arthropod species and 54 plant species) (Appendix B, b-3), for the bush rat, 101 food items were detected (36 arthropods and 65 plants) (Appendix B, b-4), and for the heath mouse 77 food items (15 arthropods and 62 plants) (Appendix B, b-5). The mean number of food items per scat was similar for all species: bush rat

11.5, yellow-footed antechinus 10.9 and heath mouse 10.5 (Figure 3. 1, Appendix B, b-1). For all three species some of the scat consisted only of plant species ($n_{(YFA)} = 3$, $n_{(BR)} = 9$, $n_{(HM)} =15$) while no arthropod-only samples were detected.

The two-dimensional representation of NMDS results (Figure 3. 3) and pairwise comparison of diets (Table 1) suggests gross differences in overall diet between the three species, with differences among post-fire vegetation growth stages for each species less pronounced (Figure 3.4). While 2D stress values are relatively large, 3D representations (with lower stress) did not improve clarity, so we have used the 2D diagrams for simplicity. Two-way PERMANOVA results indicated a significant effect of species (pseudo-F = 5.8, $P < 0.001$, df = 2, $r^2 = 0.08$) and vegetation growth stage (pseudo-F = 1.6, $P < 0.001$, df = 2, $r^2 = 0.02$), and a significant interaction between these two factors (pseudo-F = 2.34, $P < 0.001$, df = 4, $r^2 = 0.06$).

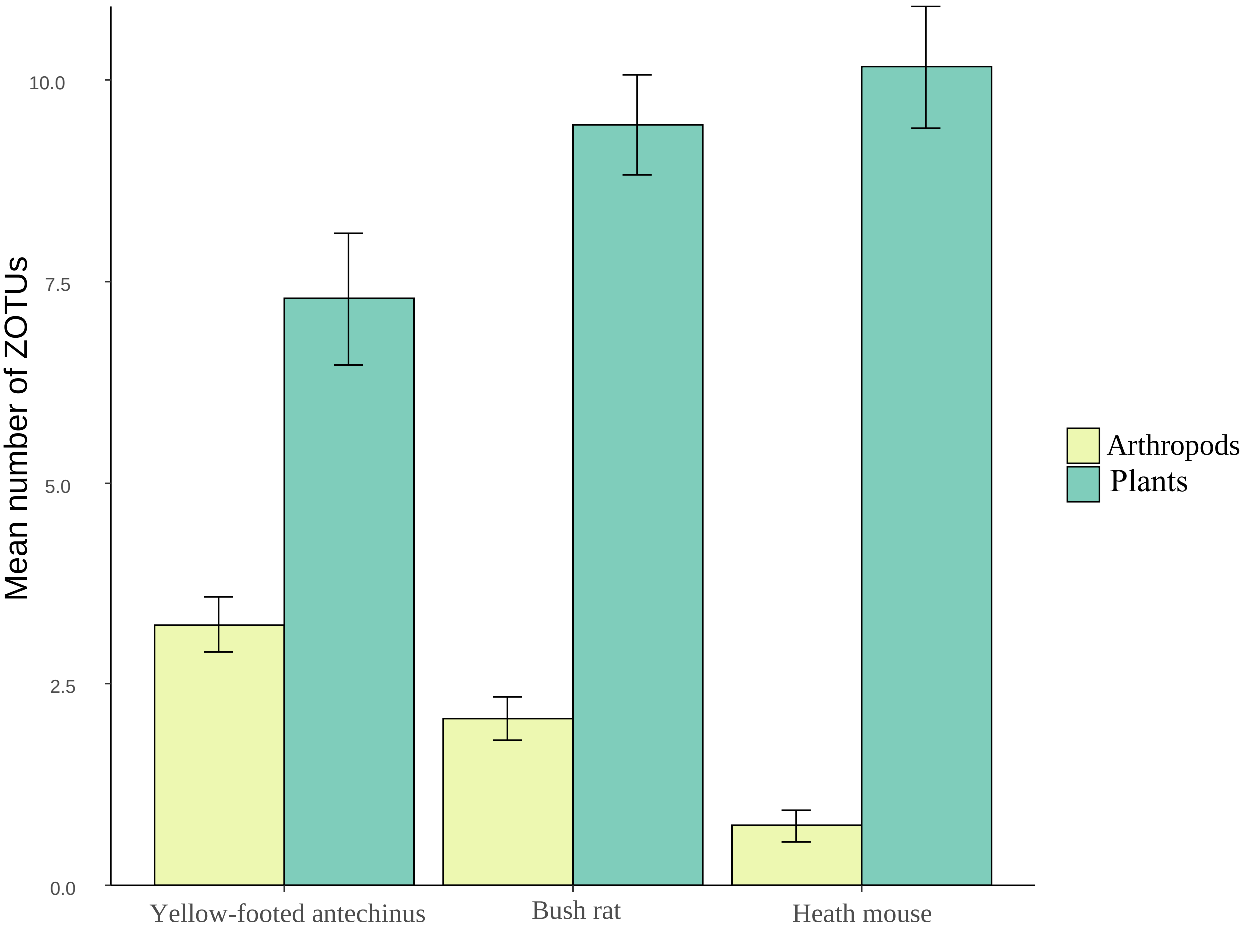


*Figure 3. 1 Mean number of ZOTUs per species that was detected from the COI and trnL metabarcodes. Error bars represent Standard Error.*

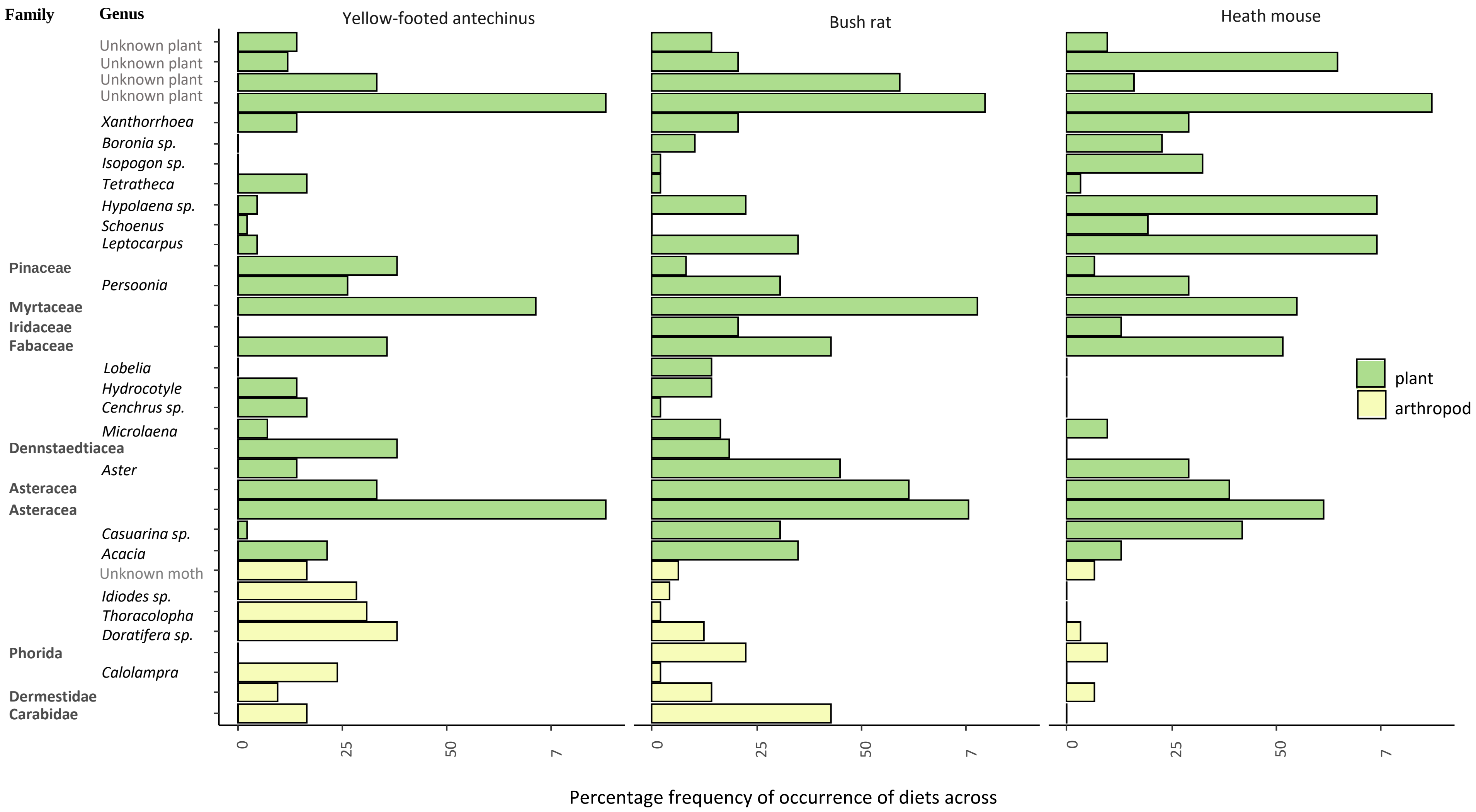


*Figure 3. 2 Percentage frequency of occurrence of diets of the major food species across individuals (scat samples) for each COI (arthropods) and trnL (plants) metabarcodes.*

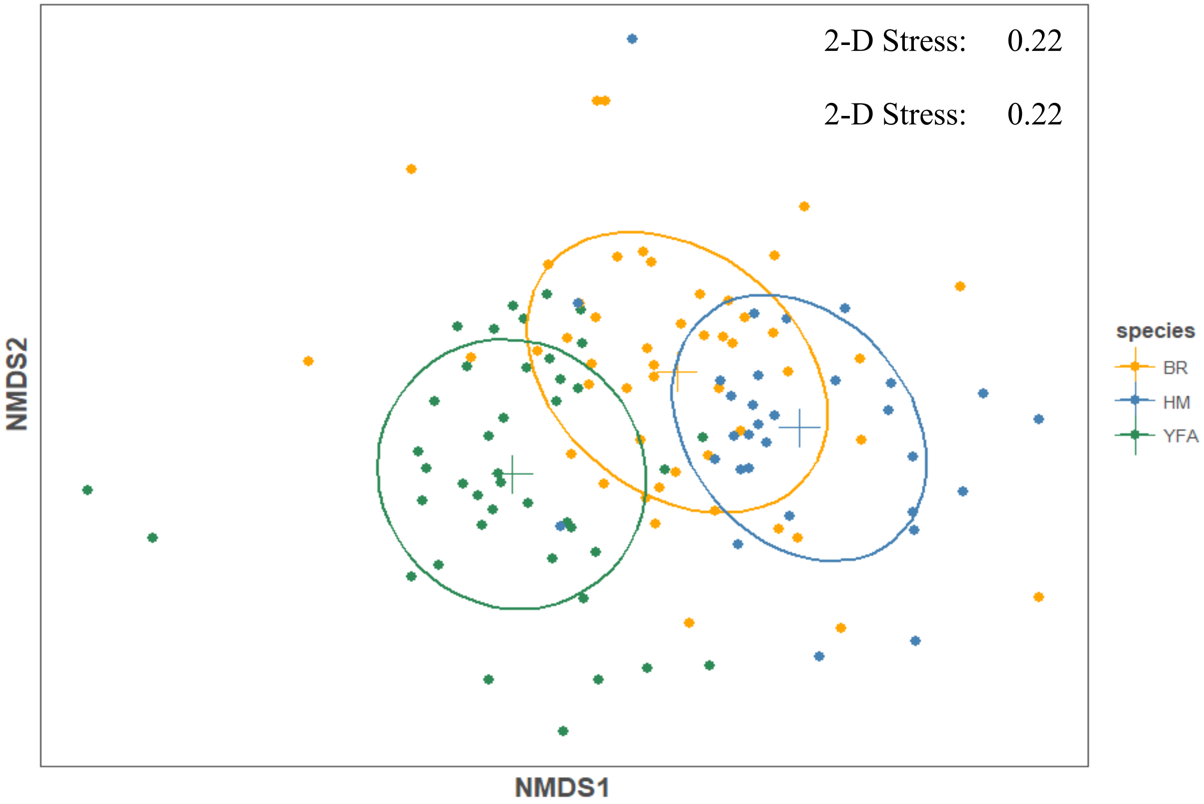


*Figure 3. 3 Two-dimensional ordination diagram representing the diets of the three species Bush rat (BR, n = 49), Heath mouse (HM, n = 31) and Yellow-footed antechinus (YFA, n = 42). Ellipses represent the 95% confidence interval around the centroid for each species.*

### 3.4.1. Diets of the three species

The yellow-footed antechinus and bush rat consumed a diverse array of plants and arthropods, while heath mouse diets consisted predominantly of plants and comparatively a low number of arthropod taxa (Figure 3. 1). Of the three species, the yellow-footed antechinus had a higher frequency of occurrence of arthropod food taxa across individuals while, for other two mammal species, plants were found in higher frequency of occurrence across individuals. However, there was a considerable variation among the diets of individuals within species (Figure 3. 2).

For the yellow-footed antechinus arthropod food items consisted of 37 insect taxa (moths, beetles, cockroaches, flies, lacewings) and a species of spider (*Cheiracanthium* sp.). Moths (Order Lepidoptera) constituted the bulk of the dietary ZOTUs, with the painted cup moth *Doratifera oxleyi* the most frequently detected, followed by two bracken moths from the family Geometridae (*Idiodes siculoides* and *Idiodes apicata*) and *Thoracolopha spilocrossa* from the family Noctuidae (Appendix B, b-3). A species of cockroach, (*Calolampra* sp., was also frequently detected. Overall, 54 species of plants were detected (myrtles, pines, ferns, daisies). Species belonging to Myrtaceae, Fabaceae (*Acacia* sp. and *Kennedia* sp.*)*, Asteraceae and Proteaceae were among those detected at the highest frequency.

Overall, bush rat arthropod food items consisted of 35 insect taxa (moths, flies, beetles) and a crustacean (yabbie). The most frequently detected insect was a species of carabid beetle, additionally beetles belonging to the family Dermestidae, dipterans belonging to the family Phoridae, and family Chironomidae (non-biting midges, *Polypedilum* sp.) were detected at high frequencies. A wide variety of moths were detected in low frequencies. Overall, plants consisted of 65 species With unidentified plant ZOTU162 the most frequently detected. Species belonging to the families Myrtaceae, Asteraceae, Fabaceae, and *Acacia* sp., *Pultenaea* sp.). *Leptocarpus sp.*, *Hypolaena sp.* and *Centrolepis monogyna* were found at the highest frequencies. A wide variety of other plant species was found at low frequencies (Appendix B, b-4).

Overall, heath mouse arthropod food items consisted of 14 taxa including moths, beetles, flies, and spiders. The most frequent insect detected was the same species of carabid beetle identified in the other two small mammals, with other taxa detected at low frequencies. A large number of plant species belonging to a broad range of families was detected in heath mouse scats, comprising 62 plant taxa (primarily rushes, Gentianales and myrtles). The most frequent plant species was an unidentified plant ZOTU162. Heath mouse scats contained a high frequency of occurrence of plants belonging to the rushes of the family Restionaceae (*Hypolaena* sp., *Leptocarpus* sp.) (Appendix B, b-5).

Differences in diet between species were a consequence of cumulative small differences across a range of ZOTUs.  While SIMPER results (Table 2) reflect some overlap in diet items, it is clear that species have, overall, distinctive diet items based on variation in their frequency of occurrence across individuals. Based on the results of the SIMPER analysis, the highest contribution to the difference of the diets of three species is given by a Fabaceae plant species (ZOTU99) and a Myrtaceae plant species (ZOTU115) that were not able to be classified beyond the class level. A Magnoliopsida (ZOTU154) plant contributed to the highest dissimilarity between yellow-footed antechinus and bush rat. Additionally, a plant species belonging to the family Pinaceae (most likely *Pinus radiata*) contributed to the dissimilarity among yellow-footed antechinus and the other two species. Only two insect species (the painted cup moth (*Doratifera oxleyi*) and a beetle species belonging to the family Carabidae contributed substantially to the dissimilarity between yellow-footed antechinus and other two species, although yellow-footed antechinus is considered an insectivore. An unidentified plant species (ZOTU154) and a daisy belonging to the family Asteraceae (ZOTU78) contributed to the highest dissimilarity among bush rat and other two species. Plant species belonging to the family Rubiaceae and a rush (*Hypolaena* sp.) contributed to the highest dissimilarity between heath mouse and the other two species. The plant ZOTU162 (unidentified plant species) also contributed to the dissimilarity of diets between heath mouse and the other two species.

### 3.4.2. Diet change over time after fire

Species specific PERMANOVA results indicated an effect of post-fire growth stage for all three species (bush rat; pseudo-F= 2.5, $P < 0.001$, yellow-footed antechinus; pseudo-F= 1.5, $P < 0.017$, heath mouse; pseudo-F= 1.4, $P < 0.022$). The diet of yellow-footed antechinus changed incrementally from the recent to the late post-fire growth stage, with a statistically significant difference between recent and late growth stages ($P = 0.013$) (Figure 3. 4, Appendix B, b-1: Table S2). In contrast, the bush rat diet was significantly different among all growth stages (recent vs late - $P = 0.002$, recent vs mid- $P = 0.001$, late vs recent - $P = 0.023$) (Figure 3. 4, Appendix B, b-1: Table S2). Pairwise analysis results indicated that the heath mouse diet in the mid post-fire growth stage differed from the recent post-fire growth stage ($P = 0.025$) (Figure 3. 4, Appendix B, b-1: Appendix B, b-2). Again, differences in diet between growth stages for each species was a consequence of cumulative small differences across a range of ZOTUs. While SIMPER results (Tables 3-5) reflect some overlap in diet items, it is clear that species have, overall, distinctive diet items based on their frequency of occurrence across individuals.

For the yellow-footed antechinus, the plant species that contributed most strongly to the pairwise dissimilarities among growth stages were unidentified plant species ZOTU162, Myrtaceae plant species ZOTU115, Asteraceae species ZOTU78. Additionally, a bracken moth species (*Idiodes siculoides*) and a cockroach species (*Calolampra* sp.) contributed to this diet difference. For the bush rat both plants and arthropods contributed to the dissimilarities between the diets of the three growth stages. Some of the prominent contributions to this dissimilarity were Asteraceae species, Magnoliopsida species and a beetle species belonging to the family Dermestidae. For the heath mouse, a plant species belonging to the family Rubiaceae and *Tetracera* sp. showed the highest percent contribution to the difference between growth stages. Arthropods did not contribute to this difference among growth stages for the heath mouse.

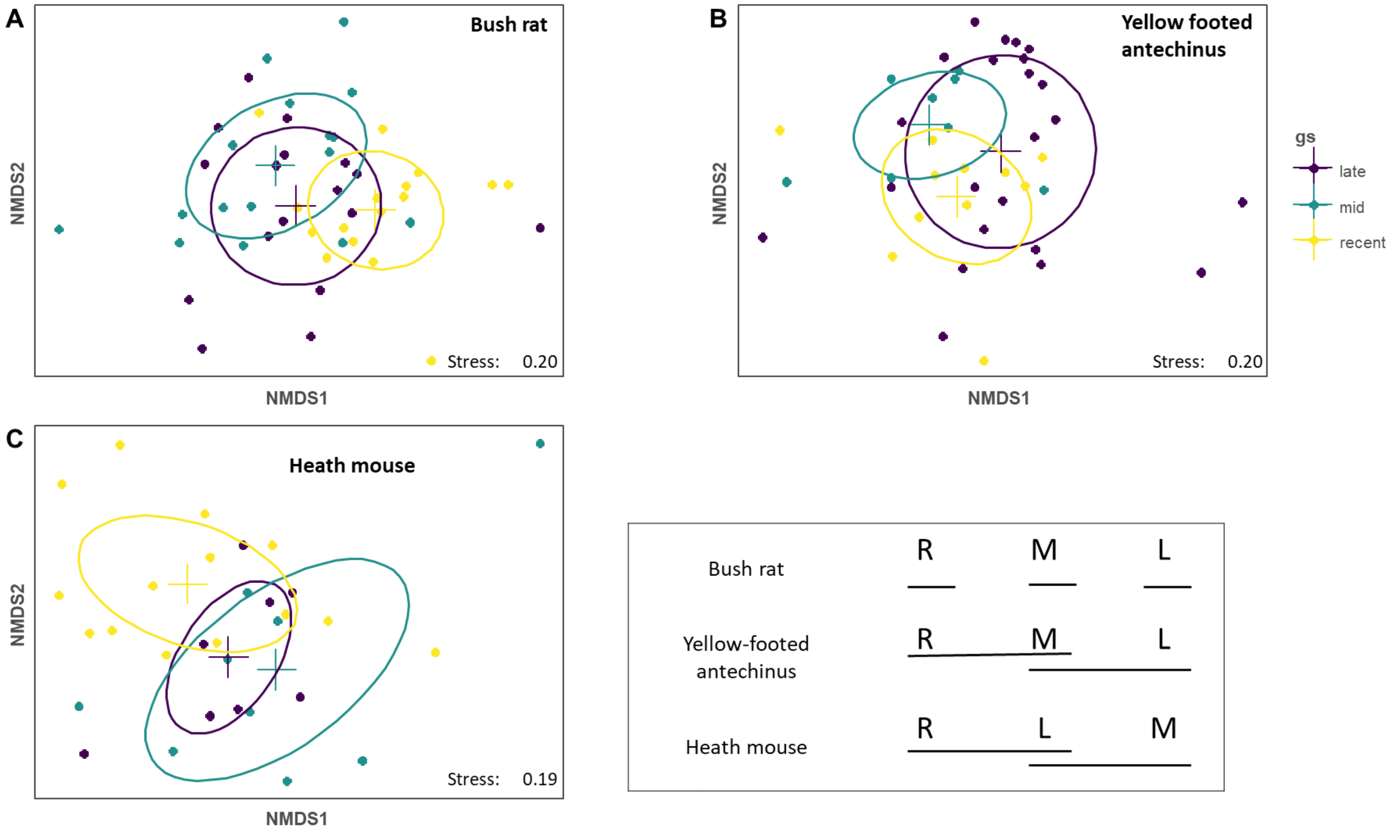


*Figure 3. 4 Two-dimensional ordination diagram representing the diets of the three species separately for three post-fire growth stages, R = recent (0.5 to 10 years post-fire), M = mid (11 to 35 years post-fire) and L = late (35+ years post-fire). Ellipses represent the 95% confidence interval around the centroid for each species. In the pairwise analysis box continuous lines that connect letters indicate no significant difference between levels of the factor (see Table 2).*

*Table 3. 1 Pairwise comparison of diets (ZOTUs) from PERMANOVA for the three small mammal species and for the three growth stages.*

| Pairwise comparison of diets for each species | | | | | |
|---|---|---|---|---|---|
| **Pairs** | **df** | **Sums of squares** | **Pseudo-*F*** | **$R^2$** | **P** |
| Yellow-footed antechinus vs bush rat | 1 | 1.87 | 7.70 | 0.08 | 0.001** |
| Yellow-footed antechinus vs heath mouse | 1 | 2.96 | 12.58 | 0.15 | 0.001** |
| Bush rat vs heath mouse | 1 | 1.57 | 6.83 | 0.08 | 0.001** |
| **Pairwise comparison of diets for each growth stage** | | | | | |
| **Pairs** | **df** | **Sums of squares** | **Pseudo-*F*** | **$R^2$** | **P** |
| Mid vs late | 1 | 0.66 | 2.57 | 0.031 | 0.003** |
| Mid vs recent | 1 | 0.57 | 2.15 | 0.029 | 0.023* |
| Late vs recent | 1 | 0.33 | 1.24 | 0.01 | 0.211 |

*Table 3. 2 Mean frequency of occurrence of ZOTUs identified by similarity percentages (SIMPER) as contributing to the overall compositional dissimilarity between the three mammal species fire). YFA-yellow-footed antechinus, BR – bush rat, HM- heath mouse.*

| **ZOTU** | **Family/Genus/Species name (if identified)** | **Average frequency of occurrence** | | | **Percentage contribution to pairwise dissimilarity** | | |
|---|---|---|---|---|---|---|---|
| | | **YFA** | **BR** | **HM** | **YFA-BR** | **YFA-HM** | **BR-HM** |
| **162** | Plant (Unidentified) | 0.88 | 0.80 | 0.87 | 2.5 | 1.9 | 2.3 |
| **114** | Myrtaceae | 0.88 | 0.76 | 0.61 | 2.7 | 3.3 | 3.3 |
| **115** | Myrtaceae | 0.71 | 0.78 | 0.55 | 3.1 | 3.5 | 3.5 |
| **28** | *Doratifera oxleyi* | 0.38 | 0.12 | 0.03 | 2.9 | 2.7 | 0.8 |
| **160** | Dennstaedtiaceae | 0.38 | 0.18 | 0.00 | 2.7 | 2.3 | 1.1 |
| **157** | Pinaceae | 0.38 | 0.08 | 0.06 | 2.3 | 2.2 | 0.8 |
| **78** | Asteraceae | 0.33 | 0.61 | 0.39 | 3.9 | 2.9 | 3.7 |
| **154** | Plant (Unidentified) | 0.33 | 0.59 | 0.16 | 3.8 | 2.1 | 3.8 |
| **99** | Fabaceae | 0.36 | 0.43 | 0.52 | 3.4 | 3.4 | 3.5 |
| **138** | *Leptocarpus sp.* | 0.05 | 0.35 | 0.74 | 2.4 | 4.7 | 4.0 |
| **77** | *Aster sp.* | 0.14 | 0.45 | 0.29 | 3.3 | 2.2 | 3.3 |
| **104** | Rubiaceae | 0.12 | 0.20 | 0.65 | 1.7 | 4.3 | 4.1 |
| **100** | *Casuarina sp.* | 0.02 | 0.31 | 0.42 | 2.1 | 2.6 | 3.1 |
| **4** | Carabidae | 0.17 | 0.43 | 0.13 | 3.0 | 1.7 | 2.9 |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **140** | *Isopogon anemonifolius* | 0.00 | 0.02 | 0.32 | 0.1 | 1.9 | 2.0 |
| **137** | *Hypolaena sp.* | 0.05 | 0.22 | 0.74 | 1.7 | 4.6 | 4.2 |

*Table 3. 3 Mean frequency of occurrence of ZOTUs identified by similarity percentages (SIMPER) as contributing to the overall compositional dissimilarity between growth stages for the yellow-footed antechinus.*

| **ZOTU** | **Family/Genus/Species name (if identified)** | **Average frequency of occurrence** | | | **Percentage contribution to pairwise dissimilarity** | | |
|---|---|---|---|---|---|---|---|
| | | **Recent** | **Mid** | **Late** | **R-M** | **R-L** | **M-L** |
| **162** | Plant (Unidentified) | 0.91 | 1.00 | 0.83 | 1.0 | 3.2 | 2.1 |
| **114** | Myrtaceae | 0.91 | 0.88 | 0.87 | 2.8 | 2.6 | 2.3 |
| **115** | Myrtaceae | 0.73 | 0.88 | 0.65 | 3.9 | 4.4 | 3.4 |
| **28** | *Doratifera oxleyi* | 0.45 | 0.25 | 0.39 | 4.1 | 4.6 | 3.5 |
| **157** | Pinaceae | 0.36 | 0.38 | 0.39 | 4.2 | 3.9 | 2.9 |
| **3** | *Calolampra sp.* | 0.27 | 0.00 | 0.30 | 2.7 | 4.0 | 2.5 |
| **57** | Plant (Unidentified) | 0.27 | 0.00 | 0.17 | 2.1 | 2.5 | 0.9 |
| **4** | Carabidae | 0.18 | 0.50 | 0.04 | 4.9 | 1.8 | 3.7 |
| **141** | *Persoonia sp.* | 0.18 | 0.38 | 0.26 | 3.5 | 2.4 | 2.9 |
| **35** | *Thoracolopha spilocrossa* | 0.18 | 0.00 | 0.43 | 1.7 | 3.3 | 2.3 |
| **78** | Asteraceae | 0.00 | 0.50 | 0.43 | 3.9 | 2.6 | 3.4 |
| **23** | *Idiodes siculoides* | 0.09 | 0.38 | 0.39 | 4.7 | 2.5 | 3.8 |
| **66** | *Hydrocotyle sp.* | 0.09 | 0.38 | 0.09 | 3.2 | 0.9 | 2.5 |
| **160** | Dennstaedtiaceae | 0.09 | 0.25 | 0.57 | 2.8 | 4.4 | 3.7 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **99** | Fabaceae | 0.09 | 0.38 | 0.48 | 2.9 | 4.0 | 3.5 |
| **154** | Plant (Unidentified) | 0.09 | 0.38 | 0.43 | 3.3 | 3.0 | 3.1 |

*Table 3. 4 Mean frequency of occurrence of ZOTUs identified by similarity percentages (SIMPER) as contributing to the overall compositional dissimilarity between growth stages for the bush rat.*

| **ZOTU** | **Family/Genus/Species name (if identified)** | **Average Frequency of Occurrence** | | | **% Contribution to pairwise dissimilarity** | | |
|---|---|---|---|---|---|---|---|
| | | **Recent** | **Mid** | **Late** | **R-M** | **R-L** | **M-L** |
| **78** | Asteraceae | 0.88 | 0.44 | 0.53 | 4.2 | 3.8 | 3.4 |
| **154** | Plant (Unidentified) | 0.88 | 0.38 | 0.53 | 4.4 | 3.9 | 3.3 |
| **77** | Asteraceae | 0.75 | 0.38 | 0.24 | 4.1 | 5.0 | 2.7 |
| **114** | Myrtaceae | 0.81 | 0.69 | 0.76 | 2.9 | 3.0 | 2.9 |
| **115** | Myrtaceae | 0.75 | 0.81 | 0.76 | 2.6 | 3.1 | 2.8 |
| **162** | Plant (Unidentified) | 0.75 | 0.75 | 0.88 | 2.9 | 2.8 | 2.4 |
| **6** | Dermestidae | 0.31 | 0.06 | 0.06 | 2.0 | 2.1 | 0.6 |
| **75** | Iridaceae | 0.00 | 0.63 | 0.00 | 4.1 | 0.0 | 4.1 |
| **100** | *Casuarina sp.* | 0.06 | 0.63 | 0.24 | 3.9 | 2.0 | 3.7 |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
| **4** | Carabidae | 0.31 | 0.56 | 0.41 | 3.4 | 3.5 | 3.4 |
| **93** | *Acacia sp.* | 0.25 | 0.50 | 0.29 | 3.2 | 2.9 | 3.3 |
| **141** | *Persoonia sp.* | 0.19 | 0.50 | 0.24 | 3.2 | 2.2 | 3.2 |
| **99** | Fabaceae | 0.31 | 0.38 | 0.59 | 3.2 | 4.1 | 3.5 |
| **138** | *Leptocarpus sp.* | 0.13 | 0.38 | 0.53 | 2.5 | 3.6 | 3.3 |
| **137** | *Hypolaena sp.* | 0.13 | 0.13 | 0.41 | 1.3 | 3.1 | 2.8 |

*Table 3. 5 Mean frequency of occurrence of ZOTUs identified by similarity percentages (SIMPER) as contributing to the overall compositional dissimilarity between growth stages for the heath mouse.*

| **ZOTU** | **Family/Genus/Species name (if identified)** | **Average Frequency of Occurrence** | | | **% Contribution to pairwise dissimilarity** | | |
|---|---|---|---|---|---|---|---|
| | | **Recent** | **Mid** | **Late** | **R-M** | **R-L** | **M-L** |
| **104** | Rubiaceae | 0.93 | 0.33 | 0.50 | 5.4 | 4.2 | 3.8 |
| **162** | Plant (Unidentified) | 0.86 | 0.89 | 0.88 | 2.1 | 2.0 | 2.0 |
| **138** | *Leptocarpus sp.* | 0.71 | 0.78 | 0.75 | 3.3 | 3.4 | 3.2 |
| **137** | *Hypolaena sp.* | 0.64 | 0.67 | 1.00 | 3.6 | 3.5 | 3.1 |
| **99** | Fabaceae | 0.57 | 0.33 | 0.63 | 3.8 | 4.0 | 4.3 |
| **140** | *Isopogon anemonifolius* | 0.43 | 0.11 | 0.38 | 3.0 | 3.7 | 2.9 |
| **100** | *Casuarina sp.* | 0.43 | 0.22 | 0.63 | 3.1 | 4.2 | 4.3 |
| **114** | Myrtaceae | 0.43 | 0.78 | 0.75 | 4.3 | 4.7 | 3.0 |
| **115** | Myrtaceae | 0.36 | 0.67 | 0.75 | 4.0 | 4.9 | 3.5 |
| **74** | *Xanthorrhoea sp.* | 0.29 | 0.44 | 0.13 | 3.2 | 2.4 | 3.2 |
| **77** | Asteraceae | 0.29 | 0.33 | 0.25 | 3.3 | 3.0 | 3.4 |
| **78** | Asteraceae | 0.43 | 0.33 | 0.38 | 3.5 | 3.7 | 3.6 |
| **141** | *Persoonia sp.* | 0.36 | 0.11 | 0.38 | 2.4 | 3.8 | 3.4 |
| **91** | *Tetracera sp.* | 0.07 | 0.00 | 0.38 | 0.5 | 3.0 | 2.8 |

## 3.4. Discussion

It is important to understand how diet is influenced by disturbances such as fire as this will help conservation management in the future when fires are predicted to be larger and more frequent (Flannigan *et al.,* 2000). Our focal species: the yellow-footed antechinus, the bush rat, and the heath mouse, have been studied extensively in other ecological aspects such as genetics, population structure, landscape, and fire ecology (Cockburn *et al.,* 1981, Smith, 1984, Marchesan and Carthew, 2004, Flanagan-Moodie et al., 2018, Nalliah *et al.,* 2021). However, there is a paucity of in-depth information on their diets. In this study, we used faecal eDNA metabarcoding to determine differences in the diets of these three small mammal species and changes in their diets over time after fire. Our focus was on longer-term effects, with sites ranging from 1-79 years since last burnt. We obtained a robust set of data on diets at a high taxonomic resolution. eDNA metabarcoding allowed new insight into the dietary patterns of these species, such as the yellow-footed antechinus consuming a wide variety of plants and moths. Overall, the diets of the three species were fundamentally different from each other, as was the nature of diet changes after a fire. The bush rat showed the most pronounced diet changes throughout the post-fire vegetation growth stages, while the heath mouse showed the least.

### 3.4.3. Diet of the three species

The rate of passage of food in small mammals is fast, generally within few hours of the food intake (Karasov *et al.,* 1986), thus detected food species detections in scat can be inferred as items ingested in a foraging bout close to the time of capture. The average number of food items per scat for individuals of all three species was similar suggesting that in a single foraging bout all three species consumed a high variety of food species from several broad types of food. Being a generalist is an advantageous foraging strategy in a fire prone environment where resource availability is unpredictable or variable after fires (Sutherland and Dickman, 1999, Di Stefano *et al.,* 2014, Cruz-Rivera and Hay, 2000).

We expected to find gross dietary differences between the three species and our results largely agree with previous work (Hindmarsh and Majer, 1977, Cheal, 1987, Di Stefano *et al.,* 2014). Yellow-footed antechinus and bush rat consumed a diverse array of plants and arthropods, while heath mouse diet consisted of prominently plants and comparatively a low number of arthropod taxa. Braithwaite et al. (1978) suggested five food niches for the small mammals in heathland environments, and their activity patterns are directly related to the diet and predation pressure. Here we can broadly classify the three species into that categorization: bush rat - omnivore, heath mouse - generalist herbivore, and yellow-footed antechinus - scansorial insectivore, however our results indicate that yellow-footed antechinus diet shows considerable plasticity compared to that of an exclusive insectivore.

Surprisingly, there were many plants detected in the diet of yellow-footed antechinus in contrast to earlier microscopic work that found only invertebrates and vertebrates (Hindmarsh and Majer, 1977). One likely explanation for this is that the metabarcoding analysis is detecting plant products such as nectar, pollen and plant sap that would not be detected in microscopic analysis. There have been records of yellow-footed antechinus feeding on the nectar of *Banksia* flowers and sap of the sticky hop bush *Dodonaea viscosa* (Goldingay, 2000, McCreadie, 2017); similarly we suspect that yellow-footed antechinus could be feeding on the sap of pine wildlings (*Pinus radiata*) which was frequently recorded. Our findings on plant matter are further confirmed by a micro-histological study (York *et al.,* 2022) carried out in the same landscape indicating that there is a considerable amount of plant matter such as leaves, seeds and flowers in yellow-footed antechinus diet. Thus, we suggest that this species is not solely insectivorous, and individuals often supplement their diet with plant material. Many diet studies have reported plant material in carnivore and insectivore stomach content and scats (Yoshimura *et al.*, 2021). Carnivorous mammals such as foxes, badgers civets, and insectivorous mammals such as aardvarks, and bats are reported to seasonally augment their diets with plant material such as berries, roots, nectar and in some instances, foliage (Milton and Dean, 2001, Koike *et al.*, 2008, Mudappa *et al.*, 2010, Frick *et al.*, 2014). Berries, nectar, and seeds contain high carbohydrate levels, amino acids, and other micronutrients (Ball and Golightly Jr, 1992, Venjakob *et al.*, 2022) substantially contributing to an animal's nutritional requirements. Furthermore, acquiring nutrient-rich sessile plant material while actively foraging for arthropod prey could be an energy optimizing strategy. Thus, utilizing supplementary plant material in order survive in a patchy resource environment could be a strategy that helps antechinus complete its dietary requirements while looking for arthropod prey.

We recorded more lepidopterans in the diet of yellow-footed antechinus than previous studies (Kelly, 2006, Lada *et al.*, 2008). The difference could be due to the soft body parts of lepidopterans remaining undetected in micro-histological analysis. Due to the nature of the metabarcoding results, it was not possible to conclude which developmental stage (eggs, larvae, pupae, or adults) of moths yellow-footed antechinus preyed on. Being nocturnal and scansorial in nature we assume they could be foraging on resting adult moths (Kawahara *et al.*, 2017). For the moth species that was detected in the highest frequency, *Doratifera oxleyi* (painted cup moth), the larval host plants are *Eucalyptus* trees, the dominant canopy species at our sites. For two bracken moth species detected at a high frequency (*Idiodes siculoides* and *Idiodes apicata*) larval host plants included ferns such as *Pteridium esculentum*, a common element of the heathy woodland understory. Semi-arboreal nature of yellow-footed antechinus is reflected in the diet with the presence of both arboreal and understory-dwelling arthropods. Similar to earlier records (Hindmarsh and Majer, 1977), cockroaches were found in the diet of several individuals. Although we expected to see more Arachnida in the diets of yellow-footed antechinus see (Hindmarsh and Majer, 1977, Dickman, 1986, Dickman and Happold, 2022), there was only a single record of that Class. However, in our study sites arachnids were found abundantly based on the invertebrate surveys; it is possible that arachnida species that yellow-footed antechinus prey on are sparsely represented in our study sites or underrepresented by the eDNA metabarcoding because of mismatches between the arthropod primers and template sequence. The assays were not designed to detect vertebrate prey items; thus, there is a possibility that diet information on vertebrates is lacking in our set of results. We suspect that this could be the case for one yellow-footed antechinus scat for which we did not detect any food items. We assume that this individual recently consumed a diet of vertebrates and as such were not identified in the metabarcoding process.

For the bush rat, our observations were similar to that reported in the literature, where rats are following an opportunistic foraging pattern (Cheal, 1987, Carron *et al.,* 1990). This could be an indicator that bush rats have the ability to adjust their diets according to the resource availability and successfully utilizing the most optimal strategy of foraging according to different resources available (Kelt *et al.*, 2004, Dickman and Happold, 2022) Bush rat diets consisted of the highest number of unique ZOTUs (n = 101) including different types of arthropods as well as plants, making its diet more diverse compared to the other two species. Some of the major arthropod food types found in bush rat diets were ground beetles (family Carabidae) and skin beetles (family Dermestidae), which feed on dry and dead plant materials. Furthermore, a wide variety of moths were recorded in bush rat diets. This dietary flexibility is most likely one of the reasons for its large geographic distribution. Given that bush rats have been reported consuming considerable amounts of fungi in wet sclerophyll forests in south-eastern Australia (Vernes *et al.,* 2015) their diet in these drier woodlands may be even broader than the metabarcoding results suggest. However, in this study fungi was not added as an assay due to logistic reasons and the samples being collected in the summer where sporocarps are less likely to be found.

Compared to other two species, the heath mouse diet consisted predominantly of plant species and a very low numbers of arthropods. Plants of family Restionaceae which include *Hypolaena* sp. (possibly *Hypolaena fastigiate* – a common species in heathlands of the region (Duff *et al.,* 2013a)) and *Leptocarpus tenax* which are found in wet soils and seasonal swamps, formed a major component of their diet. Heath mice were generally confined to vegetation with a very dense understory such as wet heaths and prefers floristically diverse habitats (Nalliah *et al.,* 2021), our finding suggests that these species are consuming the plant species that are commonly found in wet heath and confirms that this species can be classified as a generalist herbivore within the specific habitat in which it occurs.

### 3.4.4. Effect of post-fire growth stage on diet

After a fire, habitats often progress through a series of successional stages where productivity and species composition change over time (Smith, 2018). Thus, fire changes the distribution and abundance of numerous resources including plants and arthropods that are commonly consumed by small mammals (Fox, 1982, Kelly *et al.*, 2011, Pulsford *et al.*, 2014, Dickman and Happold, 2022). Luo and Fox (1994) found that the diet of the eastern chestnut mouse *Pseudomys gracilicaudatus* varied with post-fire successional stage; initially consuming a high proportion of leaf material, then stem, seeds, fungi and insects, then as vegetation matured into the old stage, the composition of seeds, fungi and insects was reduced. At the landscape scale, multiple post-fire ages are often available for small mammal species, providing a greater diversity of habitats and potential food items (Kelly *et al.*, 2017a, Jones and Tingley, 2021). Different dietary strategies may make species more or less vulnerable to post-fire changes and can potentially influence the ability of species to exploit the resources available in a mosaic of post-fire ages.

Here, we found that the three species shifted their diets in response to post-fire growth stage, with this pattern being most pronounced for the bush rat and least for heath mice. This may be because bush rats are generalist omnivores that can shift their diet in response to local abundance of resources. In this study they frequently consumed plants of the genus *Asteraceae* in the recently burnt growth stage. This could indicate that that they are feeding on flowers of annual plants or small shrubs that may be locally abundant after fires, while later in the succession woody shrubs such as *Casuarina* and sedges were more commonly detected, highlighting a shift with changing resource availability. As such, dietary plasticity may allow this species to persist immediately after fires and throughout long-term succession (Sutherland and Dickman, 1999, Di Stefano *et al.*, 2014).

Yellow-footed antechinus diet shifts were most pronounced when comparing recent compared to late successional stages. The plants that changed in frequency over time included plants of the families Myrtaceae and Asteraceae and this could be due to yellow-footed antechinus targeting certain resources that may be abundant at different times in the post-fire succession. Fire could change the time of seedling recruitment and the time of flowering and nectar production thus changing the resource available at different post-fire ages (Benwell, 1998, Pyke, 2017). However, we were not able to identify to defined species many of the particular plant resources that were being utilised by yellow-footed antechinus and further work needs to be done to identify the tissue types consumed by these species.

In contrast to the yellow-footed antechinus and bush rat, the heath mouse is a generalist herbivore, thus may be more limited in their options in change in their diets in response to changing resources. We only found a small dietary shift from early to the mid post-fire age in the heath mouse. This could be because they eat common plants that are present at all stages of the succession (Di Stefano *et al.,* 2014). For example, *Hypolaena fastigiata* is a common plant present in all the growth stages of post-fire ages in treeless heath (Duff *et al.,* 2013a). Thus, the feeding strategy of heath mice appears to rely on a common plant species that are found in these areas, where they do not have to change their diets substantially in response to fire. Furthermore, wetter heath areas regenerate rapidly after fires creating ideal environments for heath mouse (Benwell, 1998). Our conclusions are well aligned with the confined distribution of these species in wet heath areas, and they are already selecting for habitats that provide them with preferred diet items. This clearly contrasts with other two species with a broader distribution and more prominent change of diets in response to changing conditions in post-fire environments. Determining species dietary plasticity in response to disturbance would be further enhanced by pairing a diet study with an assessment of how food availability and quality changes over time (e.g., (Di Stefano and Newell, 2008)). While we have, general knowledge of the shifting post-fire food resource base in these ecosystems (Duff *et al.,* 2013a) we lack detailed information about how the availability of different food species changes over time.

### 3.4.5. Metabarcoding considerations

While we were able to gain powerful insights into the diets of the three species in this study, there were examples where we could not identify common plant species beyond the class level. eDNA metabarcoding is only as good as the target taxonomic libraries that underpin them

(Rathnasingham and Hebert, 2007, Dormontt *et al.,* 2018), thus it is important to create complete metabarcoding libraries for different taxa in order to increase the accuracy of results. Metabarcoding will become even more powerful as libraries become more complete, as demonstrated by our ability to detect moths at the species level, where well-developed libraries exist.

As the number of sequence reads obtained in eDNA metabarcoding results do not represent the abundance of particular ZOTUs present in the sample, the relative proportions (e.g., volume) of individual food species cannot be determined. As such the importance of particualr food types (e.g. by volume) cannot be determined. While this places some constraints on interpretation, our results have shed new light on the breadth of food items consummed by our three target species.

Paradoxically, the power of the technique can create issues whereby secondary predation is detected in diets. Generally, when DNA-based diet studies are carried out for omnivores, multiple makers for different taxa such as plants, arthropods and fungi are used to obtain an understanding of the range of diets (Robeson *et al.,* 2018, Taberlet *et al.,* 2018, Bonin *et al.,* 2020). In this study we used two markers to identify plants and arthropods as our study species consume a wide variety of dietary items in both categories. Thus, there is a possibility for secondary predation to be detected in diets (Taberlet *et al.,* 2018, Tercel *et al.,* 2021, Berman and Moshe, 2022). For example, it is possible that some plant material detected in yellow-footed antechinus scat were originally eaten by invertebrates. However, we consider it likely that most of the ZOTUs in our diet results were a consequence of primary predation, as they showed similar trends as past records and earlier data from the same study area (York *et al.,* 2022).

Animals can select highly nutritious tissues over less nutritious tissues of the same plant or animal (Deagle *et al.,* 2010). Understanding which functional parts of plants and what larval stages of arthropods are being consumed is an important aspect of understanding small mammal-habitat interactions. Such information can provide important insight into animal behaviour such as predator-prey interactions, and ecological functions performed by species such as seed dispersal and pollination (Gende *et al.,* 2001, Klare *et al.,* 2011, Tercel *et al.,* 2021). However, eDNA metabarcoding alone cannot differentiate between the tissue types that are consumed (Tercel *et al.,* 2021). For example, micro-histological analysis of silky mice *(P. apodemoides)* diet showed that they ate more seeds in recently burnt compared to older post-fire stages (Di Stefano *et al.,* 2014), a finding that would have been missed if metabarcoding alone had been used. For yellow-footed antechinus questions remain to be explored on what type of plant tissue and what developmental stage of arthropods are consumed in order to get a complete understanding of diets. Thus, incorporating micro-histological methods with eDNA metabarcoding studies will give better insight on how animal diets are changing in response to changing environments.

## 3.5. Conclusion

Analysis of animal diets sheds light on critical ecological interactions and is beneficial in conservation management decision making. For example, new information on the diets of flying foxes improved the understanding of how they function as pollinators and seed dispersers (Bell *et al.,* 2020). However, information regarding diet changes over time after disturbance is lacking for many animals living in habitats prone to disturbances such as fire. Using eDNA metabarcoding of scat samples, we obtained high taxonomic resolution data on the diet of three species and identified cryptic taxa that would have gone unnoticed if conventional dietary analysis methods were used.

Although eDNA metabarcoding is a powerful biodiversity monitoring tool, in dietary analysis it cannot differentiate different tissue types such as seeds, flowers, foliage or development stages of arthropod species which are essential in understanding ecological interactions. The use of complementary biodiversity monitoring methods has been recommended in many eDNA metabarcoding studies (Tordoni *et al.,* 2021, Valdivia-Carrillo *et al.,* 2021, Ryan *et al.,* 2022), similarly dietary analysis can be improved in future by combining molecular and histological methods (Deiner *et al.,* 2017, Shutt *et al.,* 2020).

From a land management perspective, this study revealed important information about changes of diet over time after fire, highlighting differences among the three species which reflect their life history strategies. Through identification of critical resources, appropriate conservation management actions can be undertaken to protect and augment such resources. For example, in this woodland ecosystem, after the critical nesting (hollows) and food (seed) resources for the south-eastern red-tailed black-cockatoo (*Calyptorhynchus banksii graptogyne*) were identified, appropriate conservation measures have been implemented to sustain these endangered bird populations (Maron *et al.,* 2008). The three species studies here do not specialise in individual food sources, however information gleaned from metabarcoding can be used to guide future research and management. For example, determining how the quality and quantity of important food sources, such as the sedges for heath mice and moths for yellow-footed antechinus, are affected by variation in fire regimes will help to determine appropriate fire management actions for these species. Furthermore, determining fire management strategies that promotes a diversity of food resources at both local and landscape scales would be beneficial, especially to species with broad diets such as bush rats and yellow-footed antechinus. By shedding light on the dietary requirements of three native mammal species and changes in resource use over time after fire, this study provides guidance to land managers to conserve populations of small mammals across the landscape through appropriate fire management.

# 4. FINE-SCALE RESOURCE SELECTION OF YELLOW-FOOTED ANTECHINUS (*Antechinus flavipes*) IN SOUTH-WEST VICTORIAN HEATHY WOODLANDS

## 4.1. Abstract

Understanding how animals select resources is essential in ecology in order to gain important insights into the survival and persistence of animal populations. Resource selection is hierarchical in nature, and various factors can drive patterns of species occurrence and abundance at different scales. For many species research data on drivers of distribution at landscape scales is abundant, but studies are scarce on which resources are selected for at a fine scale (e.g., within individual home ranges for foraging). Structural resources such as vegetation and vegetation-derived attributes are used by small mammals as foraging substrates as well as refuges to avoid predators. Therefore, exploring foraging movements of small mammals can provide insights on the structural resources that individuals select for while foraging. We aimed to identify the resources that are utilized by yellow-footed antechinus (*Antechinus flavipes*) in foraging events within their home ranges. Individuals were live trapped and radio transmitters were attached to healthy individuals, movements were detected, and habitat resource assessments were carried out. We utilized the 'Resource Selection Study Design III' for this study, which identifies individuals, and resource use and resource availability is defined at the individual level. Our findings indicate that the foraging behaviour of yellow-footed antechinus is influenced by the density of the understory;

consistent with the findings of previous studies on similar-sized mammals. Our data suggests that individuals tend to choose locations with denser vegetation for foraging as a predator avoidance strategy. However, the understorey vegetation of the study area is affected by seasonal natural fires as well as planned fires.  Therefore, further studies are critical to identify what structural resources are used by species in response to the changes of vegetation cover due to disturbances such as fires.

## 4.2. Introduction

Understanding how animals select resources in their habitats and investigating the underlying mechanisms can provide insights into how patterns of resource selection can influence the survival and persistence of animal populations. Resource selection is a spatially and temporally scale-sensitive process where each order of selection is constrained on selection made in former levels (Mayor *et al.,* 2009, Brennan *et al.,* 2019, Johnson, 1980). In order to understand the relationship between animal species and their environment, it is important to recognise the hierarchical nature of resource selection, because different factors can affect a species at different scales which can be misleading (Mayor *et al.,* 2009, Johnson, 1980).

To further clarify the selection of resources, multiple orders of selection have been defined based on scale. The First order of selection is defined as the geographic range of a species, the Second order of selection is defined by the selection of home range within a landscape, and the Third order of selection is defined by the specific habitat resources an individual selects within its home range. The Fourth order of selection is the actual procurement of a particular resource within the Third order resource (Brennan *et al.,* 2019, Johnson, 1980). Therefore, *Third* and *Fourth order of resource selection* occurs within the home range of individual animals. The habitat resources that an animal uses within a home range can broadly be categorised into structural resources in the context of the *Fourth order* of selection of resources. Habitat structure can be defined as the amount, composition and three-dimensional spatial arrangement of resources in a location (McCoy *et al.*, 1990, Byrne, 2007, Manly *et al.*, 2007). In a forest or a woodland, habitat structure can be represented as the arrangement of vegetation and vegetation-derived resources such as understorey vegetation, dead wood and leaf litter (McElhinny *et al.*, 2005). Animals associate their movements with the habitat resources in order to acquire food, shelter and mates (Stapp, 1997, Wells *et al.*, 2008).

Moving to search for food is carried out regularly by active foraging animals to meet their daily energy requirements (Donihue, 2016). Therefore, an individual is required to make decisions on exploiting the resource environment under different situations such as the presence of competitors or predators (Arcis and Desor, 2003, Donihue, 2016, Koike *et al.*, 2008). Such movements will depend on habitat features as well as the life-history strategies of the species (Wells *et al.*, 2008, Nams, 2005). Studying the habitat attributes directly associated with animal movement is usually an effective approach to obtain data on how resources are selected within the home ranges of animals.

Australian ground-dwelling small mammals are a group of animals that are highly dependent on habitat structure for movement, survival and reproduction (Marchesan and Carthew, 2004, Spencer *et al.*, 2005, McElhinny *et al.*, 2005, McElhinny *et al.*, 2006). Important habitat structures include components such as shrub cover, coarse woody debris, tree hollows and leaf litter. Such features provide shelter, refuge from predators, nesting sites, nesting materials, foraging sites and food (Swinburn *et al.*, 2007a, Flanagan-Moodie *et al.*, 2018, Fox and Monamy, 1999, Morris *et al.*, 2000). However, many identified relationships between small mammals and habitat structure have been primarily assessed by relating animal abundance or occurrence to variation in structure across multiple scales (Masters, 1993, Rader and Krockenberger, 2006, Tokushima and Jarman, 2008, Swan *et al.*, 2015). Fewer studies have investigated habitat relationships at scales smaller than the home range where a more detailed understanding of resource selection by individuals can be obtained (Nimmo *et al.*, 2013, Jorgenson, 2004, Clarke, 2008). Individuals will have variations in perceiving the resource environment and differences in decision making (Mazza *et al.*, 2019). Therefore, individual variations in resource selection will be reflected in the persistence of the population (Haus *et al.*, 2020).

The yellow-footed antechinus (*Antechinus flavipes*) is a marsupial commonly found throughout eastern Australia, ranging from north-east Queensland to extreme south-east South Australia, with a disjunct population found in southwestern Australia (Crowther, 2002, Sumner and Dickman, 1998). At the landscape scale (*Second order of resource selection*), forest structure appears to have a strong correlation to the distribution of yellow-footed antechinus, with several studies showing that it has a positive response to coarse litter, rock cover, hollow tree density, coarse woody debris and other microhabitat vegetation conditions (Dickman, 1991b, Kelly and Bennett, 2008, Lada *et al.*, 2008, Moore *et al.*, 2014). However, except for information on the usage of den sites and tree hollows as shelters by individuals (Flanagan-Moodie *et al.*, 2018), little is known about the specific habitat resources individuals select within the home range (*Third order of resource selection*); specifically, the structural resources utilized by individuals while foraging.

### 4.2.1. Aims

We aimed to identify the resources that are utilized by yellow-footed antechinus in foraging events within their home ranges. Informed by past literature and the results from Chapter 2, we selected three main structural resource variables that may be associated with movements and foraging patterns of yellow-footed antechinus. The structural resources that were assessed in this study are vegetation structure, hollow bearing trees and logs (coarse woody debris). We hypothesised that, (i) some variables will be selected disproportionately to their availability in the landscape, and individuals will select foraging locations nonrandomly and (ii) species will select for coarse woody debris as a foraging substrate, favour areas with denser understory, and associate with hollow-bearing trees in preference to more open areas.

## 4.3. Methodology

### 4.3.1. Study area

This study forms a component of a larger project investigating the responses of animals to fire in a fragmented landscape (Delaney *et al.*, 2021, Nalliah *et al.*, 2021). The study area is located in south-western Victoria to the west of the town of Casterton (37°27’26” S, 141°2’13” E). The predominant vegetation type in this region is Heathy Woodland (Ecological Vegetation Community 48), where the canopy is dominated by *Eucalyptus* species such as brown stringybark (*Eucalyptus baxteri*) and desert stringybark (*E. arenacea)*, with the sparse understory dominated by grass trees (*Xanthorrhoea australis* and *X. caespitosa), Acacia* spp., *Banksia* spp., shrubs, sedges and forbs (Duff *et al.*, 2013a). These woodlands occur on sandy nutrient poor soils, displaying very low growth and decomposition rates (Cheal, 2010). The elevation above sea level lies between 75-131 m. The climate of the region is cool temperate with warm summers and cool to cold winters, with a mean annual rain fall of 647.9 mm and mean annual maximum and minimum temperatures of 20.2 °C and 8.3 °C respectively (Bureau of Meteorology, 2022).

### 4.3.2. Site Selection

The selected sites were a subset of sites from the larger landscape-scale study where sites were established using a restricted random protocol to sample a range of post-fire growth stages. These included sites that were 0.5 to 79 years post-fire, within three vegetation types following Cheal (2010). We initially selected a total of six sites; three sites from long-unburnt (time after fire 58 years to 79 years) and, as a contrast, three sites more recently burnt (time after fire nine years to 15 years), informed by the results from previous yellow-footed antechinus captures and habitat resource surveys (Chapter 2).

### 4.3.3. Elliott trapping, fitting radio collars and radio tracking

Trapping and radiotracking was carried out in the Autumn and winter of 2020. At each site 100 Elliott traps (33 cm × 10 cm × 10 cm) were deployed 10 m apart in a grid pattern. A piece of unbleached cotton was placed in the trap as an insulating material and the trap was covered with a plastic bag to protect animals from moisture. Traps were baited with a mixture of oats, peanut butter, golden syrup, and pistachio essence and checked between sunrise and 10 am for five to seven consecutive nights (500-700 trapping nights at each site), depending on rates of yellow-footed antechinus capture. Traps were closed during the daytime to reduce the stress on animals and bycatch. Individuals caught were identified to species level, weighed, head-body length and tail length measured, sexed, and identified as juveniles or adults and marked with a unique identifier using white correction fluid. We fitted 1 g Lotek© cable tie radio collars to individuals that weighed more than 20 grams so that collars were ≤ 5% of the body weight. We only fitted the collars to individuals if they were alert, responsive and visibly healthy. Collars were fitted in the morning between 6 am and 10 am. All collared animals were released at the site of the capture. Individuals were tracked using R–1000 Radio telemetry receiver and a VHF Yagi Directional Antenna (148 – 174 MHz frequency).

Tracking was conducted a maximum of three times per night between dusk and dawn for 5-6 consecutive nights per tracking week for 3 to 4 weeks. There was at least a four-to-five-days gap between the tracking weeks to reduce the stress on animals. An animal was identified and detected using the homing-in technique where a signal is followed towards the signal's greatest strength (Fattebert *et al.*, 2015). Additionally, we attempted to circle around the animal at an approximate distance of 2-5 m to determine the precise location and used the signal direction to recognise if the animal moved while being tracked. Once the animal was located, the location was saved using a Garmin GPS. Initially a set of points were obtained for each animal to locate their den sites during the daytime (3 to 5 fixes for each animal). However, the main focus of the study was to obtain night-time foraging locations, rest of the sampling points were obtained at the night-time. At the end of the tracking period, Elliot traps were placed at each individuals' activity centre to recapture individuals and remove collars.

### 4.3.4. Resource variable selection and habitat surveys

We considered the GPS points obtained for each individual as 'used' points (Appendix B, b-1), and a random set of similar number of points were created as 'available' points. To define a practical area for the available points with the assumption that all areas within the home range were available, we created potential home ranges (polygons) for each individual by producing a minimum convex polygon, using the minimum bounding geometry function in data management toolbox in Arc GIS software (ArcMap 10.8). A 20-m buffer was added to each polygon margin. This minimum convex polygon was used as the initial reference for creating available points. To this aim, a set of random points were generated using the data management toolbox in Arc Map. Habitat assessments were carried out by referencing these used and available GPS points.

An earlier study (Chapter 2) suggested that the probability of occurrence of yellow-footed antechinus in the study area was related to the presence of hollow-bearing trees and vegetation cover. Informed by these results and previous literature (Kelly and Bennett, 2008, Moore *et al.*, 2014, Lada *et al.*, 2008) we selected three major habitat attributes overall: vegetation, trees and logs (coarse woody debris) (Table 1).

At each used or available point, habitat assessments were conducted within 5 m radius plots (Figure 4. 1). Vegetation structure was measured using the point intercept method at 20 sampling points (total of 100 points collectively in each plot) positioned at 1 m intervals along a cross-section centred on each point and extending 5 m out. Each arm extended along cardinal bearings for consistency. A 2-metre structure pole was held vertically at each sampling point and the presence and absence of vegetation functional groups (Table 1) was recorded within five height classes (0-50 cm, 50-100 cm, 100-200 cm, 200cm-canopy and canopy). A densitometer was used to record vegetation above 200 m. Logs (coarse woody debris, ≥5cm diameter and ≥50cm long) were measured along each arm of the cross (Figure 4. 1). Each quarter of the plot was used to record tree and tree hollow attributes, the diameter at the breast height was recorded for each tree, and the presence and absence of tree hollow classes (hollow class 1—tree hollows diameter < 5 cm, hollow class 2—tree hollows with diameter 5 cm - 10 cm, hollow class 3—tree hollows diameter > 10 cm) for each tree was recorded.

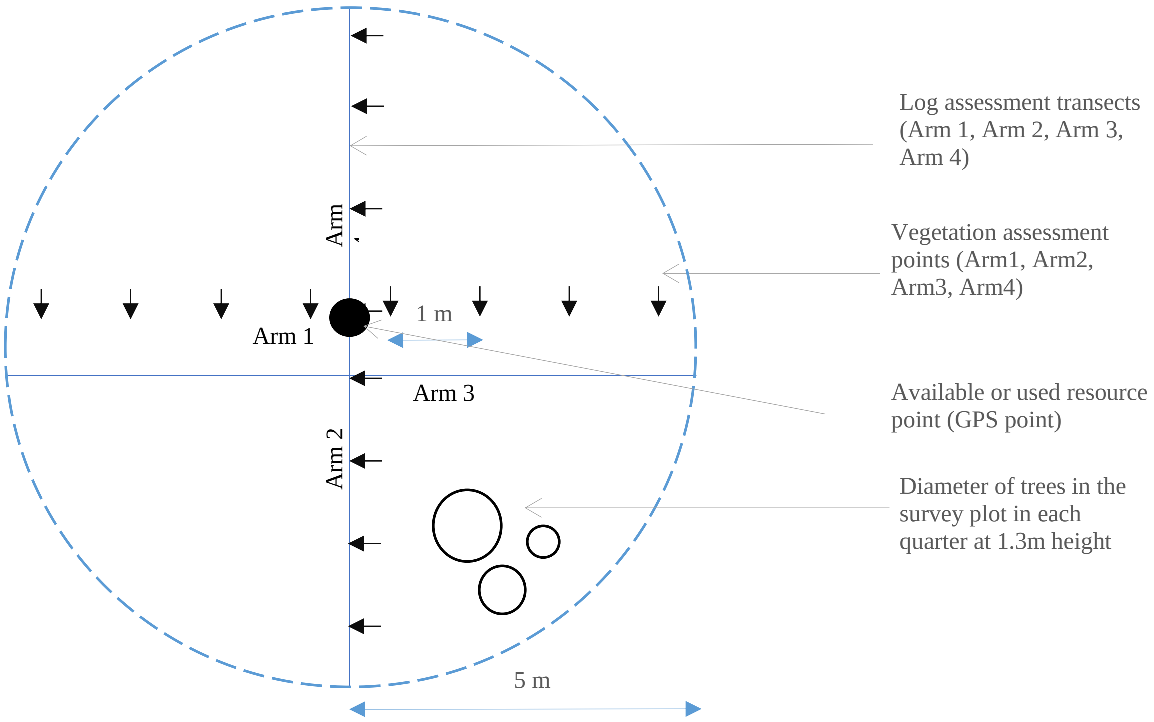


*Figure 4. 1 Structural attributes were measured using a 5 m radius plot, in each plot vegetation assessments were carried out on vegetation assessment points (Arm1, Arm2, Arm3, Arm4) and logs were assessed along log assessment transects (Arm 1, Arm 2, Arm 3, Arm 4). Diameter of trees in each quarter in the plot was measured at 1.3 m height and all trees were scanned for hollows and Prescence and absence of tree hollow classes (Hollow class 1—tree hollows diameter < 5 cm, hollow Class 2—tree hollows with diameter 5 cm to 10 cm, hollow Class 3—tree hollows diameter > 10 cm) for each tree was recorded.*

*Table 4. 1 Habitat variables measured during the survey*

| **Habitat Attribute** | **Measured characteristic** | **Description** | **Measurement** |
|---|---|---|---|
| **Overall Vegetation** | Vegetation height class | Five height classes, 0 to 50 cm, 50 to 100 cm, 100 cm to 200 cm, 200 cm to canopy and canopy | Presence/Absence |
| **Trees** | Diameter at the breast height | Diameter of the tree | cm |
| | Tree hollow classes | Hollow Class 1—tree hollows diameter < 5 cm | Presence/Absence |
| | | Hollow Class 2—tree hollows with diameter 5 cm to 10 cm | Presence/Absence |
| | | Hollow Class 3—tree hollows diameter > 10 cm | Presence/Absence |
| **Logs** | Log diameter | Fallen logs not attached to roots that are >5 cm diameter and >50 cm length | cm |
| | Charring | Evidence of the log being burnt- charred surface | Presence/Absence |
| | Hollows | Presence of hollows in logs | Presence/Absence |

### 4.3.5. Data analysis

In traditional resource selection studies, the resources that are assumed to be accessible to animals are denoted as the *available resources* and within these accessible resources, resources that are being actually acquired are denoted as *used resources* (Johnson, 1980, Manly *et al.*, 2004, Thomas and Taylor, 2006). The sampling protocols of resource selection studies are generally based on four designs explained by Johnson (1980). We used ‘Resource Selection Study Design III’, where individuals are identified and resource use and resource availability is defined at the individual level (Manly *et al.*, 2004). Data analysis was carried out within the R statistical environment (R Core Team, 2018) using two approaches: (i) nMDS ordination and PERMANOVA to compare used and available resource locations, and (ii) generalised linear models (GLMs) to explore the relationship between the habitat resources and used and available resource locations for individuals.

### 4.3.6. Exploratory data analysis

Initially, exploratory data analysis of habitat variables was undertaken to investigate the distribution of data and to identify trends and outliers. These variables were converted into suitable values such as proportions or counts for further analysis. Relationships between resource variables were explored using correlation analysis; where there were groups of correlated variables (Pearson’s $r > 0.6$), a single representative variable from each group was selected for subsequent analysis (Table 2).

### 4.3.7. Ordinations

We created a dissimilarity matrix (Euclidean distances) of selected variables after standardising the data (Table 2). The matrix was analysed using nonmetric multidimensional scaling (NMDS) using the R package “vegan” (Oksanen *et al.*, 2020) and results displayed graphically as two-dimensional representations of the NMDS results (bi-plots). Initially, we pooled the data from the two sites in the analysis; however, the bi-plot indicated a clear separation of sites (site 1: 4 individuals and site2: single individual), so we subsequently created separate matrices for each site. The used and available resources were compared using two-way permutational analysis of variance (PERMANOVA - (Anderson *et al.*, 2008) with site (1, 2) and resources (used, available) as orthogonal factors.

### 4.3.8. Generalized linear models

We created generalized linear models (GLMs) for each individual animal to understand the selection patterns for and against selected habitat variables. We included multivariate models for the three types of resources (vegetation structure, tree and tree hollow attributes and log attributes (Table 2)) in additive combinations. The Akaike Information Criterion corrected for small sample size (AICc) was used to compare the GLMs, and model ranking was completed using the R package MuMIn (Bartoń, 2020). Models were ranked from most parsimonious to the least parsimonious using delta AICc and Akaike weight. Individual animals were included as the random effect for GLMMs, and binomial error distribution was used in the analysis. GLMMs were created using the package lme4 (Bates *et al.*, 2015) and GLMs were created and analysed using the base R package.

## 4.4. Results

Elliott trapping resulted in the capture of 15 individuals at three sites (Appendix C, c-1), comprising 10 females and five males. We attached radio transmitters to 11 individuals. However, six of these animals could not be located soon after collar attachments. Eventually we were able to collect data from five individuals (three females and two males) with 180 radio tracking points collectively using the homing-in method. Of the five individuals, four were captured at one study site (site 1), whereas the remaining female was captured in a separate site (site 2). For the ease of identification henceforth the five yellow-footed antechinus individuals will be termed as YFA1 (15 radio tracking points with 15 random points), YFA2 (15 radio tracking points with 15 random points), YFA3 (15 radio tracking points with 15 random points), YFA4 (15 radio tracking points) (from site 1), YFA5 (30 radio tracking points with 30 random points) (from site 2).

### 4.4.1. Ordinations

Bi-plots indicated a low level of separation of centroids with considerable overlap between used and available locations (Figure 4. 2). The PERMANOVA results indicated a strong effect of site (pseudo-F = 384.77, P = 0.001) (where points cluster separately on initial ordination) and a weak difference between used and available locations (pseudo-F = 3.62, P = 0.03) (Table 3). This pattern is consistent at both sites as indicated by the non-significant interaction term (pseudo-F = 0.91 P = 0.37).

### 4.4.2. Generalized linear models

Compared to the tree and log attributes, the vertical vegetation layer was a better predictor of individual yellow-footed antechinus overall foraging resource usage (Figure 4. 3). Specifically, for YFA1, the 50cm to 100 cm vegetation layer was significantly a better predictor, whereas for YFA2, the 200 cm to canopy layer was a better predictor. For YFA3, the 0 cm to 50 cm vegetation layer was a better predictor and it correlated positively, whereas the 50 cm to 100 cm vegetation layer correlated negatively for YFA3 (Table 4) (Figure 4. 3). The best model describing YFA4 included tree attributes, however interactions were not statistically significant. Nevertheless, vertical vegetation cover 0-50 cm and 200 cm to canopy layers were selected as the second-best models with a statistically significant positive interaction for YFA4 (Table 4) (Figure 4. 3). Although the best model for YFA5 included log attributes, none of the models were statistically significant.

*Table 4. 2 Variables used in model building, these variables were selected from an initial set of variables by creating a correlation matrix with all the candidate variables and examining Pearson's correlation coefficients. Variables with a correlation coefficient of ≤ 0.6 were selected for constructing models, where there*

| **Variable** | **Description** | **Mean (min - max)** | **Units** | **Abbreviation** |
|---|---|---|---|---|
| 0 to 50 cm Vegetation cover (Ground cover) | Frequency of vegetation (out of 20 points) | 13.92 (6.00 - 16.00) | Proportion | 0_50 |
| 50 to 100 cm Vegetation cover (Small shrub layer) | Frequency of vegetation (out of 20 points) | 9.05 (0.00 - 17.00) | Proportion | 50_100 |
| 100 to 200 cm Vegetation cover (Medium shrub layer) | Frequency of vegetation (out of 20 points) | 2.35 (0.00 – 8.00) | Proportion | 100_200 |
| 200 cm to Canopy vegetation cover (Understory layer) | Frequency of vegetation (out of 20 points) | 5.13 (0.00 – 19.00) | Proportion | 200_Can |
| Canopy vegetation cover | Frequency of vegetation (out of 20 points) | 5.91 (0.00 – 19.00) | Proportion | Can |

| | | | | |
|---|---|---|---|---|
| (Canopy) | | | | |
| Hollow log volume | Log volume per unit area calculated using the diameter of the logs and the length of the transect | 0.96 (0.00 – 10.00) | $m^3$ $ha^{-1}$ | hollow_logs |
| Charred logs | Total counts of charred logs | 0.45(0.00 – 5.00) | Counts | charred_logs |
| Hollow bearing tree density | Number of hollow-bearing trees per a unit area | 0.72 (0.00 – 4.00) | $m^{-1}$ | tree_hollows |
| Stem Basal area | Sum of the stand basal areas of all trees (live and dead) | 0.002 (0.00 – 0.01) | $m^2 ha^{-1}$ | stand.dbh |

*Table 4. 3 two-way PERMANOVA results with site (1,2) and resources (used, available) as orthogonal factors*

| **Terms** | **df** | **Sums of squares** | **Mean of squares** | **Pseudo-*F*** | **$R^2$** | **P** |
|---|---|---|---|---|---|---|
| Used and available points | 1 | 860 | 860 | 3.62 | 0.06 | 0.03* |
| Site | 1 | 91485 | 91485 | 384.77 | 0.68 | 0.00*** |
| Used and available points site | 1 | 217 | 217 | 0.91 | 0.00 | 0.37 |
| Residuals | 176 | 41846 | 238 |  | 0.31 |  |
| Total | 176 | 134408 |  |  | 1.00 |  |

*Table 4. 4 Habitat selection models for individual yellow-footed antechinus derived from generalized linear models   Akaike's information criterion was used to (AICc) rank the models. Model 1 includes the predictor variables of vertical vegetation, Model 2 incudes the predictor variables of logs attributes and Model 3 includes the predictor variables of tree attributes and tree hollows.*

| **Individual** | **Model (variables)** | **ΔAICc** | **r2** | **Term** | **Estimate** | **CI 95%** | **p** |
|---|---|---|---|---|---|---|---|
| YFA1 | Model 1 | 0.00 | 0.33 | | | | |
| | (0_50+ 50_100+ 100_200+ 200_can+ can) | | | | | | |
| | | | | 0_50 | 0.19 | -0.85, 1.33 | 0.73 |
| | | | | 50_100 | 2.24 | 1.01, 3.87 | 0.00 ** |
| | | | | 100_200 | -0.47 | -1.37, 0.368 | 0.27 |
| | | | | 200_can | -0.65 | -1.57, 0.09 | 0.11 |
| | | | | can | -0.51 | -1.33, 0.23 | 0.18 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Model 3 | 17.24 | 0.07 | | | | |
| | (tree_hollows + stand.dbh) | | | | | | |
| | | | | tree_hollows | -1.20 | -2.67, -0.16 | 0.06**.** |
| | | | | stand.dbh | 0.42 | -0.37, 1.18 | 0.26 |
| | Model 2 | 22.38 | 0.00 | | | | |
| | (hollow_logs + charred_logs) | | | | | | |
| | | | | hollow_logs | -0.15 | -0.94, 0.50 | 0.67 |
| | | | | charred_logs | 0.22 | -0.46, 0.87 | 0.49 |
| YFA2 | Model 1 | 0.00 | 0.14 | | | | |
| | (0_50+ 50_100+ 100_200+ 200_can+ can) | | | | | | |
| | | | | 0_50 | 0.64 | -0.11, 1.53 | 0.11 |
| | | | | 50_100 | -0.58 | -1.55, 0.32 | 0.21 |
| | | | | 100_200 | -0.26 | -1.24, 0.60 | 0.55 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | 200_can | 0.80 | 0.13, 1.60 | 0.03 * |
| | | | | can | -0.23 | -0.94, 0.43 | 0.50 |
| | Model 2 | 2.50 | 0.01 | | | | |
| | (hollow_logs + charred_logs) | | | | | | |
| | | | | hollow_logs | -0.32 | -1.39, 0.50 | 0.49 |
| | | | | charred_logs | -0.00 | -0.94, 0.73 | 0.98 |
| | Model 3 | 2.54 | 0.01 | | | | |
| | (tree_hollows + stand.dbh) | | | | | | |
| | | | | tree_hollows | 0.33 | -0.41, 1.06 | 0.36 |
| | | | | stand.dbh | -0.20 | -1.11, 0.53 | 0.62 |
| YFA3 | Model 1 | 0.00 | 0.24 | | | | |
| | (0_50+ 50_100+ 100_200+ 200_can+ can) | | | | | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | 0_50 | 1.58 | 0.62, 2.92 | 0.00 ** |
| | | | 50_100 | -1.64 | -2.99, -0.60 | 0.00 ** |
| | | | 100_200 | 0.79 | -0.26, 1.97 | 0.15 |
| | | | 200_can | 0.26 | -0.589, 1.10 | 0.53 |
| | | | can | -0.44 | -1.33, 0.31 | 0.28 |
| Model 2 (hollow_logs + charred_logs) | 9.89 | 0.04 | | | | |
| | | | hollow_logs | -0.31 | -1.46, 0.60 | 0.54 |
| | | | charred_logs | -0.65 | -2.18, 0.32 | 0.29 |
| Model 3 (tree_hollows + stand.dbh) | 13.51 | 0.00 | | | | |
| | | | tree_hollows | -0.03 | -0.87, 0.71 | 0.95 |
| | | | stand.dbh | -0.02 | -0.89, 0.70 | 0.95 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Model 3 | 0.00 | 0.12 | | | | |
| YFA4 | | | | | | | |
| | (tree_hollows + stand.dbh) | | | | | | |
| | | | | tree_hollows | 0.36 | -0.39,1.12 | 0.32 |
| | | | | stand.dbh | 0.59 | -0.13, 1.36 | 0.12 |
| | Model 1 | 0.74 | 0.19 | | | | |
| | (0_50+ 50_100+ 100_200+ 200_can+ can) | | | | | | |
| | | | | 0_50 | 1.26 | 0.38, 2.45 | 0.01 * |
| | | | | 50_100 | -0.11 | -0.91, 0.66 | 0.77 |
| | | | | 100_200 | -0.95 | -2.07, -0.06 | 0.06. |
| | | | | 200_can | 0.90 | 0.21, 1.72 | 0.02 * |
| | | | | can | 0.16 | -0.45, 0.79 | 0.60 |
| | Model 2 | 9.59 | 0.00 | | | | |
| | (hollow_logs + charred_logs) | | | | | | |

|  |  |  |  |  |  |  |  |
|---|---|---|---|---|---|---|---|
|  |  |  |  | hollow_logs | 0.02 | -0.78, 0.73 | 0.95 |
|  |  |  |  | charred_logs | -0.04 | -0.89, 0.64 | 0.91 |
| YFA5 | Model 2 | 0.00 | 0.01 |  |  |  |  |
|  | (hollow_logs + charred_logs) |  |  |  |  |  |  |
|  |  |  |  | hollow_logs | 0.24 | -0.38, 0.95 | 0.45 |
|  |  |  |  | charred_logs | -0.05 | -0.70, 0.57 | 0.85 |
|  | Model 3 | 0.45 | 0.00 |  |  |  |  |
|  | (tree_hollows + stand.dbh) |  |  |  |  |  |  |
|  |  |  |  | tree_hollows | 0.15 | -0.70, 1.00 | 0.73 |
|  |  |  |  | stand.dbh | -0.20 | -1.10, 0.63 | 0.63 |
|  | Model 1 | 5.22 | 0.03 |  |  |  |  |
|  | (0_50+ 50_100+ 100_200+ 200_can+ can) |  |  |  |  |  |  |
|  |  |  |  | 0_50 | 0.32 | -0.24, 0.95 | 0.28 |

| | | | | |
|---|---|---|---|---|
| | 50_100 | -0.30 | -0.89, 0.26 | 0.31 |
| | 100_200 | 0.00 | -0.52, 0.53 | 0.99 |
| | 200_can | -0.15 | -0.78, 0.38 | 0.60 |
| | can | 0.16 | -0.36, 0.70 | 0.544 |

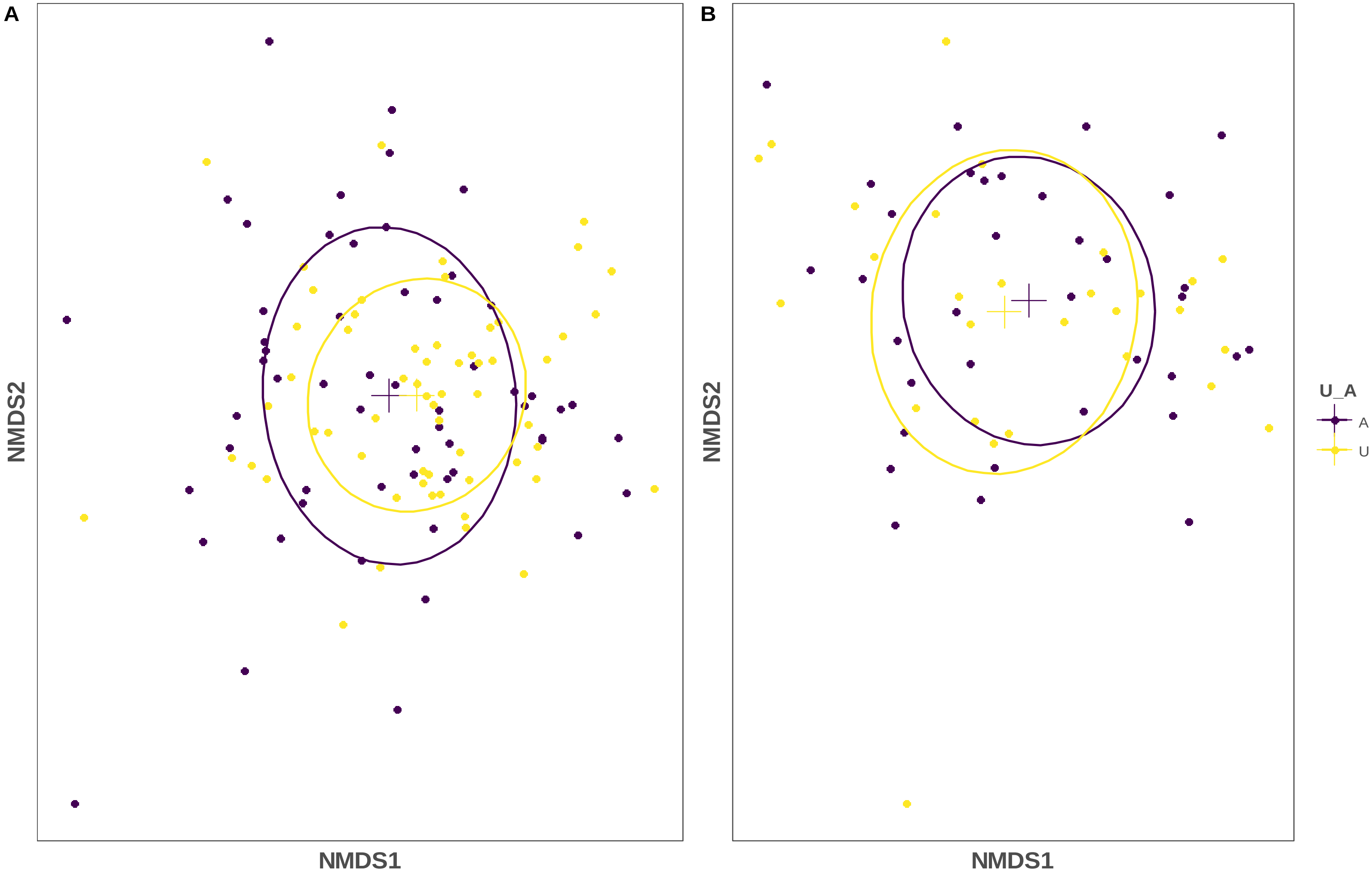


*Figure 4. 2 A – site 1, B – site 2: Two-dimensional ordination diagram for used (U) and available (A) resources. Ellipses represent the 95% confidence interval around the centroid for each variable.*

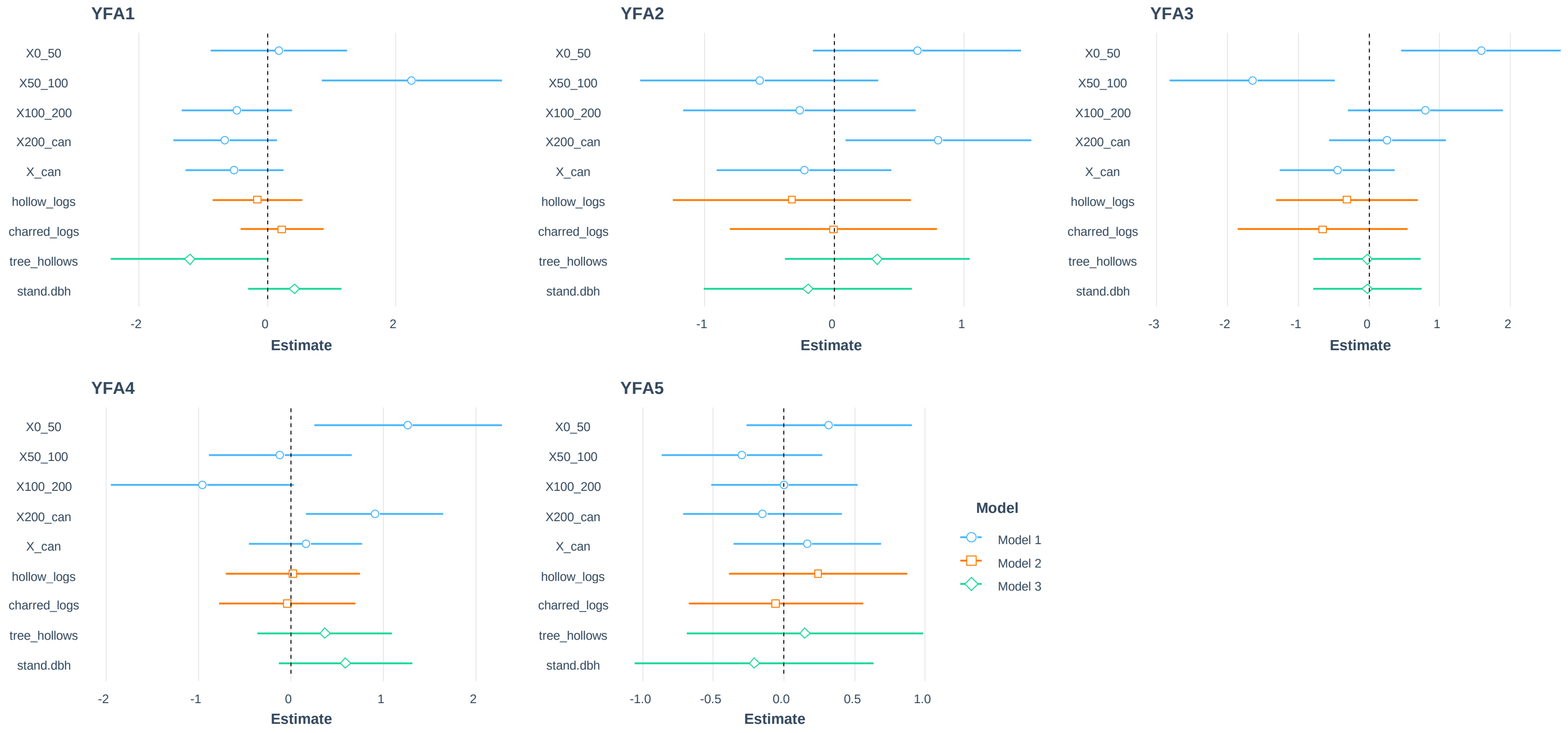


*Figure 4. 3 Parameter estimates with 95% CI limits for individuals for different variables. Model 1 includes the predictor variables of vertical vegetation, Model 2 incudes the predictor variables of logs attributes and Model 3 includes the predictor variables of tree attributes and tree hollows. Where confidence limits don't overlap zero, we considered a resource to be selected. A positive effect indicates selection for, and a negative effect indicates selection against a particular resource.*

## 4.5. Discussion

Understanding which structural resources animals utilize in foraging environments can provide critical insights into animal behaviour (Forester *et al.*, 2009). This information can be useful in conservation and land management, specifically in environments subject to regular disturbance events such as seasonal fires (Nimmo *et al.*, 2018). In this study we utilized radio tracking to understand the structural resources that yellow-footed antechinus individuals use while foraging. We focused on three habitat resources: overall vegetation; trees and logs (coarse woody debris) as the most prominent set of resources associated with the foraging movement. Our findings suggest that individuals move nonrandomly while foraging, and preferentially associate their movements with locations that has dense vegetation cover, compared to other resources.

The ordinations and the associated PERMANOVA results showed that there were differences between the locations individuals used and locations that were defined as available. This observation indicates that individuals utilise habitat nonrandomly while they moved for foraging. Non-random selection of foraging locations are related to the way resources are scattered throughout a foraging patch (Abrahms *et al.*, 2021). Therefore, selecting the locations that include preferred resources involves a series of behavioural choices of an individual, and it is related to the survival of the animal and, subsequently the persistence of the population (Orians and Wittenberger, 1991, Stapp, 1997, McElhinny *et al.,* 2006, Forester *et al.,* 2009).

When individual resource selection was examined, we observed that some habitat features were being consistently selected for and against. Results showed that individuals were using locations that had a disproportionately high vegetation density, and different individuals were associated with vegetation at different heights. When small mammals are foraging there is a risk of individuals being subjected to predation, particularly from introduced predators (Hradsky *et al.*, 2017). Individuals are more likely to use denser vegetation as a predator avoidance strategy, and this could be the driver of selecting locations with denser vegetation for foraging (Chute *et al.*, 1974, Glen *et al.*, 2009, Stokes *et al.*, 2004). This is consistent with a previous giving-up density experiment (Stokes *et al.*, 2004) on yellow-footed antechinus which reported that the number of meal worms consumed were higher under artificial netting provided to imitate shelter compared to open areas. Similar studies have indicated the preference of other small mammals to associate with cover that provides shelter when foraging. For example, a study carried out by Orrock *et al.* (2004) demonstrated that old-field mice (*Peromyscus polionotus*) removed more seeds from trays beneath sheltered areas compared to exposed areas.

Our study further confirms the importance of a dense understory for the yellow-footed antechinus foraging, consistent with the findings of past studies on other similarly-sized mammals (Marchesan and Carthew, 2004, Swinburn *et al.*, 2007b, Kelly and Bennett, 2008, Lada *et al.*, 2008, Moore *et al.*, 2014). Similar patterns of resource selection have been observed in the threatened heath mouse (*Pseudomys shortridgei*), which selected dense understorey in wet heaths (Cockburn, 1981, Nalliah *et al.*, 2021, Di Stefano *et al.*, 2011). Furthermore, in Chapter 3, we observed that yellow-footed antechinus consumes a diverse array of plant matter, in addition to invertebrate prey. Associating foraging with vegetation could facilitate an additional advantage where dietary requirements as well as predator avoidance can be obtained from the same resource. However, it should be kept in mind that this study is correlative, and there may be other factors that are correlated with dense vegetation that drive the observed patterns, such as specific food resources.

Although overall foraging location selection was associated with density in vertical vegetation layers, different individuals were associated with vegetation density at different heights. The two females (YFA2 and YFA4) at the same site were associated with both near-ground and near-canopy vegetation cover, whereas location selection for the two males (YFA1 and YFA3) was associated with the vegetation layers closest to the ground. However, the sample size was not sufficient to generalize the patterns observed between male and female individuals. It should be noted that although these relationships are a good fit for individuals, the causative relationship of these individual variations could be related to other vegetation layers, even though it was not evident from the models that were selected (Arif and MacNeil, 2022).

The lone female (YFA5) that was tracked at the second site did not show any significant selection to any of the resources. We observed that this individual was foraging in the daytime while other four individuals were observed foraging between the dusk and dawn. One possible reason for this variation could be different behavioural choices of an individual and differences in decision making due to variations in their cognitive perceptions depending on their age, sex and experiences within the home range (Mazza *et al.,* 2019, Haus *et al.,* 2020). Information about the heterogeneity of resource selection in individuals can help in understanding the plasticity of populations to changes in resource environments, since ultimately, individual variations will aid in shaping the population (Houston *et al.,* 1988, Haus *et al.,* 2020). However further investigation is required to determine if the differential selection of vegetation layers is a patch-related factor or related to population demographics of the yellow-footed antechinus.

Hollows are ideal structures for avoiding predators, and provides foraging patches containing invertebrates and fungi, therefore we expected yellow-footed antechinus to be associated with hollow bearing trees and hollowed logs while they are foraging within their home range (Dickman, 1986, Westerhuis *et al.,* 2019, Korodaj, 2007). In past studies, some of the yellow-footed antechinus populations were found to be foraging most frequently in areas with a high density of logs, and where rock crevices are present (Moore *et al.,* 2014, Lada *et al.,* 2008). In Chapter 2, the probability of occurrence for yellow-footed antechinus was associated with the presence of hollow-bearing trees; past studies have also indicated that they select hollow bearing trees for nesting (Kelly and Bennett, 2008, Moore *et al.*, 2014, Lada *et al.*, 2008, Flanagan-Moodie *et al.*, 2018). In the study site, coarse woody debris (logs) and hollow bearing trees are abundant, and these resources are seemingly used, but only in proportion to their availability in the landscape. Further study of fine-scale resource selection in landscapes where these resources are more limited in abundance would be valuable to determine their importance in different ecological contexts.

Although we were unable to incorporate fire into the study design due to low capture rates, the study area is subjected to planned and natural fires. In habitats mediated by disturbances such as fires, structural resources alter as the patch goes through regeneration, requiring animals to likewise alter their movement and behaviour regularly (Fisher *et al.,* 2009, Miehs *et al.,* 2010, Flanagan-Moodie *et al.,* 2018, Fox, 1982, Fox and Monamy, 2000). The information obtained from the resource selection of yellow-footed antechinus indicates that, within the home range scale, individuals require dense vegetation for the foraging movements, a resource that is impacted by fire. Fire regimes in naturally fire-mediated environments are changing due to climate change; and as a consequence, severe unprecedented wildfires are becoming more common (Di Virgilio *et al.,* 2020, Ward *et al.,* 2020, Abram *et al.,* 2021). For example, the megafires in Australia during 2019 to 2020 were the largest fire events that occurred since the establishment of European settlements, with many species losing at least half of their habitat and some species over 80% of their habitat (Wintle *et al.,* 2020). Therefore, natural responses to changes that populations have adapted to may not be sufficient for the survival of populations, and research data on the resources that animals use within their home ranges is critical to identify and conserve refugia for animals.

### 4.5.1. Limitations of the study

In this study, we employed radio tracking to locate foraging yellow-footed antechinus; a technique that has been used for tracking small mammals and other animals in ecological studies for over fifty years (Tremblay *et al.,* 2017). However, the process of obtaining locations for animals is time consuming and resulted in low numbers of GPS points available for individual animals. Furthermore, there is a potential for animals to perceive the tracker as a predator or a threat and this could bias the results towards potential anti-predator behaviours. However, this is an important aspect of the movement of individuals, and therefore the GPS points that are obtained via field trials would be related to a valid behaviour. Furthermore, animals did not appear to flee when the trackers approached them, and therefore we can infer that individuals were not disturbed to an extent that affected the pattern of their general and regular movements. Recent developments in the Unmanned Aerial Vehicles technology have facilitated the development of novel and sophisticated methods to obtain radio signals from collared individuals within shorter timeframes, however pinpointing the exact locations an animal has used is more difficult (Tremblay *et al.,* 2017, Muller *et al.,* 2019). To further understand the usage of space withing the home range in a finer scale, fluorescent powder markers and spool and line tracking could be employed, however these techniques have some drawbacks as well (Kalcounis-RÜPpell *et al.,* 2001, Kearney *et al.,* 2007, Lees *et al.,* 2022).

## 4.6. Conclusion

The findings of this study demonstrates that the most important structural resource for yellow-footed antechinus foraging is understory vegetation. The study area is subjected to natural as well as planned fires, with fire events substantially altering the density and spatial patterning of understorey vegetation (Penman *et al.,* 2008, Holland *et al.,* 2017). Furthermore, temporal changes in habitats are affected by numerous independent and interacting environmental variables such as fire severity, inter-fire intervals, rainfall and herbivory (Whelan, 1995, Flanagan-Moodie *et al.*, 2018, McLauchlan *et al.*, 2020, Klop *et al.*, 2007). Therefore, further studies are essential to identify the critical structural resources utilized by yellow-footed antechinus, and how spatial arrangement of vegetation cover responds to disturbance events, in order to implement effective conservation and management strategies for this species.

# 5. SYNTHESIS

Inappropriate fire regimes are altering fire-mediated habitats globally and are creating altered resource environments, threatening flora and fauna (Kelly *et al.,* 2020). Although the direct effect of fire is often mortality, in environments where fires are occurring these disturbances affect resource availability and hence can influence species long after a fire has passed through a habitat (Smith, 2018, Fox, 1982, Fairman *et al.*, 2016, Chick *et al.*, 2016, Miehs *et al.*, 2010). Therefore, understanding how animals are using resources in post-disturbance environments such as fire-mediated habitats is important for both conservationists, wildlife biologists and land managers.

The selection of resources by animals is a spatially and temporally hierarchical process (Pavlacky *et al.*, 2012, Mayor *et al.*, 2009). Resources selected at one level might not be selected in another level and studying only one spatial level of a resource might lead into inaccurate conclusions of the links between animals and habitats (Kolka *et al.,* 2014, Pellegrini *et al.,* 2018). Links between resources and animals should be analysed at multiple levels to gain a more complete understanding of resource selection. Johnson (1980) introduced four levels of resource selection: *first order selection* (range of the species), *second order selection* (selection of the home range), *third order selection* (specific habitat resources selected within a home range), *fourth order of selection* (actual resource procurement within the home range).

In this thesis I have set up a framework to investigate resource selection of small mammals after fire at multiple spatial scales. Details of resource selection was undertaken using both conventional methods such as live trapping and radiotracking, as well as a novel molecular analysis method, eDNA metabarcoding.

The overarching aim of this thesis is to find links between fire, environmental gradients, resources and small mammals at multiple scales. In this chapter I summarise the findings of the three data chapters (Chapter 2, 3 and 4) and discuss the results of my work connecting the three data chapters in a broader perspective, considering possible future directions. Summary of key findings of each chapter are as follow (Table 5.1).

*Table 5.1 The key findings of the three data chapters*

| **Chapter 2** | |
|---|---|
| **Title**:<br>Small mammals respond more strongly to environmental gradients and habitat resources than fire history and foraging resources in a woodland ecosystem | |
| **Objectives** | **Key Findings** |
| To determine the interrelationships between fire, resources, and small mammals at a range of spatial scales from the larger landscape scale to the smaller scale relevant to the home ranges of small mammals.<br>The four Australian small mammal species selected for this chapter were: yellow-footed antechinus (Antechinus flavipes), heath mouse (Pseudomys shortridgei), bush rat (Rattus fuscipes) and house mouse (Mus musculus). | 1. Distribution of three species was not uniform throughout the landscape, with yellow-footed antechinus having a more northerly distribution, the bush rat a more southernly distribution, and heath mouse found in both northern most and southern most ends of the study area. The house mouse showed no spatial trend.<br>2. Fire had a clear effect on some of the habitat resource variables such as the medium shrub layer, canopy layers, hollowed logs and tree size.<br>3. Compared to time since fire, habitat and environmental variables were better predictors of occurrence for all four small mammal species.<br>4. The spatial distribution of annual rainfall was negatively correlated with the occurrence of the yellow-footed antechinus and positively with the bush rat. Surface soil carbon content was positively correlated with the occurrence of the bush rat and house mouse. However, heath mouse occurrence did not correlate with any of the environmental variables that were considered in this study.<br>5. Yellow-footed antechinus occurrence was positively correlated to the presence of tree hollows in its home range. Occurrences of all three species of native small mammals (yellow-footed antechinus, bush rat and heath mouse) were positively correlated with the vegetation cover within their |

| | |
|---|---|
| | home ranges; however, the introduced house mouse occurrence was negatively correlated with litter biomass.<br>6. Surprisingly none of the small mammals responded to invertebrate biomass as we expected. |

## Chapter 3

**Title**:

Using eDNA metabarcoding to understand the effect of fire on the diet of small mammals in a woodland ecosystem

| **Objectives** | **Key Findings** |
|---|---|
| To utilize eDNA metabarcoding to obtain an improved understanding of the diet of three native Australian small mammal species: yellow-footed antechinus, heath mouse and bush rat in the study area and how diets are changing over time after fire. | 1. I was able to obtain a robust set of information on the diets of the three species in high taxonomic resolution, demonstrating that eDNA metabarcoding can be successfully employed to understand the diets of small mammals. This is the first known study that used eDNA metabarcoding to describe the diets of small mammals in fire-prone environments. The metabarcoding data allowed new insight into patterns of diet preferences of the three species.<br>2. All three species were found to be consuming high variety of food taxa within a single foraging bout. While the average number of diet items found in the scats of each species was similar, overall, the diets of the three species was different, with all three species consuming arthropods as well as plants. For all three species, in some individuals, diets were detected as plants-only. However, there were no individuals found with detected diets of arthropods-only.<br>3. he three species shifted their diet in response to post-fire growth stages, with yellow-footed antechinus diet changing incrementally from the recent post-fire growth stages to the late post-fire growth stage. In contrast bush rat diet was different between the three growth stages, whereas for the heath mouse the mid post-fire growth stage was different from the recent post-fire growth stage, Again the differences between the growth stages for all three species was a cumulative differences between the detected food taxa.<br>4. A set of cryptic taxa was identified within the diet of the three species which would have gone unnoticed if histological analyses were carried out; |

specifically, if animals are foraging on arthropods with soft body parts such as moths or feeding on plant sap, nectar or in some cases pollen.

5. Yellow-footed antechinus consumed a wide array of arthropod taxa, specifically moths, beetles, cockroaches, flies and lacewings. Moths consisted of the bulk of the consumed arthropods; however, it was surprising to not detect arachnids in antechinus' diets as suggested by past literature. Myrtles, pines, ferns and daisies were among the top plant material consumed.
6. One of the key novel factors resulted from this study was the detection of high number of plant taxa in the predominantly insectivorous yellow-footed antechinus diet.
7. Much of the micro-histological studies on yellow-footed antechinus scat did not report any plant matter in the antechinus diet and yellow-footed antechinus was deemed as an insectivore generally. However, results from my study indicated that scats of yellow-footed antechinus contained a high diversity of plant. One of the key issues with analysing scat samples that have both plant and animal material (specifically of omnivores) is secondary predation. In metabarcoding studies, multiple markers for different taxa such as plants, arthropods and fungi are used detect the range of diets. Due to the high detection precision of the eDNA metabarcoding, it is possible that some of the plant matter that has been consumed by invertebrates could be detected in the final analysis. Therefore, it is important to examine if the scat contained plant material as primary prey specifically in instances where past records are limited. However, one micro histological study carried out in the same landscape (York et al., 2022) indicated that yellow-footed antechinus scat containing a considerable proportion of plant tissue.
8. Bush rats consumed moths, flies and beetles, with the most frequent arthropod a species of a carabid beetle. Plants such as myrtles, daisies and legumes were found in high frequencies.
9. Heath mouse diet predominantly consisted of plants such as rushes and sedges, with the arthropod consumption low, including species of moths, beetles, flies and spiders.
10. Although there was an overlap between the diets of the three species to some extent, it was found out that species have, overall, distinctive diet items based on variation in their frequency of occurrence across individuals. This difference was a

| | |
|---|---|
| | consequence of cumulative differences from a range of different diet taxa. |
| **Chapter 4** | |
| Title | Fine-scale resource selection of Yellow-footed Antechinus (Antechinus flavipes) in south-west Victorian heathy woodlands |
| **Objectives** | **Key Findings** |
| To examine how structural resources are being utilized by yellow-footed antechinus in their home ranges while foraging. | 1. There were differences between the locations individuals used for foraging compared to the random resource locations, which suggests that individuals are moving nonrandomly through their home ranges while foraging.<br>2. Compared to the other resources vertical vegetation layers were a better predictor of individual yellow-footed antechinus overall structural foraging resource usage. Although in Chapter 2 the occurrence of yellow-footed antechinus was predicted by abundance of hollow bearing trees (in the third order of resource section), in the fourth order of resource selection at the home range scale this was not consistently selected. This indicates that yellow-footed antechinus selects different resources at different levels demonstrating the importance of investigative the resource selection in different levels.<br>3. All individuals preferentially selected locations with high vegetation cover compared to other resources while foraging. This pattern was consistent between individuals. However, all individuals did not select the same vegetation layer and there were differences between males and females. However, sample size was insufficient for further analysis of the preference based on sex of animals. |

## 5.1. Structural and foraging resources of small mammals at landscape scales

In Chapter 2 small mammals were live trapped and habitat assessments were carried out to understand the influence of fire, environmental variables, structural resources and food (invertebrates) resource on small mammal occurrence. The four species studied for this chapter were: yellow-footed antechinus (*Antechinus flavipes*), heath mouse (*Pseudomys shortridgei*) and bush rat (*Rattus fuscipes*) and house mouse (*Mus musculus*). Presence and absence of species was analysed against time since fire, environmental and resource variables using generalized linear mixed models (GLMs).

Results of Chapter 2 (Table 5.1) supports previous findings in the literature where time since fire was a poor predictor for the occurrence of small mammals (Di Stefano *et al.,* 2011, Swan *et al.,* 2015, Burns *et al.,* 2019, Rainsford *et al.,* 2020a). This is most likely related to the variable relationship between fire and habitat resources in heathy woodlands, a pattern also seen in other forests where the dominant regeneration strategy is resprouting (Rainsford *et al.,* 2020a).

Furthermore, the findings of Chapter 2 and in combination with those of the other data chapters suggest that animals are associating with available resources at different spatial scales. This further confirms that single management approaches are highly unlikely to benefit all the species within fire-prone landscapes. Therefore, plans to manage fire within the landscape should incorporate as many studies as practically feasible on different scales of resource requirements for different fauna within a landscape. Subsequently these can be used to tailor more comprehensive species-specific management actions in fire-mediated environments.

This study incorporated invertebrate biomass as a proxy for food resource availability for small mammals, as food resource selection has been often overlooked in studies carried out in post-fire environments. Invertebrates are an important resource and a crucial component in food webs, and three study species (yellow-footed antechinus, bush rat and house mouse) out of the four are known to feed on invertebrates, I expected a significant correlation with the invertebrate food resource availability. The lack of effect of biomass on species occurrence could be because biomass is a coarse measurement and does not sensitively capture food availability. This prompted the motivation for Chapter 3 to better understand what the small mammals are actually consuming in fire prone landscapes. Future study could investigate different indicators of invertebrates such as functional diversity, relative abundance of different groups or nutritional quality. Furthermore, now we have a higher resolution picture of what these species eat from Chapter 3. As such different collecting methods could be trialled (such as catching moths or other flying insects) to see if abundance of different invertebrate taxonomic groups is associated with small mammal distribution and abundance.

## 5.2. Foraging resources of small mammals; diets

In Chapter 3 I used novel eDNA metabarcoding technology to understand the effect of fire on the diet of the selected three small mammals:  the yellow-footed antechinus (*Antechinus flavipes*), the bush rat (*Rattus fuscipes*) and the heath mouse (*Pseudomys shortridgei*).

Although exploring what animals are foraging on is one of the most crucial and elementary factors to explore in ecology, obtaining accurate information on what animals are eating in their natural habitats is time consuming and can give low taxonomic resolution when traditional micro histological methods are used. However recent molecular biology advancements have permitted identifying food DNA in scats which can be used as an appropriate proxy to explore what animals are eating. This method is less time consuming compared to the micro-histological methods and can create high resolution taxonomic data if the reference libraries for metabarcoding are robust and complete. Scats were collected during live trapping of small mammals, then samples were analysed using the novel eDNA metabarcoding to understand the differences among the diets of the three species as well as the differences of diets between post-fire age classes. The eDNA metabarcoding detected the presence of different food species (ZOTUs- zero oriented operational taxonomic units) within each scat sample (individual) (Table 5.1). I used post-fire growth stages to characterise fire history. A combination of non-metric multidimensional scaling (NMDS), permutational analysis of variance (PERMANOVA) and similarity percentage (SIMPER) was used analyse the data.

In conventional methods of identifying food items in scat, results could only be obtained up to the coarse functional levels. In this chapter I was able to establish a robust set of high-resolution taxonomic data for the three small mammal species which adds to the body of knowledge of small mammals ecology. I was able to demonstrate that eDNA metabarcoding can be used to determine the diet changes of small mammals in post-fire environments. Similar methods can easily be employed to promptly quantify and qualify diets of animals living in different post disturbance environments. For example, my work has provided new information on the diet of the heath mouse, a threatened herbivore, I found that the diet of the species remains constant throughout the post-fire succession. When planned burns are designed this knowledge can be used to identify critical areas of heath mouse occupancy and carry out burns to favour conditions that are beneficial for heath mouse food species such as *Hypolaena fastigiata.* The diet analysis was carried out in a single point of time in the Austral summer and does not contain the information on how the diets are changing seasonally as the study was not carried out in other seasons. However small mammal diets tend to be subjected to seasonal changes (Luo and Fox, 1994), it would be beneficial to carry out a further work to understand the dietary changes of animals throughout the year. In the post fire context understanding the impacts of food availability is important specifically with unprecedented wildfires creating extreme biodiversity loss, having prior knowledge on the food sources that animals can utilize will help land managers in decision making. Specifically on which plants and animals to focus on restoration with regards to threatened species and native populations. This can help land managers and conservationists to understand how fires impact the ecological interactions of the post fire habitats and communities. Specifically in understanding the recovery and recolonization of animal populations.

The method of eDNA metabarcoding is only good as the strength of the reference taxonomic libraries prepared for different taxa. Reference libraries are used to match the DNA sequences obtained by the metabarcoding process can be matched to known species metabarcodes using databases such as NCBI (GenBank) (Stoeckle *et al.,* 2020). This type of study will become more powerful as the libraries improve over time. Investment in sequencing different underrepresented groups should be a priority for research.

Another caveat of the eDNA metabarcoding is the inability to quantify the particular food types for an example as a portion of the volume or the biomass. However, statistical and molecular methods are improving for eDNA metabarcoding which is a promising technique to be used in various ecological studies. A potential area of future research would invest in pairing eDNA metabarcoding with histological techniques to create quantitative measures of relative abundance of food items paired with high resolution quantitative data.

Analysing scats of animals in different trophic levels inhabiting post-fire environments using eDNA metabarcoding could potentially be used to describe species interaction networks. Such networks are valuable in determining the overall community changes happening in different post-fire environments. Furthermore, dietary data can be used to understand how niche partitioning will be influenced by different disturbance factors such as fire. Additionally, due to the simple method of collecting scat samples for eDNA metabarcoding and the accurate results, it is an ideal method to study seasonal diet changes of animals. Therefore, eDNA metabarcoding has a great potential in obtaining data for answering various important ecological questions specifically in disturbance environments.

## 5.3. Foraging resources of small mammals; structural resources

In Chapter 4, I aimed to identify the structural resources used by yellow-footed antechinus during foraging events. As animals move within their home ranges in order to carry out foraging to meet their resource requitements, they will interact with structural resources within the surroundings, both to avoid predators and to get a better advantage in competing for resources. In fire-mediated environments, habitat structure become an important factor for actively foraging small mammals. Investigating the structural resources these animals are associating with can give important insights in how the landscape should be managed in order to create resource rich habitat patches. The yellow-footed antechinus (*Antechinus flavipes*) is one such species occupying fire-prone environments and potentially using the habitat structure to avoid predators while foraging. However, little is known about the actual structural resources that are selected within its home range while foraging. Chapter 2 results suggest that yellow-footed antechinus occurrence is associated with the hollow-bearing trees and aspects of understory vegetation structure within their home ranges.

Initially I had two study designs with a correlative approach to identify the exact resources that are selected within the home range while foraging in different post-fire environments, followed by an experimental design to understand the mechanistic links between the activity and resources. The correlative study involved radio tracking foraging individuals to create a baseline of information on what structural resources are being selected. The planned experimental study was to use a before-after control-impact (BACI) study; adding or subtracting relevant resource attributes thus enabling causative relationships between resources and home range to be determined. The resources that were identified in the correlative study would therefore inform what resources to be removed to mimic a fire. This was planned to be followed by a radio tracking study to compare changes within home ranges of individuals to get an understanding, in an event of a fire when the exact resource is being depleted how animals are responding to resource changes. Due to the COVID 19 restrictions (travel bans, permit cancelation, campus closure and restricted access to university facilities) I was only able to carry out the initial part of the study design (correlative study). I have included both study designs in this paragraph and have mentioned the specific factors that restricted carrying out the experimental design in detail in COVID 19 impact statement.

COVID 19 affected both approaches; the correlative approach was carried out within a very limited time window and due to delays was pushed towards the breeding season of the yellow-footed antechinus. Since the species shows semelparity where adult males die off following the mating season, it was not possible to complete another round of radiotracking within the timeframe of my PhD.

Nonetheless, I carried out live-trapping and fitted radio collars on healthy individuals and tracked their foraging locations and carried out a subsequent habitat resource assessment. Due to a limited time window, low capture rates and collar failure, I was only able collect a reasonable set of data from 5 individuals within 2 sites. This chapter would benefit from a strong experimental approach followed by the initial correlative approach as this will directly shed light into direct mechanistic relationships with the yellow-footed antechinus and the habitat variables.

### Correlative Approach

The overall aim of the Chapter 4 was to identify the structural resources that are utilized by yellow-footed antechinus in foraging events within their home ranges. Spatial data were collected from individuals using the radio-tracking method and a used / available resource approach was applied, with habitat structural resources measured for both used and available locations. Used locations were denoted by actual locations where individuals were found, and available locations were created at random. To understand what resources individuals are actually selecting, a combination of generalized linear mixed models (GLMs), non-metric multidimensional scaling (NMDS) and permutational analysis of variance (PERMANOVA) was carried out.

By utilising radio-tracking on foraging individuals, I was able to add to the body of ecological knowledge on resource selection of yellow-footed antechinus within this landscape. Chapter 4 creates the baseline for a completed hierarchical level resource selection information for the yellow-footed antechinus, compiling information from the previous two data chapters; in *first order of resource selection* in areas where the rainfall is low. In the *second order of resource selection* individuals were found in the north-western side of the study area. In the *third order of resource* selection individuals prefer to establish their home ranges in areas with high number of trees with hollows and dense vegetation. In the *fourth order of resource selection* individuals are selecting dense vegetation cover while foraging on an array of invertebrates such as moths, beetles, cockroaches, flies and lacewings as well as possible plant matter from myrtles, pines, ferns and daisies. This gives a more comprehensive idea of the resource selection of yellow-footed antechinus, enabling appropriate fire management plans in order to create suitable resource environments for this species.

Yellow-footed antechinus populations undergo male die-off (semelparity) (Smith 1984), thus there is a possibility of the resource requirements of males and females of this species changing intensely compared to species that does not show semelparity. This creates an ideas system to investigate the differential resource selection of males and females throughout the seasons as well as in post-fire environments. This chapter facilitates an appropriate baseline for such future studies that will help in developing the understanding of underlying resource selection theories.

Furthermore, this will aid in understanding the alternative resources individuals will be using once the main structural resources are removed from the environment (mimicking a fire). Further studies could be built into this experimental design by utilizing artificial shades/refugia and creating experiments for testing giving-up densities. Therefore, correlative experiments in fine scale are essential in creating a strong base for experimental manipulation studies which will further strengthen the knowledge on resource selection of animals.

## 5.4. Overall conclusion

Fire can be used to manipulate and modify landscapes to generate desirable outcomes in conservation and land management. To generate successful conservation and land management plans an understanding of different resource requirements of animals is crucial. Selection and utilization of resources is generally a hierarchical process at both spatial and temporal scales. This thesis highlights the importance of creating comprehensive ecological information for both conservation and land management studies, and that requirements vary between the species as well as at different scales of resource selection.

For an example focusing on habitat conservation in larger landscape levels the knowledge on hierarchical resource selection can be used for identifying critical habitat for threatened species. The threatened heath mouse (Cockburn, 1981) occupies the patchy treeless heath areas in southwestern Victoria within the matrix in the study area. This knowledge will be crucial in promoting habitat connectivity by planning suitable habitat corridors within the landscape. Heath mice prefer floristically diverse structurally complex densely vegetated areas and primarily feeds on ruses, sedges and grasses on moist soils. At the patch level the conservation actions can be focused on activities such as creating wildlife refuges after fires specifically to avoid predators. Furthermore, implementing suitable prescribed fire regimes can promote the availability of food species for heath mouse. In contrast the yellow-footed antechinus prefer more open woodlands with hollow trees and considerably dense understory and high amounts of coarse woody debris and is predominantly an insectivore which feeds on some plant matter, which will require a different conservation and fire management strategies in the patch scale compared to the heath mouse. Additionally long-term studies on different hierarchical levels of resource selection can further aid in evaluating the efficiency of ongoing conservation and fire management decisions.

I was able to demonstrate the importance of using various approaches such as live trapping, radio tracking and novel eDNA metabarcoding to understand interrelationships between resources and small mammals in post-fire environments in multiple spatial scales. The knowledge of resource selection of animals at various hierarchical levels can be beneficial to conservation and fire ecology management, providing guidelines to ensure species persistence and habitat conservation in a period of climate change and unprecedented fire regimes.

# References

Abrahms, B., Aikens, E. O., Armstrong, J. B., Deacy, W. W., Kauffman, M. J., & Merkle, J. A. (2021). Emerging Perspectives on Resource Tracking and Animal Movement Ecology. *Trends in Ecology & Evolution, 36*(4), 308-320. doi:10.1016/j.tree.2020.10.018

Abram, N. J., Henley, B. J., Sen Gupta, A., Lippmann, T. J. R., clarke, H., Dowdy, A. J., Sharples, J. J., Nolan, R. H., Zhang, T., Wooster, M. J., Wurtzel, J. B., Meissner, K. J., Pitman, A. J., Ukkola, A. M., Murphy, B. P., Tapper, N. J. & Boer, M. M. (2021). Connections of climate change and variability to large and extreme forest fires in southeast Australia. *Communications Earth & Environment, 2*(1). doi:10.1038/s43247-020-00065-8

Abramsky, Z., & Rosenzweig, M. L. (1984). Tilman's predicted productivity-diversity relationship shown by desert rodents. *Nature, 309*, 150-151. Retrieved from https://www.nature.com/articles/309150a0

Anderson, M. J., Gorley, R. N., & Clarke, K. R. (2008). PERMANOVA + for PRIMER: Guide to Software and Statistical Methods. Plymouth.

Anderson, T. M., Ngoti, P. M., Nzunda, M. L., Griffith, D. M., Speed, J. D. M., Fossøy, F., Røskaft, E. & Graae, B. J. (2018). The burning question: does fire affect habitat selection and forage preference of the black rhinoceros Diceros bicornis in East African savannahs? *Oryx, 54*(2), 234-243. doi:10.1017/s0030605318000388

Andres, S. E., Powell, J. R., Rymer, P. D., & Emery, N. J. (2022). Fire severity and the post-fire soil environment affect seedling regeneration success of the threatened Persoonia hirsuta (Proteaceae). *Austral Ecology, 47*(6), 1248-1259. doi:https://doi.org/10.1111/aec.13217

Aponte, C., Tolhurst, K., & Bennett, L. T. (2014). Repeated prescribed fires decrease stocks and change attributes of coarse woody debris in a temperate eucalypt forest. *Ecological Applications*, *24*(5), 976- 989.

Apps, C. D., McLellan, B. D., Kinley, T. A., & Flaa, J. P. (2001). Scale-Dependent Habitat Selection by Mountain Caribou, Columbia Mountains, British Columbia. *The Journal of Wildlife Management, 65*(1), 65-77.

Arcis, V., & Desor, D. (2003). Influence of environment structure and food availability on the foraging behaviour of the laboratory rat. *Behavioural Processes, 60*, 191-198.

Arif, S., & MacNeil, M. A. (2022). Predictive models aren't for causal inference. *Ecology Letters, 25*(8), 1741-1745. doi:10.1111/ele.14033

Ball, L. C., & Golightly Jr, R. T. (1992). Energy and nutrient assimilation by gray foxes on diets of mice and Himalaya berries. *Journal of Mammalogy, 73*(4), 840-846.

Bartoń, K. (2020). MuMIn: Mult-mode inference. R package, Version 1.43.17. Retrieved from https://cran.r-project.org/web/packages/MuMIn/index.html.

Bassett, M., Leonard, S. W. J., Chia, E. K., Clarke, M. F., & Bennett, A. F. (2017). Interacting effects of fire severity, time since fire and topography on vegetation structure after wildfire. *Forest Ecology and Management, 396,* 26-34. doi:10.1016/j.foreco.2017.04.006

Bates, B. C., McCaw, L., & Dowdy, A. J. (2018). Exploratory analysis of lightning-ignited wildfires in the Warren Region, Western Australia. *Journal of Environmental Management, 225,* 336-345. doi:https://doi.org/10.1016/j.jenvman.2018.07.097

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). "Fitting Linear Mixed-Effects Models Using lme4.". *Journal of Statistical Software, 67,* 1-48. doi:10.18637/jss.v067.i01.

Bell, K. L., Batchelor, K. L., Bradford, M., McKeown, A., Macdonald, S. L., & Westcott, D. (2020). Optimisation of a pollen DNA metabarcoding method for diet analysis of flying-foxes (*Pteropus spp*.). *Australian Journal of Zoology, 68*(6). doi:10.1071/zo20085

Benwell, A. S. (1998). Post-fire Seedling Recruitment in Coastal Heathland in Relation to Regeneration Strategy and Habitat. *Australian Journal of Botany, 46*, 75-101.

Berman, T., & Moshe, I. (2022). Revealing cryptic interactions between large mammalian herbivores and plant-dwelling arthropods. *Ecology, 103,* e03548.

Bilney, R. J. (2014). Poor historical data drive conservation complacency: The case of mammal decline in south-eastern Australian forests. *Austral Ecology, 39*(8), 875-886. doi:10.1111/aec.12145

Bilney, R. J., Cooke, R., & White, J. G. (2010). Underestimated and severe: Small mammal decline from the forests of south-eastern Australia since European settlement, as revealed by a top-order predator. *Biological Conservation, 143*(1), 52-59. doi:10.1016/j.biocon.2009.09.002

Bonin, M., Dussault, C., Taillon, J., Lecomte, N., & Cote, S. D. (2020). Combining stable isotopes, morphological, and molecular analyses to reconstruct the diet of free-ranging consumers. *Ecology & Evolution, 10*(13), 6664-6676. doi:10.1002/ece3.6397

Bowman, D., & Legge, S. (2016). Pyrodiversity why managing fire in food webs is relevant to restoration ecology. *Restoration Ecology, 24*(6), 848-853. doi:10.1111/rec.12401

Bowman, D. M., Perry, G. L., Higgins, S. I., Johnson, C. N., Fuhlendorf, S. D., & Murphy, B. P. (2016). Pyrodiversity is the coupling of biodiversity and fire regimes in food webs. *Philosophical Transactions of the Royal Society B: Biological Sciences, B 371*(1696), 20150169. doi:10.1098/rstb.2015.0169

Braithwaite, R. W., Cockburn, A., & Lee, A. K. (1978). Resource partitioning by small mammals in lowland heath communities of south-eastern Australia. *Australian Journal of Ecology, 3,* 423-445.

Brennan, L. A., Tri, A. N., & Marcot, B. G. (2019). *Quantitative Analysisi in Wildlife Science*. Baltimore, Maryland: John Hopkins University Press.

Broughton, S., K, , & Dickman, C., R, . (1991). The effect of supplementary food on home range of the southern brown bandicoot, Isoodon obesulus (Marsupialia: Peramelidae). *Australian Journal of Ecology, 16*, 71- 78.

Brown, S. M., Harrisson, K. A., Clarke, R. H., Bennett, A. F., & Sunnucks, P. (2013). Limited population structure, genetic drift and bottlenecks characterise an endangered bird species in a dynamic, fire-prone ecosystem. *PLoS ONE, 8*(4), e59732. doi:10.1371/journal.pone.0059732

Browning, B. J., Jordan, G. J., Dalton, P. J., Grove, S. J., Wardlaw, T. J., & Turner, P. A. M. (2010). Succession of mosses, liverworts and ferns on coarse woody debris, in relation to forest age and log decay in Tasmanian wet eucalypt forest. *Forest Ecology and Management, 260*(10), 1896-1905. doi:10.1016/j.foreco.2010.08.038

Bureau of Meteorology. (2018, 27 September 2018). Climate statistics for Australian locations. Retrieved from http://www.bom.gov.au/climate/averages/tables/cw_090182.shtml

Bureau of Meteorology. (2022). Climate statistics for Australian locations: Casterton. Retrieved from http://www.bom.gov.au/climate/averages/tables/cw_090182.shtml

Burnham, K. P., & Anderson, D. R. (2016). Multimodel Inference. *Sociological Methods & Research, 33*(2), 261-304. doi:10.1177/0049124104268644

Burns, P. A. (2020). Testing the decline of the New Holland mouse (*Pseudomys novaehollandiae*) in Victoria. *Australian Mammalogy, 42*(2). doi:10.1071/am19006

Burns, P. A., Phillips, B. L., & Pavey, C. (2019). Time since fire is an over-simplified measure of habitat suitability for the New Holland mouse. *Journal of Mammalogy*. doi:10.1093/jmammal/gyz157

Burrows, N. D. (2008). Linking fire ecology and fire management in south-west Australian forest landscapes. *Forest Ecology and Management, 255*(7), 2394-2406. doi:10.1016/j.foreco.2008.01.009

Burt, W. H. (1943). Territoriality and Home range as Applied to Mammals. *Journal of Mammalogy, 24*(3), 346- 352.

Byrne, L. B. (2007). Habitat structure: A fundamental concept and framework for urban soil ecology. *Urban Ecosystems, 10*(3), 255-274. doi:10.1007/s11252-007-0027-6

Carron, P. L., Happold, D. C. D., & Bubela, T. M. (1990). Diet of 2 Sympatric Australian Sub-Alpine Rodents, *Mastacomys fuscus* and *Rattus fuscipes*. *Wildlife Research, 17*(5), 479. doi:10.1071/wr9900479

Cary, G. J., & Morrison, D. A. (1995). Effects of fire frequency on plant species composition of sandstone communities in the Sydney region: Combinations of inter-fire intervals. *Australian Journal of Ecology, 20*, 148-426.

Catling, P. C., & Burt, R. J. (1995). Studies of the Ground-dwelling Mammals of Eucalypt Forests in South-eastern New South Wales: the Effect of Habitat Variables on Distribution and Abundance. *Wildlife Research, 22,* 271-288.

Chambers, L. K., Singleton, G. R., & Krebs, C. J. (2000). Movements and social organization of wild house mice (*Mus domesticus)* in the wheatlands of northwestern victoria, australia. *Journal of Mammalogy, 81*(1), 59-69.

Cheal, D. (1987). The Diets and Dietary Preferences of *Rattus fuscipes* and *Rattus lutreolus* at Walkerville in Victoria. *Australian Wildlife Research, 14,* 35-44.

Cheal, D. (2010). *Growth stages and tolerable fire intervals for Victoria's native vegetation data set. Fire and adaptive management Report No 84*. Retrieved from East Melbourne, Victoria, Australia: Victorian Government Department of Sustainability and Environment.

Chick, M. P., Cohn, J. S., Nitschke, C. R., & York, A. (2016). Lack of soil seedbank change with time since fire: relevance to seed supply after prescribed burns. *International Journal of Wildland Fire, 25*(8). doi:10.1071/wf15013

Chisholm. R., Taylor, R., (2007) Null-hypothesis significance testing and the critical weight range for Australian mammals. *Conservation Biology, 21*(6):1641-5.

Chute, F. S., Fuller, W. A., Harding, P. R. J., & B., H. T. (1974). Radio tracking of small mammals using grid of overhead wire antennas. *Canadian Journal of Zoology, 52*, 1481- 1488.

Clare, E. L. (2014). Molecular detection of trophic interactions: emerging trends, distinct advantages, significant considerations and conservation applications. *Evolutionary Applications, 7*(9), 1144-1157. doi:10.1111/eva.12225

Clarke, H., & Evans, J. P. (2019). Exploring the future change space for fire weather in southeast Australia. *Theoretical and Applied Climatology, 136*(1), 513-527. doi:10.1007/s00704-018-2507-4

Clarke, K. R. (1993). Non-parametric multivariate analyses of changes in community structure. *Austral Ecology, 18*(1), 117-143. doi:10.1111/j.1442-9993.1993.tb00438.x

Clarke, K. R., & Gorley, R. N. (2016). PRIMER v7: User Manual/Tutorial. Plymouth: PRIMER-E.

Clarke, M. F. (2008). Catering for the needs of fauna in fire management: science or just wishful thinking? *Wildlife Research, 35*(5), 385. doi:10.1071/wr07137

Cockburn, A. (1981). Diet and Habitat Preference of the Silky Desert Mouse, *Pseudomys apodemoides* (Rodentia). *Australian Wildlife Research, 8,* 479- 497.

Cockburn, A., Braithwaite, R. W., & Lee, A. K. (1981). The Response of the Heath Rat, *Pseudomys shortridgei*, to Pyric Succession: A Temporally Dynamic Life-History Strategy. *Journal of Animal Ecology, 50,* 649-666.

Converse, S. J., Block, W. M., & White, G. C. (2006). Small mammal population and habitat responses to forest thinning and prescribed fire. *Forest Ecology and Management, 228*(1-3), 263-273. doi:10.1016/j.foreco.2006.03.006

Crowther, M. S. (2002). Distributions of species of the Antechinus stuartii–A. flavipes complex as predicted by bioclimatic modelling. *Australian Journal of Zoology, 50,* 77- 91.

Cruz-Rivera, E., & Hay, M. E. (2000). Can quantity replace quality? Food choice, compensatory feeding, and fitness of marine mesograzers. *Ecology, 81*(1), 201-219.

Dawson, J. P., Claridge, A. W., Triggs, B., & Paull, D. J. (2007). Diet of a native carnivore, the spotted-tailed quoll (*Dasyurus maculatus*), before and after an intense wildfire. *Wildlife Research, 34*(342- 351).

Data. Vic. (2018) Fire history overlay of most recent fires. Retrived from https://discover.data.vic.gov.au/dataset/fire-history-overlay-of-most-recent-fires

Day, J. D., Birrell, J. H., Terry, T. J., Clark, A., Allen, P., & St. Clair, S. B. (2019). Invertebrate community response to fire and rodent activity in the Mojave and Great Basin Deserts. *Ecology and Evolution, 9*(10), 6052-6067. doi:10.1002/ece3.5189

Deagle, B. E., Chiaradia, A., McInnes, J., & Jarman, S. N. (2010). Pyrosequencing faecal DNA to determine diet of little penguins: is what goes in what comes out? *Conservation Genetics, 11*(5), 2039-2048. doi:10.1007/s10592-010-0096-6

Deagle, B. E., Thomas, A. C., Mcinnes, J. C., Clarke, L. J., Vesterinen, E. J., Clare, E. L., Kartzinel, T. R. & Eveson, J. P. (2018). Counting with DNA in metabarcoding studies: How should we convert sequence reads to dietary data? *Molecular Ecology*, 1-16. doi:10.1111/mec.14734

Deiner, K., Bik, H. M., Machler, E., Seymour, M., Lacoursiere-Roussel, A., Altermatt, F., Creer, S., Bista, I., Lodge, D. M., De Vere, N., Pfrender, M. E. & Bernatchez, L. (2017). Environmental DNA metabarcoding: Transforming how we survey animal and plant communities. *Molecular Ecology, 26*(21), 5872-5895. doi:10.1111/mec.14350

Delaney, L., Di Stefano, J., & Sitters, H. (2021). Mammal responses to spatial pattern in fire history depend on landscape context. *Landscape Ecology, 36,* 897-914. doi:10.1007/s10980-020-01186-3

Department of Sustanability and Environment (2003). *Ecological effects of repeated low-intensity fire in a mixed eucalypt foothill forest in south-eastern Australia* (Summary report 1984-1999). In: (57). Victoria, Australia.

DiCarlo, L. A., DeBano, S. J., & Burrows, S. (2019). Short-Term Response of Two Beneficial Invertebrate Groups to Wildfire in an Arid Grassland System, United States. *Rangeland Ecology & Management, 72*(3), 551-560. doi:10.1016/j.rama.2018.11.011

Di Stefano, J., Ashton, A., & York, A. (2014). Diet of the silky mouse (*Pseudomys apodemoides*) and the heath rat (*P. shortridgei*) in a post-fire environment. *International Journal of Wildland Fire, 23*(5), 746. doi:10.1071/wf13168

Di Stefano, J., & Newell, G. R. (2008). Diet selection by the swamp wallaby (*Wallabia bicolor*): feeding strategies under conditions of changed food availability. *Journal of Mammalogy, 89*(6), 1540-1549.

Di Stefano, J., Owen, L., Morris, R., Duff, T., & York, A. (2011). Fire, landscape change and models of small mammal habitat suitability at multiple spatial scales. *Austral Ecology, 36*(6), 638-649. doi:10.1111/j.1442-9993.2010.02199.x

Di Virgilio, G., Evans, J. P., Clarke, H., Sharples, J., Hirsch, A. L., & Hart, M. A. (2020). Climate Change Significantly Alters Future Wildfire Mitigation Opportunities in Southeastern Australia. *Geophysical Research Letters, 47*(15). doi:10.1029/2020gl088893

Dickman, C. R. (1986). Niche compression: Two tests of an hypothesis using narrowly sympatric predator species. *Australian Journal of Ecology, 11*, 121-134.

Dickman, C. R. (1991). Mechanisms of Competition among Insectivorous Mammals. *Oecologia, 85*(4), 464- 471.

Dickman, C. R. (1991). Use of trees by ground-dwelling mammals: implications for management. In *Conservation of Australia's Forest Fauna* (pp. 125-136).

Dickman, C. R. (2021). Ecological consequences of Australia's "Black Summer" bushfires: Managing for recovery. *Integrated Environmental Assessment and Management, 17*(6), 1162-1167. doi:https://doi.org/10.1002/ieam.4496

Dickman, C. R., & Happold, D. C. (2022). Demographic and dietary responses of small mammals to high severity fire. *Australian Zoologist*.

Dickman, C. R., & Huang, C. (1988). The Reliability of Fecal Analysis as a Method for Determining the Diet of Insectivorous Mammals. *Journal of Mammalogy, 69*(1), 108- 113.

Dickman, C. R., Mahon, P. S., Masters, P., & Gibson, D. F. (1999). Long-term dynamics of rodent populations in arid Australia: the influence of rainfall. *Wildlife Research, 26*(4), 389-403. doi:10.1071/wr97057

Dickman, C. R., Parnaby, H. E., Crowther, M. S., & King, D. H. (1998). *Antechinus agilis* (Marsupialia : Dasyuridae), a new species from the A. stuartii complex in south-eastern Australia. *Australian Journal of Zoology, 46*, 1- 26.

Donihue, C. M. (2016). Aegean wall lizards switch foraging modes, diet, and morphology in a human-built environment. *Ecology and Evolution, 6*(20), 7433-7442. doi:10.1002/ece3.2501

Dormontt, E. E., Van Dijk, K. J., Bell, K. L., Biffin, E., Breed, M. F., Byrne, M., . . . Shapcott, A. (2018). Advancing DNA barcoding and metabarcoding applications for plants requires systematic analysis of herbarium collections—an Australian perspective. *Frontiers in Ecology and Evolution, 6*, 134.

Dorph, A., Swan, M., Di Stefano, J., & Penman, T. D. (2021). Relating mammal species richness to landscape patterns across multiple spatial scales. *Landscape Ecology, 36*(4), 1003-1022.

Dorph, A., Swan, M., Rochelmeyer, E., & Di Stefano, J. (2020). Complex habitat drives mammal communities in a flammable landscape. *Forest Ecology and Management, 462*. doi:10.1016/j.foreco.2020.117979

Driessen, M. M., & Kirkpatrick, J. B. (2017). The implications of succession after fire for the conservation management of moorland invertebrate assemblages. *Journal of Insect Conservation, 21*(1), 15-37. doi:10.1007/s10841-016-9948-9

Driscoll, D. A., Lindenmayer, D. B., Bennett, A. F., Bode, M., Bradstock, R. A., Cary, G. J., Clarke, M. F., Dexter, N., Fensham, R., Friend, G., Gill, M., James, S., Kay, G., Keith, D. A., Macgregor, C., Russell-Smith, J., Salt, D., Watson, J. E. M., Williams, R. J. & York, A. (2010). Fire management for biodiversity conservation: Key research questions and our capacity to answer them. *Biological Conservation, 143*(9), 1928-1939. doi:10.1016/j.biocon.2010.05.026

Duff, T. J., Bell, T. A., & York, A. (2014). Recognising fuzzy vegetation pattern: the spatial prediction of floristically defined fuzzy communities using species distribution modelling methods. *Journal of Vegetation Science, 25*, 323337. doi:10.1111/jvs

Duff, T. J., Bell, T. L., & York, A. (2013a). Managing multiple species or communities? Considering variation in plant species abundances in response to fire interval, frequency and time since fire in a heathy Eucalyptus woodland. *Forest Ecology and Management, 289*, 393-403. doi:10.1016/j.foreco.2012.10.032

Duff, T. J., Bell, T. L., & York, A. (2013b). Predicting continuous variation in forest fuel load using biophysical models: a case study in south-eastern Australia. *International Journal of Wildland Fire, 22*(3), 318. doi:10.1071/wf11087

Edgar, R. C. (2018). Updating the 97% identity threshold for 16S ribosomal RNA OTUs. *Bioinformatics, 34*(14), 2371-2375. doi:10.1093/bioinformatics/bty113

Fairman, T. A., Nitschke, C. R., & Bennett, L. T. (2016). Too much, too soon? A review of the effects of increasing wildfire frequency on tree mortality and regeneration in temperate eucalypt forests. *International Journal of Wildland Fire, 25*(8). doi:10.1071/wf15010

Fattebert, H., Robinson, H. S., Balme, G., Slotow, R., & Hunter, L. (2015). Structural habitat predicts functional dispersal habitat of a large carnivore: how leopards change spots. *Ecological Applications, 25*, 191-1921.

Fick, S. E., & Hijmans, R. J. (2017). WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. *International Journal of Climatology, 37*(12), 4302-4315. doi:10.1002/joc.5086

Fisher, D. O. & Dickman, C. R. 1993. Body Size-Prey Relationships in Insectivorous Marsupials: Tests of Three Hypotheses. *Ecology*, *74*, 1871-1883.

Fisher, J. L., Loneragan, W. A., Dixon, K., Delaney, J., & Veneklaas, E. J. (2009). Altered vegetation structure and composition linked to fire frequency and plant invasion in a biodiverse woodland. *Biological Conservation, 142*(10), 2270-2281. doi:10.1016/j.biocon.2009.05.001

Fiske, I., & Chandler, R. (2011). unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance. *Journal of Statistical Software, 43*, 1-23. Retrieved from https://www.jstatsoft.org/v43/i10/.

Flanagan-Moodie, A. K., Holland, G. J., Clarke, M. F., & Bennett, A. F. (2018). Prescribed burning reduces the abundance of den sites for a hollow-using mammal in a dry forest ecosystem. *Forest Ecology and Management, 429*, 233-243. doi:10.1016/j.foreco.2018.07.023

Flannigan, M. D., Amiro, B. D., Logan, K. A., Stocks, B. J., & Wotton, B. M. (2006). Forest Fires and Climate Change in the 21st Century. *Mitigation and Adaptation Strategies for Global Change, 11*(4), 847-859. doi:10.1007/s11027-005-9020-7

Flannigan, M. D., Stocks, B. J., & Wooton, B. M. (2000). Climate change and forest fires. *Science of the Total Environment, 262*, 221–229.

Fordyce, A., Hradsky, B. A., Ritchie, E. G., & Di Stefano, J. (2016). Fire affects microhabitat selection, movement patterns, and body condition of an Australian rodent (*Rattus fuscipes*). *Journal of Mammalogy, 97*(1), 102-111. doi:10.1093/jmammal/gyv159

Forester, J. D., Kyung, H., & Rathouz, P. J. (2009). Accounting for animal movement in estimation of resource selection functions: sampling and data analysis. *Ecological Society of America, 90*(12), 3554-3565.

Fox, B. J. (1982). Fire and Mammalian Secondary Succession in an Australian Coastal Heath. *Ecology, 63*(5), 1332- 1341.

Fox, B. J., Fox, M. D., & McKay, G. M. (1979). Litter Accumulation after Fire in an Eucalypt Forest. *Australian Journal of Botany, 27*, 157- 165.

Fox, B. J., & Monamy, V. (1999). Habitat Selection by Female *Rattus Lutreolus* Drives Asymmetric Competition and Coexistence with *Pseudomys higginsi*. *80*(1), 232- 242.

Fox, B. J., & Monamy, V. (2000). Small mammal succession is determined by vegetation density rather than time elapsed since disturbance. *Austral Ecology, 25*, 580- 587.

Frick, W. F., Shipley, J. R., Kelly, F. J., Heady III, P. A., & Kay, K. M. (2014). Seasonal reliance on nectar by an insectivorous bat revealed by stable isotopes. *Oecologia, 174*(1), 55-65. doi:10.1007/s00442-013-2771

Gallagher, R. V., Allen, S., Mackenzie, B. D. E., Yates, C. J., Gosper, C. R., Keith, D. A., Merow, C., White, M. D., Wenk, E., Maitner, B. S., He, K., Adams, V. M., Auld, T. D. & Nimmo, D. (2021). High fire frequency and the impact of the 2019–2020 megafires on Australian plant diversity. *Diversity and Distributions, 27*(7), 1166-1179. doi:10.1111/ddi.13265

Garden, J. G., McAlpine, C. A., Possingham, H. P., & Jones, D. N. (2007). Habitat structure is more important than vegetation composition for local-level management of native terrestrial reptile and small mammal species living in urban remnants: A case study from Brisbane, Australia. *Austral Ecology, 32*(6), 669-685. doi:10.1111/j.1442-9993.2007.01750.x

Geary, W. L., Doherty, T. S., Nimmo, D. G., Tulloch, A. I. T., & Ritchie, E. G. (2020). Predator responses to fire: A global systematic review and meta-analysis. *Journal of Animal Ecology, 89*(4), 955-971. doi:10.1111/1365-2656.13153

Gende, S. M., Quinn, T. P., & Willson, M. F. (2001). Consumption choice by bears feeding on salmon. *Oecologia, 127*(3), 372-382. doi:10.1007/s004420000590

Gill, A. M. (1975). Fire and The Australian Flora: A Review. *Australian Forestry, 38*(1), 4-25. doi:10.1080/00049158.1975.10675618

Gill, A. M., Woinarski, J., & York, A. (1999). *Australias Biodiversity Response to Fire, Plants Birds and Invertebrates*. Retrieved from Canbera: Canbera: Department of Environment and Heritage.

Glen, A. S., Sutherland, D. R., & Cruz, J. (2009). An improved method of microhabitat assessment relevant to predation risk. *Ecological Research, 25*(2), 311-314. doi:10.1007/s11284-009-0653-y

Goldingay, R. L. (2000). Small dasyurid marsupials – are they effective pollinators? *Australian Journal of Zoology, 48*, 597-606.

González, T. M., González-Trujillo, J. D., Muñoz, A., & Armenteras, D. (2021). Differential effects of fire on the occupancy of small mammals in neotropical savanna-gallery forests. *Perspectives in Ecology and Conservation, 19*(2), 179-188. doi:https://doi.org/10.1016/j.pecon.2021.03.005

Gott, B. (2005). Aboriginal fire management in south-eastern Australia: aims and frequency. *Journal of Biogeography, 32*(7), 1203-1208. doi:10.1111/j.1365-2699.2004.01233.x

Hale, S., Nimmo, D. G., Cooke, R., Holland, G., James, S., Stevens, M., De Bondi, N., Woods, R., Castle, M., Campbell, K., Senior, K., Cassidy, S., Duffy, R., Holmes, B., White, J. G. & Syphard, A. (2016). Fire and climatic extremes shape mammal distributions in a fire-prone landscape. *Diversity and Distributions, 22*(11), 1127-1138. doi:10.1111/ddi.12471

Haris, S., Cresswell, W. J., Forde, P. G., Trewhella, W. J., Woollard, T., & Wray, S. (1990). Home-range analysis using radio-tracking data a review of problems and techniques. *Mammal Review, 20*(97-123).

Harmon, M. E., Franklin, J. F., Swanson, F. J., Sollins, P., Gregory, S. V., Lattin, J. D., Anderson, N. H., Cline, S. P., Aumen, N. G., Sedell, J. R., Lienkaemper, G. W., Cromack, K. & Cummins, K. W. (1986). Ecology of Coarse Woody Debris in Temperate Ecosystems. *Advances in Ecological Research, 34*, 59-234. doi:10.1016/s0065-2504(03)34002-4

Hartig, F. (2017). DHARMa: Residual Diagnostics for Hierarchical (Multi-Level / Mixed) Regression Models. R package version 0.1.5. Retrieved from http://florianhartig.github.io/DHARMa/

Haus, J. M., Webb, S. L., Strickland, B. K., Mccarthy, K. P., Rogerson, J. E., & Bowman, J. L. (2020). Individual heterogeneity in resource selection has implications for mortality risk in white-tailed deer. *Ecosphere, 11*(4), e03064. 03010. 01002/ecs03062.03064.

He, T., Lamont, B. B., & Pausas, J. G. (2019). Fire as a key driver of Earth's biodiversity. *Biological reviews of the Cambridge Philosophical Society*. doi:10.1111/brv.12544

Heinrichs, J. A., Bender, D. J., & Schumaker, N. H. (2016). Habitat degradation and loss as key drivers of regional population extinction. *Ecological Modelling, 335*, 64-73. doi:10.1016/j.ecolmodel.2016.05.009

Hengl, T., Mendes de Jesus, J., Heuvelink, G. B., Ruiperez Gonzalez, M., Kilibarda, M., Blagotic, A., Kempen, B. (2017). SoilGrids250m: Global gridded soil information based on machine learning. *PLoS ONE, 12*(2), e0169748. doi:10.1371/journal.pone.0169748

Hindmarsh, R., & Majer, J. D. (1977). Food requirements of mardo (*Antechinus flavipes* (Waterhouse)) and the effect of fire on mardo abundance *Research paper (Western Australia. Forests Department), 31*.

Holland, G. J., Clarke, F., & Bennett, A. F. (2017). Prescribed burning consumes key forest structural components: implications for landscape heterogeneity. *Ecological Applications, 27*, 845-858.

Hollis, J. J., Matthews, S., Anderson, W. R., Cruz, M. G., & Burrows, N. D. (2011). Behind the flaming zone: Predicting woody fuel consumption in eucalypt forest fires in southern Australia. *Forest Ecology and Management, 261*(11), 2049-2067. doi:10.1016/j.foreco.2011.02.031

Houston, A., Clark, C., McNamara, J., & Mangel, M. (1988). Dynamic models in behavioral and evolutionary ecology. *Nature, 332*(29- 34).

Hradsky, B. A. (2020). Conserving Australia’s threatened native mammals in predator-invaded, fire-prone landscapes. *Wildlife Research, 47*(1). doi:10.1071/wr19027

Hradsky, B. A., Mildwaters, C., Ritchie, E. G., Christie, F., & Di Stefano, J. (2017). Response of invasive predators and native prey to a prescribed forest fire *Journal of Mammalogy, 98*(3), 8335- 8847.

Hughes, L. (2010). Climate change and Australia: key vulnerable regions. *Regional Environmental Change, 11*(S1), 189-195. doi:10.1007/s10113-010-0158-9

Hutto, R. L. (2016). Should scientists be required to use a model-based solution to adjust for possible distance-based detectability bias? *Ecological Applications, 26*(5), 1287-1294.

IBM Corp. (2019). IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.

Johnson, H. D. (1980). The Comparison of Usage and Availability Measurements for Evaluating Resource Preference. *Ecological Society of America, 61*(1), 65-71.

Johnson, M. D. (2007). Measuring Habitat Quality: A Review. *The Condor, 109*(3), 489. doi:10.1650/8347.1

Jolly, C. J., Dickman, C. R., Doherty, T. S., Van Eeden, L. M., Geary, W. L., Legge, S. M., Woinarski, J. C. Z. & Nimmo, D. G. (2022). Animal mortality during fire. *Global Change Biology, 28*(6), 2053-2065. doi:https://doi.org/10.1111/gcb.16044

Jones, G. M., & Tingley, M. W. (2021). Pyrodiversity and biodiversity: A history, synthesis, and outlook. *Diversity and Distributions*. doi:10.1111/ddi.13280

Jorgenson, E. E. (2004). Small Mammal Use of Microhabitat Reviewed. *Journal of Mammology, 85*(3), 531-539.

Kalcounis-RÜPpell, M. C., Patrick, A., & Millar, J. S. (2001). Effect of Fluorescent Powder Marking of Females on Mate Choice by Male White-Footed Mice (*Peromyscus leucopus*). *The American midland Naturalist, 146*(2), 429-433. doi:10.1674/0003-0031(2001)146[0429:eofpmo]2.0.co;2

Karasov, W. H., Petrossian, E., Rosenberg, L., & Diamond, J. M. (1986). How do food passage rate and assimilation differ between herbivorous lizards and nonruminant mammals? *Journal of Comparative Physiology B-Biochemical Systems and Environmental Physiology, 156,* 599--609.

Kawahara, A. Y., Plotkin, D., Hamilton, C. A., Gough, H., St Laurent, R., Owens, H. L., Homziak, N. T. & Barber, J. R. (2017). Diel behavior in moths and butterflies: a synthesis of data illuminates the evolution of temporal activity. *Organisms Diversity & Evolution, 18*(1), 13-27. doi:10.1007/s13127-017-0350-6

Kearney, N., Handasyde, K., Ward, S., & Kearney, M. (2007). Fine-scale microhabitat selection for dense vegetation in a heathland rodent, Rattus lutreolus: Insights from intraspecific and temporal patterns. *Austral Ecology, 32*(3), 315-325. doi:10.1111/j.1442-9993.2007.01697.x

Keeley, J. E., Pausas, J. G., Rundel, P. W., Bond, W. J., & Bradstock, R. A. (2011). Fire as an evolutionary pressure shaping plant traits. *Trends in Plant Science, 16*(8), 406-411. doi:https://doi.org/10.1016/j.tplants.2011.04.002

Keith, D. A. (2012). Functional traits: their roles in understanding and predicting biotic responses to fire regimes from individuals to landscapes. *Flammable Australia: fire regimes, biodiversity and ecosystems in a changing world,* 97-125.

Kelly, L. T. (2006). Distribution and habitat requirements of the Yellow-footed Antechinus *Antechinus flavipes* at multiole scale: a review. *The Victorian Naturalist, 123*(2), 91- 99.

Kelly, L. T., & Bennett, A. F. (2008). Habitat requirements of the yellow-footed antechinus (*Antechinus flavipes*) in box–ironbark forest, Victoria, Australia. *Wildlife Research, 35*, 128- 133.

Kelly, L. T., Bennett, A. F., Clarke, M. F., & McCarthy, M. A. (2015). Optimal fire histories for biodiversity conservation. *Conservation Biology, 29*, 473-481. doi:10.1111/cobi

Kelly, L. T., Giljohann, K. M., Duane, A., Aquilué, N., Archibald, S., Batllori, E., Brotons, L. (2020). Fire and biodiversity in the Anthropocene. *Science, 370*(6519). doi:10.1126/science.abb0355

Kelly, L. T., Haslem, A., Holland, G. J., Leonard, S. W. J., Machunter, J., Bassett, M., York, A. (2017a). Fire regimes and environmental gradients shape vertebrate and plant distributions in temperate eucalypt forests. *Ecosphere, 8*(4), e01781. 01710.01002/ecs01782.01781.

Kelly, L. T., Haslem, A., Holland, G. J., Leonard, S. W. J., MacHunter, J., Bassett, M., York, A. (2017b). Fire regimes and environmental gradients shape vertebrate and plant distributions in temperate eucalypt forests. *Ecosphere, 8*(4), 31. doi:10.1002/ecs2.1781

Kelly, L. T., Nimmo, D. G., Spence-Bailey, L. M., Haslem, A., Watson, S. J., Clarke, M. F., & Bennett, A. F. (2011). Influence of fire history on small mammal distributions: insights from a 100-year post-fire chronosequence. *Diversity and Distributions, 17*(3), 462-473. doi:10.1111/j.1472-4642.2011.00754.x

Kelt, D. A., Meserve, P. L., Nabros, L. K., Forister, M. L., & Gutierrez, J. R. (2004). Foraging Ecology of Small Mammals in Semiarid Chile: The Interplay of Biotic and Abiotic Effects. *Ecology, 85*(2), 383- 397.

Kircher, M., Sawyer, S., & Meyer, M. (2012). Double indexing overcomes inaccuracies in multiplex sequencing on the Illumina platform. *Nucleic acids research, 40*(1), e3-e3.

Klare, U., Kamler, J. F., & Macdonald, D. W. (2011). A comparison and critique of different scat-analysis methods for determining carnivore diet. *Mammal Review, 41*(4), 294-312. doi:10.1111/j.1365-2907.2011.00183.x

Klop, E., van Goethem, J., & de Longh, H. H. (2007). Resource selection by garzing herbevores on post fire regrowth in a West African woodland savanna. *Wildlife Research, 34*, 77- 83.

Knox, K. J. E., & Clarke, P. J. (2006). Fire Season and Intensity Affect Shrub Recruitment in Temperate Sclerophyllous Woodlands. *Oecologia, 149*(4), 730-739. Retrieved from http://www.jstor.org/stable/20446044

Koike, S., Morimoto, H., Goto, Y., Kozakai, C., & Yamazaki, K. (2008). Frugivory of carnivores and seed dispersal of fleshy fruits in cool-temperate deciduous forests. *Journal of Forest Research, 13*(4), 215-222. doi:10.1007/s10310-008-0069-5

Kolka, R., Sturtevant, B., Townsend, P., Miesel, J., Wolter, P., Fraver, S., & DeSutter, T. (2014). Post-Fire Comparisons of Forest Floor and Soil Carbon, Nitrogen, and Mercury Pools with Fire Severity Indices. *Soil Science Society of America Journal, 78*(S1), S58-S65. doi:10.2136/sssaj2013.08.0351nafsc

Korodaj, T. (2007). Determinants of Antechinus occurrence in a fragmented landscape: dead wood matters.

Lada, H., Nally, R. M., & Taylor, A. C. (2008). Responses of a Carnivorous Marsupial (*Antechinus flavipes*) to Local Habitat Factors in Two Forest Types. *Journal of Mammalogy, 89*(2), 398-407. doi:10.1644/07-mamm-a-080r.1

Lada, H., Thomson, J. R., Cunningham, S. C., & Mac Nally, R. (2013). Rainfall in prior breeding seasons influences population size of a small marsupial. *Austral Ecology, 38*(5), 581-591. doi:10.1111/aec.12002

Lashley, M. A., Chitwood, M. C., Harper, C. A., DePerno, C. S., & Moorman, C. E. (2015). Variability in Fire Prescriptions to Promote Wildlife Foods in the Longleaf Pine Ecosystem. *Fire Ecology, 11*(3), 62-79. doi:10.4996/fireecology.1103062

Lawrence, J. F., & Britton, E. B. (1994). *Australian Beetles*. Victoria, Australia Melbourne University Press.

Lees, D. M., Watchorn, D. J., Driscoll, D. A., & Doherty, T. S. (2021). Microhabitat selection by small mammals in response to fire. *Australian Journal of Zoology, 69*(3), 67-79. doi:10.1071/zo21022

Lees, D. M., Watchorn, D. J., Driscoll, D. A., & Doherty, T. S. (2022). Microhabitat selection by small mammals in response to fire. *Australian Journal of Zoology, 69*(3), 67-79.

Letnic, M., Dickman, C. R., Tischler, M. K., Tamayo, B., & Beh, C. L. (2004). The responses of small mammals and lizards to post-fire succession and rainfall in arid Australia. *Journal of Arid Environments, 59*(1), 85-114. doi:10.1016/j.jaridenv.2004.01.014

Luo, J., & Fox, B. J. (1994). Diet of the Eastern Chestnut Mouse (Pseudomys gracilicaudatus). II. Seasonal and Successional Patterns. *Wildlife Research, 21*, 491- 431.

Mac Nally, R., Parkinson, A., Horrocks, G., Conole, L., & Tzaros, C. (2001). Relationships between terrestrial vertebrate diversity, abundance and availability of coarse woody debris on south-eastern Australian floodplains. *Biological Conservation, 99*(2), 191-205. doi:10.1016/s0006-3207(00)00180-4

Manly, B., McDonald, L., Thomas, D. L., McDonald, T. L., & Erickson, W. P. (2007). *Resource selection by animals: statistical design and analysis for field studies*: Springer Science & Business Media.

Manly, B. F. J., McDonals, L. L., Thomas, D. L., McDonald, T. L., & Erickson, W. P. (2004). *Resource Selection By Animals: Statistical Design and Analysis for Field Studies* Dordrecht: Kluwer Academic Publisher.

Marchesan, D. (2002). *Presence, breeding activity and movement of the yellow- footed antechinus (Antechinus flavipes ), in a fragmented landscape of the southern Mt Lofty Ranges.* (Master of Applied Science). University of Adelaide,

Marchesan, D., & Carthew, S. M. (2004). Autecology of the yellow-footed antechinus (*Antechinus flavipes*) in a fragmented landscape in southern Australia. *Wildlife Research, 31*, 273- 282.

Mark, K. J. O., Auld, T. D., & Whelan, R. J. (2007). Distinguishing between Persistence and Dormancy in Soil Seed Banks of Three Shrub Species from Fire-Prone Southeastern Australia. *Journal of Vegetation Science, 18*(3), 405-412. Retrieved from http://www.jstor.org/stable/4499240

Maron, M., Koch, P., Freeman, J., Schultz, S., & Dunn, P. (2008). *Modelling and planning to increase future habitat of the Redtailed Black-Cockatoo, including the endangerd Buloke woodland.*

Masters, P. (1993). The Effects of Fire-driven Succession and Rainfall on Small Mammals in Spinifex Grassland at Ulup National Park, Northern Territory. *Wildlife Research, 20*, 803-813.

Mayor, S. J., Schneider, D. C., Schaefer, J. A., & Mahoney, S. P. (2009). Habitat selection at multiple scales. *Écoscience, 16*(2), 238-247. doi:10.2980/16-2-3238

Mazza, V., Jacob, J., Dammhahn, M., Zaccaroni, M., & Eccard, J. A. (2019). Individual variation in cognitive style reflects foraging and anti-predator strategies in a small mammal. *Scientific Reports, 9*(1), 10157. doi:10.1038/s41598-019-46582-1

McCoy, E. D., Bell, S. S. & Mushinsky, H. R. (1990). *Habitat structure: synthesis and perspectives.Habitat structure: the physical arrangement of objects in space.* . London: Chapman & Hall

McCreadie, D. (2017). Observations of wildlife feeding on sap produced by sticky hopbush (dodonaea viscosa) in morialta conservation park. *The South Australian Naturalist, 91* 38-39. doi:10.3316/informit.985365862807326

McDonald, M. (2020). After the fires? Climate change and security in Australia. *Australian Journal of Political Science*, 1-18. doi:10.1080/10361146.2020.1776680

McElhinny, C., Gibbons, P., Brack, C., & Bauhus, J. (2005). Forest and woodland stand structural complexity: Its definition and measurement. *Forest Ecology and Management, 218*(1-3), 1-24. doi:10.1016/j.foreco.2005.08.034

McElhinny, C., Gibbons, P., Brack, C., & Bauhus, J. (2006). Fauna-habitat relationships: a basis for identifying key structural atributes in temperate Australian eucalypt forests and woodlands *Pacific Conservation Biology, 12*.

Mc Lauchlan, K. K., Higuera, P. E., Miesel, J., Rogers, B. M., Schweitzer, J., Shuman, J. K., Tepley, A. J., Varner, J. M., Veblen, T. T., Adalsteinsson, S. A., Balch, J. K., Baker, P., Batllori, E., Bigio, E., Brando, P., Cattau, M., Chipman, M. L., Coen, J., Crandall, R., Daniels, L., Enright, N., Gross, W. S., Harvey, B. J., Hatten, J. A., Hermann, S., Hewitt, R. E., Kobziar, L. N., Landesmann, J. B., Loranty, M. M., Maezumi, S. Y., Mearns, L., Moritz, M., Myers, J. A., Pausas, J. G., Pellegrini, A. F. A., Platt, W. J., Roozeboom, J., Safford, H., Santos, F., Scheller, R. M., Sherriff, R. L., SMITH, K. G., Smith, M. D. & Watts, A. C. (2020). Fire as a fundamental ecological process: Research advances and frontiers. *Journal of Ecology, 108*(5), 2047-2069. doi:10.1111/1365-2745.13403

Menkhorst, P. (2011). *A Field Guide to Mammals of Australia*. Australia: Oxford University Press.

Menkhorst, P., Bennett, A. F., Henry, S. H., Lumsden, L. F., Mansergh, I. M., Seebeck, J. H., Williams, L. M. (1995). *Mammals of Victoria : distribution, ecology and conservation*. Melbourne: Oxford University Press in association with Dept. of Conservation and Natural Resources.

Meyer, C. B., & Thuiller, W. (2006). Accuracy of resource selection functions across spatial scales. *Diversity and Distributions, 12*(3), 288-297. doi:10.1111/j.1366-9516.2006.00241.x

Miehs, A., York, A., Tolhurst, K., Di Stefano, J., & Bell, T. (2010). Sampling downed coarse woody debris in fire-prone eucalypt woodlands. *Forest Ecology and Management, 259*(3), 440-445. doi:10.1016/j.foreco.2009.10.041

Miller, R. G., Tangney, R., Enright, N. J., Fontaine, J. B., Merritt, D. J., Ooi, M. K. J., Ruthrof, K. X. & Miller, B. P. (2019). Mechanisms of Fire Seasonality Effects on Plant Populations. *Trends in Ecology & Evolution, 34*(12), 1104-1117. doi:https://doi.org/10.1016/j.tree.2019.07.009

Milton, S. J., & Dean, W. R. J. (2001). Seeds dispersed in dung of insectivores and herbivores in semi-arid southern Africa. *Journal of Arid Environments, 47*(4), 465-483. doi:10.1006/jare.2000.0727

Minitab Inc. (2010). Minitab 17 Statistical Software. State College, PA: Minitab Inc.

Monamy, V., & Fox, B. J. (2010). Responses of two species of heathland rodents to habitat manipulation: Vegetation density thresholds and the habitat accommodation model. *Austral Ecology, 35*(3), 334-347. doi:10.1111/j.1442-9993.2009.02042.x

Monterroso, P., Godinho, R., Oliveira, T., Ferreras, P., Kelly, M. J., Morin, D. J., Waits, L. P., Alves, P. C. & Mills, L. S. (2018). Feeding ecological knowledge: the underutilised power of faecal DNA approaches for carnivore diet analysis. *Mammal Review, 49*(2), 97-112. doi:10.1111/mam.12144

Moore, T. L., Valentine, L. E., Craig, M. D., Hardy, G. E. S. J., & Fleming, P. A. (2014). Does woodland condition influence the diversity and abundance of small mammal communities? *Australian Mammalogy, 36*(1), 35. doi:10.1071/am13007

Morris, D. W., Fox, B. J., Luo, J., & Monamy, V. (2000). Habitat-Dependent Competition and the Coexistence of Australian Heathland Rodents. *Oikos, 91*(2), 294- 306.

Mousavi-Derazmahalleh, M., Stott, A., Lines, R., Peverley, G., Nester, G., Simpson, T., Zawierta, M., De La Pierre, M., Bunce, M. & Christophersen, C. T. (2021). eDNAFlow, an automated, reproducible and scalable workflow for analysis of environmental DNA sequences exploiting Nextflow and Singularity. *Molecular Ecology Resources, 21*(5), 1697-1704. doi:10.1111/1755-0998.13356

Mudappa, D., Kumar, A., & Chellam, R. (2010). Diet and fruit choice of the brown palm civet *Paradoxurus jerdoni*, a viverrid endemic to the Western Ghats rainforest, India. *Tropical Conservation Science, 3*(3), 282-300.

Muller, C. G., Chilvers, B. L., Barker, Z., Barnsdale, K. P., Battley, P. F., French, R. K., Mccullough, J. & Samandari, F. (2019). Aerial VHF tracking of wildlife using an unmanned aerial vehicle (UAV): comparing efficiency of yellow-eyed penguin (*Megadyptes antipodes*) nest location methods. *Wildlife Research, 46*(2), 145. doi:10.1071/wr17147

Murray, D. C., Coghlan, M. L., & Bunce, M. (2015). From benchtop to desktop: important considerations when designing amplicon sequencing workflows. *PLoS ONE, 10*(4), e0124671.

N'Dri, A. B., Soro, T. D., Gignoux, J., Dosso, K., Koné, M., N'Dri, J. K., Koné, N. G. A. & Barot, S. (2018). Season affects fire behavior in annually burned humid savanna of West Africa. *Fire Ecology, 14*(2), 5. doi:10.1186/s42408-018-0005-9

Nalliah, R., Sitters, H., Smith, A., & Di Stefano, J. (2021). Untangling the influences of fire, habitat and introduced predators on the endangered heath mouse. *Animal Conservation*, 1-13. doi:10.1111/acv.12731

Nams, V. O. (2005). Using animal movement paths to measure response to spatial scale. *Oecologia, 143*(2), 179-188. doi:10.1007/s00442-004-1804-z

Neary, D. G., Klopatek, C. C., F., D. L., & Ffolliott, P. F. (1999). Fire effects on belowground sustainability: a review and synthesis. *Forest Ecology and Management, 122*, 57- 71.

New, T. R., Yen, A. L., Sands, D. P. A., Greenslade, P., Neville, P. J., York, A., & Collett, N. G. (2010). Planned fires and invertebrate conservation in south east Australia. *Journal of Insect Conservation, 14*(5), 567-574. doi:10.1007/s10841-010-9284-4

Nielsen, J. M., Clare, E. L., Hayden, B., Brett, M. T., Kratina, P., & Gilbert, M. T. P. (2017). Diet tracing in ecology: Method comparison and selection. *Methods in Ecology and Evolution, 9*(2), 278-291. doi:10.1111/2041-210x.12869

Nimmo, D. G., AVitabile, S., Banks, S. C., Bliege Bird, R., Callister, K., Clarke, M. F., Dickman, C. R., Doherty, T. S., Driscoll, D. A., Greenville, A. C., Haslem, A., Kelly, L. T., Kenny, S. A., Lahoz-Monfort, J. J., Lee, C., Leonard, S., Moore, H., Newsome, T. M., Parr, C. L., Ritchie, E. G., Schneider, K., Turner, J. M., Watson, S., Westbrooke, M., Wouters, M., White, M. & Bennett, A. F. (2018). Animal movements in fire-prone landscapes. *Biological reviews of the Cambridge Philosophical Society*. doi:10.1111/brv.12486

Nimmo, D. G., Kelly, L. T., Spence-Bailey, L. M., Watson, S. J., Taylor, R. S., Clarke, M. F., & Bennett, A. F. (2013). Fire mosaics and reptile conservation in a fire-prone region. *Conservation Biology, 27*(2), 345-353. doi:10.1111/j.1523-1739.2012.01958.x

O’Donnell, M. S., & Ignizio, D. A. (2012). *Bioclimatic Predictors for Supporting Ecological Applications in the Conterminous United States*. US geological survey data series, 691(10), 4-9.

Oksanen, J., Blanchet, F. G., Friendly, M., Kindt, R., Legendre, P., McGlinn, D., Minchin, P. R., O'HARA, R. B., Simpson, G. L., Solymos, P., Henry, M., Stevens, H., Szoecs, E. & Wagner, H. (2020). ‘vegan’ Community Ecology Package (Version 2.5-7).

Orians, H. G., & Wittenberger, J. F. (1991). Spatial and Temporal Scales in Habitat Selection. *The American Society of Naturalists, 137,* S29-S49.

Orrock, J. L., Danielson, B. J.,, & Brinkerhoff, R. J. (2004). Rodent foraging is affected by indirect, but not by direct, cues of predation risk. *Behavioral Ecology, 15*(3), 433-437. doi:10.1093/beheco/arh031

Ozaki, S., Fritsch, C., Valot, B., Mora, F., Cornier, T., Scheifler, R., & Raoul, F. (2018). Does pollution influence small mammal diet in the field? A metabarcoding approach in a generalist consumer. *Molecular Ecology, 00,* 1–14. doi:10.1111/mec.14823

Paull, D. J., Claridge, A. W., & Barry, S. C. (2011). There’s no accounting for taste: bait attractants and infrared digital cameras for detecting small to medium ground-dwelling mammals. *Wildlife Research, 38*(3), 188-195.

Pausas, J. G., & Parr, C. L. (2018). Towards an understanding of the evolutionary role of fire in animals. *Evolutionary Ecology, 32*(2-3), 113-125. doi:10.1007/s10682-018-9927-6

Pavlacky, D. C., Blakesley, J. A., White, G. C., Hanni, D. J., & Lukacs, P. M. (2012). Hierarchical multi-scale occupancy estimation for monitoring wildlife populations. *The Journal of Wildlife Management, 76*(1), 154-162. doi:10.1002/jwmg.245

Pellegrini, A. F. A., Ahlstrom, A., Hobbie, S. E., Reich, P. B., Nieradzik, L. P., Staver, A. C., Scharenbroch, B. C., Jumpponen, A., Anderegg, W. R. L., Randerson, J. T. & Jackson, R. B. (2018). Fire frequency drives decadal changes in soil carbon and nitrogen and ecosystem productivity. *Nature, 553*(7687), 194-198. doi:10.1038/nature24668

Penman, T. D., Binns, D. L., Shiels, R. J., Allen, R. M., & Kavanagh, R. P. (2008). Changes in understorey plant species richness following logging and prescribed burning in shrubby dry sclerophyll forests of south-eastern Australia. *Austral Ecology, 33*(2), 197-210. doi:10.1111/j.1442-9993.2007.01809.x

Penman, T. D., Christie, F. J., Andersen, A. N., Bradstock, R. A., Cary, C. J., Henderson, M. K., Price, O., Tran, C., Wardle, G. M., Williams, R. J. & York, A. (2011). Prescribed burning: how can it work to conserve the things we value? *International Journal of Wildland Fire, 20*, 721-733.

Peters, A., Hume, S., Raidal, S., Crawley, L., & Gowland, D. (2021). Mortality associated with bushfire smoke inhalation in a captive population of the Smoky Mouse (*Pseudomys fumeus*), a threatened Australian rodent. *Journal of Wildlife Diseases, 57*(1), 199-204.

Platt, W. J., Orzell, S. L., & Slocum, M. G. (2015). Seasonality of Fire Weather Strongly Influences Fire Regimes in South Florida Savanna-Grassland Landscapes. *PLoS ONE, 10*(1), e0116952. doi:10.1371/journal.pone.0116952

Prichard, S. J., Stevens-Rumann, C. S., & Hessburg, P. F. (2017). Tamm Review: Shifting global fire regimes: Lessons from reburns and research needs. *Forest Ecology and Management, 396*, 217-233. doi:10.1016/j.foreco.2017.03.035

Pulsford, S. A., Lindenmayer, D. B., & Driscoll, D. A. (2014). A succession of theories: purging redundancy from disturbance theory. *Biological reviews of the Cambridge Philosophical Society, 91*(1), 148-167. doi:10.1111/brv.12163

Pyke, G. H. (2017). Fire-Stimulated Flowering: A Review and Look to the Future. *Critical Reviews in Plant Sciences, 36*(3), 179-189. doi:10.1080/07352689.2017.1364209

R Core Team. (2018). R: A language and environment for statistical computing. Vienna, Austria. : Foundation for Statistical Computing, . Retrieved from https://www.R-project.org/.

Rader, R., & Krockenberger, A. (2006). Does resource availability govern vertical stratification of small mammals in an Australian lowland tropical rainforest? *Wildlife Research, 33*, 571-576.

Rainsford, F. W., Kelly, L. T., Leonard, S. W., & Bennett, A. F. (2020). Post-fire development of faunal habitat depends on plant regeneration traits. *Austral Ecology, 45*(6), 800-812.

Rainsford, F. W., Kelly, L. T., Leonard, S. W. J., & Bennett, A. F. (2020). Post-fire development of faunal habitat depends on plant regeneration traits. *Austral Ecology*. doi:10.1111/aec.12896

Rathnasingham, S., & Hebert, P. D. N. (2007). BOLD : The Barcode of Life Data System (www.barcodinglife.org). *Molecular Ecology Notes, 7*, 355- 364. doi:10.1111/j.1471-8286.2006.01678.x

Robeson, M. S., Khanipov, K., Golovko, G., Wisely, S. M., White, M. D., Bodenchuck, M., Smyser, T. J., Fofanov, Y., Fierer, N. & Piaggio, A. J. (2018). Assessing the utility of metabarcoding for diet analyses of the omnivorous wild pig (*Sus scrofa*). *Ecology and Evolution, 8*(1), 185-196. doi:10.1002/ece3.3638

Robson, B. J., Chester, E. T., Matthews, T. G., & Johnston, K. (2018). Post-wildfire recovery of invertebrate diversity in drought-affected headwater streams. *Aquatic Sciences, 80*(2). doi:10.1007/s00027-018-0570-7

Ruppert, K. M., Kline, R. J., & Rahman, M. S. (2019). Past, present, and future perspectives of environmental DNA (eDNA) metabarcoding: A systematic review in methods, monitoring, and applications of global eDNA. *Global Ecology and Conservation, 17*, e00547. doi:10.1016/j.gecco.2019.e00547

Ryan, E., Bateman, P., Fernandes, K., van der Heyde, M., & Nevill, P. (2022). eDNA metabarcoding of log hollow sediments and soils highlights the importance of substrate type, frequency of sampling and animal size, for vertebrate species detection. *Environmental DNA*. 4(4), 940-953.

Santos, X., Mateos, E., Bros, V., Brotons, L., De Mas, E., Herraiz, J. A., Herrando, S., Mino, A., Olmo-Vidal, J. M., Quesada, J., Ribes, J., Sabate, S., Sauras-Yera, T., Serra, A., Vallejo, V. R. & Vinolas, A. (2014). Is response to fire influenced by dietary specialization and mobility? A comparative study with multiple animal assemblages. *PLoS One, 9*, e88224.

Schnell, I. B., Bohmann, K., & Gilbert, M. T. (2015). Tag jumps illuminated--reducing sequence-to-sample misidentifications in metabarcoding studies. *Mol Ecol Resour, 15*(6), 1289-1303. doi:10.1111/1755-0998.12402

Scott, A. C., Bowman, D. M. J. S., & Bond, W. J. (2013). *Fire on Earth: An Introduction*: John Wiley & Sons, Incorporated.

Seibold, S., Bässler, C., Brandl, R., Gossner, M. M., Thorn, S., Ulyshen, M. D., & Müller, J. (2015). Experimental studies of dead-wood biodiversity — A review identifying global gaps in knowledge. *Biological Conservation, 191*, 139-149. doi:10.1016/j.biocon.2015.06.006

Shattuck, S. O. (1999). *Australian ants: their biology and identification* (Vol. 3): CSIRO Publishing.

Shutt, J. D., Nicholls, J. A., Trivedi, U. H., Burgess, M. D., Stone, G. N., Hadfield, J. D., & Phillimore, A. B. (2020). Gradients in richness and turnover of a forest passerine's diet prior to breeding: a mixed model approach applied to faecal metabarcoding data. *Molecular Ecology, 29*, 1199-1213. doi:10.1111/mec.15394

Sitters, H., Christie, F. J., Di Stefano, J., Swan, M., Penman, T., Collins, P. C., & York, A. (2014). Avian responses to the diversity and configuration of fire age classes and vegetation types across a rainfall gradient. *Forest Ecology and Management, 318*, 13-20. doi:10.1016/j.foreco.2014.01.009

Smith, A. L. (2018). Successional changes in trophic interactions support a mechanistic model of post-fire population dynamics. *Oecologia, 186*(1), 129-139. doi:10.1007/s00442-017-4016-z

Smith, G. C. (1984). The Biology of the Yellow-Footed Antechinus, *Antechinus flavipes* (Marsupialia : Dasyuridae), in a Swamp Forest on Kinaba Island, Cooloola, Queensland. *Australian Wildlife Research, 11*, 465- 480.

Southgate, R., & Carthew, S. M. (2006). Diet of the bilby (*Macrotis lagotis*) in relation to substrate, fire and rainfall characteristics in the Tanami Desert. *Wildlife Research, 33,* 507- 519.

Spencer, R. J., Cavanough, V. C., Baxter, G. S., & Kennedy, M. S. (2005). Adult free zones in small mammal populations: response of Australian native rodents to reduced cover. *Austral Ecology, 30*(868-867).

Stapp, P. (1997). Habitat selection by an insectivorous rodent: Patterns and mechanisms across multiple scales. *Journal of Mammalogy, 78*(4), 1128- 1143.

State of the Climate. (2020). State of the Climate 2020. Retrieved from http://www.bom.gov.au/state-of-the-climate/

Stevens, N. B., Claire, J. S., Iqbal, M., Jennings, J. T., LaSalle, J., & Austin, A. D. (2007). *What Wasp is that ?* Australia: Australian Biological Resource Study, Centre for Biological Information Technology.

Stoddart, D. M. (1979). *Ecology of Small Mammals*. London: Chapman and Hall.

Stoeckle, M. Y., Das Mishu, M., & Charlop-Powers, Z. (2020). Improved Environmental DNA Reference Library Detects Overlooked Marine Fishes in New Jersey, United States. *Frontiers in Marine Science, 7*. doi:10.3389/fmars.2020.00226

Stojanovic, D., Neeman, T., Crates, R., Troy, S., & Heinsohn, R. (2020). Short-term impacts of prescribed burning on Orange-bellied Parrot (*Neophema chrysogaster*) food plant abundance. *Ecological Management & Restoration, 21*(3), 211-217. doi:10.1111/emr.12421

Stokes, V. L., Pech, R. P., Banks, P. B., & Arthur, A. D. (2004). Foraging behaviour and habitat use by *Antechinus flavipes* and Sminthopsis murina (Marsupialia: Dasyuridae) in response to predation risk in eucalypt woodland. *Biological Conservation, 117*(3), 331-342. doi:10.1016/j.biocon.2003.12.012

Storr, G. M. (1961). Microscopic Analysis of Faceces, A Technique for Ascertaining the Diet of Herbivorus Mammals. *Australian Journal of Biological Science, 14*(1), 157-168.

Strauß, A., Solmsdorff, K. Y., Pech, R., & Jacob, J. (2008). Rats on the run: removal of alien terrestrial predators affects bush rat behaviour. *Behavioral Ecology and Sociobiology, 62*(10), 1551-1558. doi:10.1007/s00265-008-0584-6

Sumner, J., & Dickman, C. R. (1998). Distribution and identity of species in the Antechinus stuartii–A. flavipes group (Marsupialia : Dasyuridae) in south-eastern Australia. *Australian Journal of Zoology, 46*, 27- 41.

Sutherland, E. F., & Dickman, C., R,. (1999). Mechanisms of recovery after fire by rodents in the Australian environment: a review. *Wildlife Research, 26*, 405-419.

Swan, M., Christie, F., Sitters, H., York, A., & Di Stefano, J. (2015). Predicting faunal fire responses in heterogeneous landscapes: the role of habitat structure. *Ecological Applications, 25*(8), 2293- 2305.

Swan, M., Sitters, H., Cawson, J., Duff, T., Wibisono, Y., & York, A. (2018). Fire planning for multispecies conservation: Integrating growth stage and fire severity. *Forest Ecology and Management, 415-416*, 85-97. doi:10.1016/j.foreco.2018.01.003

Swinburn, M. L., Fleming, P. A., Craig, M. D., Grigg, A. H., Garkaklis, M. J., Hobbs, R. J., & Hardy, G. E. S. J. (2007). The importance naked of grasstrees (*Xanthorrhoea preissii*) as habitat for mardo (*Antechinus flavipes leucogaster*) during post-fire recovery. *Wildlife Research, 34*, 640- 651.

Taberlet, P., Bonin, A., Zinger, L., & Coissac, E. (2018). *Environmental DNA: For Biodiversity Research and Monitoring*: Oxford Scholarship Online.

Taberlet, P., Coissac, E., Hajibabaei, M., & Rieseberg, L. H. (2012). *Environmental DNA*. In (Vol. 21, pp. 1789-1793): Wiley Online Library.

Taberlet, P., Coissac, E., Pompanon, F., Brochmann, C., & Willerslev, E. (2012). Towards next-generation biodiversity assessment using DNA metabarcoding. *Molecular Ecology, 21*(8), 2045-2050.

Taberlet, P., Coissac, E., Pompanon, F., Gielly, L., Miquel, C., Valentini, A., Vermat, T., Corthier, G., Brochmann, C. & Willerslev, E. (2007). Power and limitations of the chloroplast trnL (UAA) intron for plant DNA barcoding. *Nucleic Acids Res, 35*(3), e14. doi:10.1093/nar/gkl938

Tercel, M., Symondson, W. O. C., & Cuff, J. P. (2021). The problem of omnivory: A synthesis on omnivory and DNA metabarcoding. *Molecular Ecology, 30*(10), 2199-2206. doi:10.1111/mec.15903

Thomas, D. L., & Taylor, E. J. (2006). Study designs and tests for comparing resource use and availability II. *The Journal of Wildlife Management, 70*(2), 324-336.

Tokushima, H., & Jarman, P. J. (2008). Ecology of the rare but irruptive Pilliga mouse (Pseudomys pilligaensis). II. Demography, home range and dispersal. *Australian Journal of Ecology, 56,* 375- 387.

Tordoni, E., Ametrano, C. G., Banchi, E., Ongaro, S., Pallavicini, A., Bacaro, G., & Muggia, L. (2021). Integrated eDNA metabarcoding and morphological analyses assess spatio-temporal patterns of airborne fungal spores. *Ecological Indicators, 121,* 107032. doi:10.1016/j.ecolind.2020.107032

Tremblay, J. A., Desrochers, A., Aubry, Y., Pace, P., & Bird, D. M. (2017). A Low-Cost Technique for Radio-Tracking Wildlife Using a Small Standard Unmanned Aerial Vehicle. *Journal of Unmanned Vehicle Systems*. doi:10.1139/juvs-2016-0021

Valdivia-Carrillo, T., Rocha-Olivares, A., Reyes-Bonilla, H., Domínguez-Contreras, J. F., & Munguia-Vega, A. (2021). Integrating eDNA metabarcoding and simultaneous underwater visual surveys to describe complex fish communities in a marine biodiversity hotspot. *Molecular Ecology Resources, 21*(5), 1558-1574.

Valentine, L. E., Fisher, R., Wilson, B. A., Sonneman, T., Stock, W. D., Fleming, P. A., & Hobbs, R. J. (2014). Time since fire influences food resources for an endangered species, Carnaby's cockatoo, in a fire-prone landscape. *Biological Conservation, 175,* 1-9. doi:10.1016/j.biocon.2014.04.006

Venjakob, C., Ruedenauer, F. A., Klein, A. M., & Leonhardt, S. D. (2022). Variation in nectar quality across 34 grassland plant species. *Plant Biology (Stuttg), 24*(1), 134-144. doi:10.1111/plb.13343

Verkuil, Y. I., Nicolaus, M., Ubels, R., Dietz, M. M., Samplonius, J. M., Galema, A., Kiekebos, K., De Knijff, P. & Both, C. (2020). DNA metabarcoding successfully quantifies relative abundances of arthropod taxa in songbird diets: a validation study using camera-recorded diets. *bioRxiv*, 2020.2011.2026.399535. doi:10.1101/2020.11.26.399535

Vernes, K., Cooper, T., & Green, S. (2015). Seasonal fungal diets of small mammals in an Australian temperate forest ecosystem. *Fungal Ecology, 18,* 107-114. doi:10.1016/j.funeco.2015.09.015

Ward, M., Tulloch, A. I. T., Radford, J. Q., Williams, B. A., Reside, A. E., Macdonald, S. L., . . . Watson, J. E. M. (2020). Impact of 2019-2020 mega-fires on Australian fauna habitat. *Nature Ecology and Evolution, 4*(10), 1321-1326. doi:10.1038/s41559-020-1251-1

Watts, C. H. S. (1977). The Foods Eaten by some Australian Rodents (Muridae). *Australian Wildlife Research, 4,* 151- 157.

Wells, C., Kalko, E. K. V., Lakim, M. B., & Pfeifer, M. (2008). Movement and Ranging Patterns of a Tropical Rat (Leopoldamys sabanus) in Logged and Unlogged Rain Forests. *American Society of Mammalogists, 89,* 7-12-720.

Westerhuis, E. L., Schlesinger, C. A., Nano, C. E. M., Morton, S. R., & Christian, K. A. (2019). Characteristics of hollows and hollow-bearing trees in semi-arid river red gum woodland and potential limitations for hollow-dependent wildlife. *Austral Ecology, 44*(6), 995-1004. doi:10.1111/aec.12765

Whelan, R. J. (1995). *The Ecology of Fire*. Cambridge, United Kingdom: Cambridge University Press.

Whitehead, P. J., Bowman, D. M., Preece, N., Fraser, F., & Cooke, P. (2003). Customary use of fire by indigenous peoples in northernAustralia: its contemporary role in savanna management. *International Journal of Wildland Fire, 12*, 415- 425.

Whittaker, R. H., Levin, S. A., & Root, R. B. (1973). Niche, Habitat and Ecotope. *The American Naturalist*, *107*(955), 321- 338.

Wickham, H. (2016). ggplot2: Elegant Graphics for Data Analysis. . Springer-Verlag New York. Retrieved from https://ggplot2.tidyverse.org.

Wikars, L. 1997. *Effects of Fire and Ecology of Fire-Adapted Insects*. PhD, UNiversity of Uppsala.

Williams, M. R., & Faunt, K. (1997). Factors affecting the abundance of hollows in logs in jarrah forest of south-western Australia. *Forest Ecology and Management, 95*, 153-160.

Williams, R. J., & Bradstock, R. A. (1996). *Fire effects on vertebrate fauna and implications for fire management and conservation.* Retrieved from Biodiversity Unit, Department of the Environment, Sport and Territories, Commonwealth of Australia.

Wilson, B. A., & Garkaklis, M. J. (2020). Patterns of decline of small mammal assemblages in vegetation communities of coastal south-east Australia: identification of habitat refuges. *Australian Mammalogy*, 43(2), 203-220

Wintle, B. A., Legge, S., & Woinarski, J. C. Z. (2020). After the Megafires: What Next for Australian Wildlife? *Trends of Ecology and Evolution, 35*(9), 753-757. doi:10.1016/j.tree.2020.06.009

Woinarski, J., Armstrong, M., Brennan, K., Fisher, A., Griffiths, A. D., Hill, B., . . . Young, S. (2010). Monitoring indicates rapid and severe decline of native small mammals in Kakadu National Park, northern Australia. *Wildlife Research*, *37*, 116-126.

Woinarski, J. C., Burbidge, A. A., & Harrison, P. L. (2015). Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. *Proceedings of the National Academy of Sciences of the United States of America, 112*(15), 4531-4540. doi:10.1073/pnas.1417301112

Wood, S. N. (2011). Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society (B), 73*, 3-36.

Yang, J., Weisberg, P. J., Dilts, T. E., Loudermilk, E. L., Scheller, R. M., Stanton, A., & Skinner, C. (2015). Predicting wildfire occurrence distribution with spatial point process models and its uncertainty assessment: a case study in the Lake Tahoe Basin, USA. *International Journal of Wildland Fire, 24*(3), 380-390. doi:https://doi.org/10.1071/WF14001

York, A., Ashton, A., & Di Stefano, J. (2022). Diet of the yellow-footed antechinus' *Antechinus flavipes'. TheVictorian Naturalist, 139*(4), 112-116.

York, A., Bell, T. A., & Weston, C. J. (2012). Fire Regimes and soil-based ecological processes: implications for biodiversity. In R. J. Bradstock, R. J. Williams, & A. M. Gill (Eds.), *Flammable Australia: Fire Regimes, Biodiversity and Ecosystems ina Changing World* (pp. 127- 148). Collingwood, Victoria: CSIRO Publishing.

Yoshimura, H., Hirata, S., & Kinoshita, K. (2021). Plant-eating carnivores: Multispecies analysis on factors influencing the frequency of plant occurrence in obligate carnivores. *Ecology and Evolution, 11*(16), 10968-10983. doi:10.1002/ece3.7885

Yunger, J. A., Meserve, P. L., & Gutierrez, J. R. (2002). Small-Mammal Foraging Behavior: Mechanisms for Coexistence and Implication for Population Dynamics. *Ecological Monographs, 72*, 561-577.

Zeale, M. R., Butlin, R. K., Barker, G. L., Lees, D. C., & Jones, G. (2011). Taxon-specific PCR for DNA barcoding arthropod prey in bat faeces. *Molecular Ecology Resources, 11*(2), 236-244. doi:10.1111/j.1755-0998.2010.02920.x

Zylinski, S., Swan, M., & Sitters, H. (2022). Interrelationships between fire, habitat, and mammals in a fragmented heathy woodland. *Forest Ecology and Management, 522*. doi:10.1016/j.foreco.2022.120464

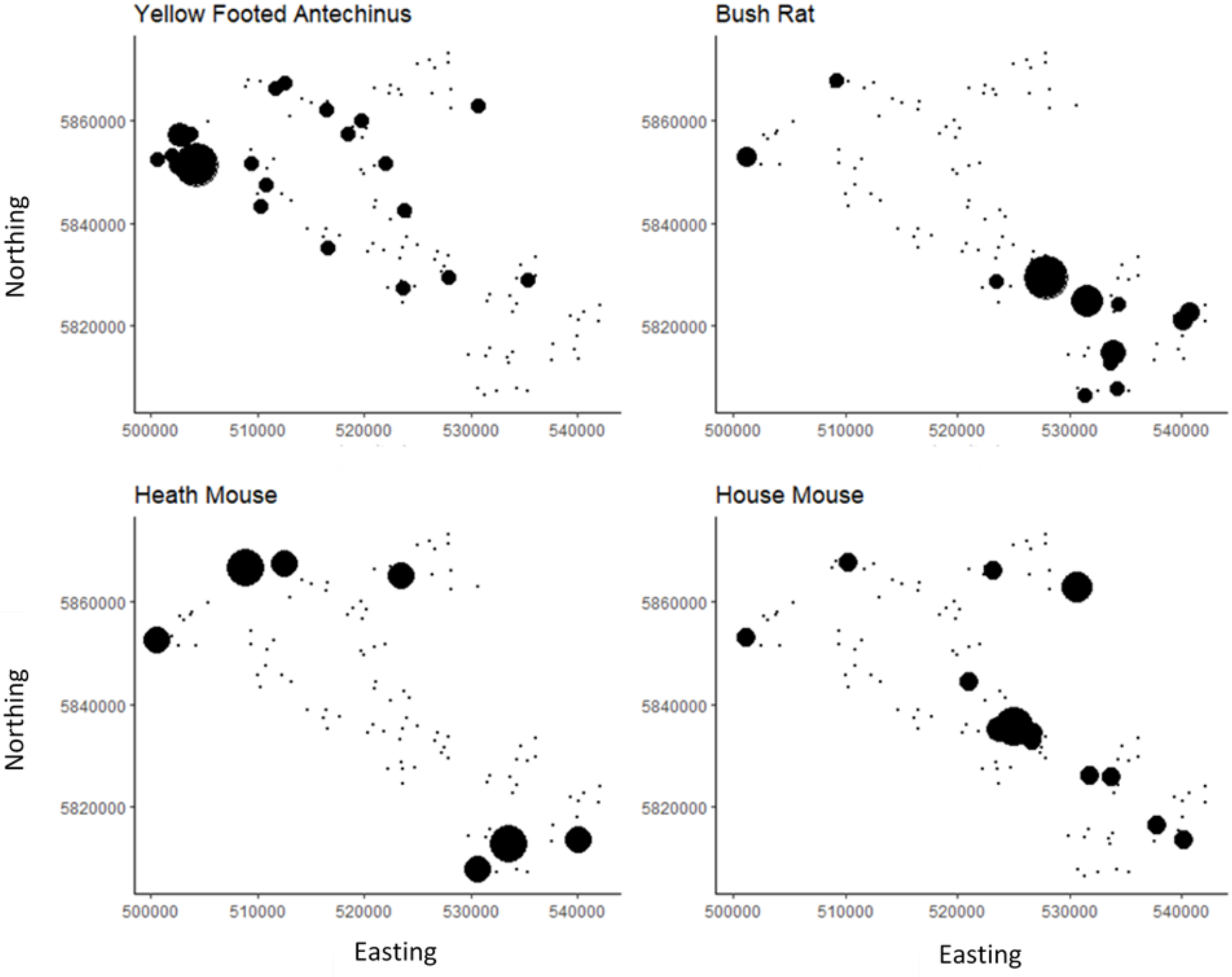
*Appendix A, Table 2 a-2 Elliott trap captures, and modelling information and error distributions used in modelling*

# Appendix

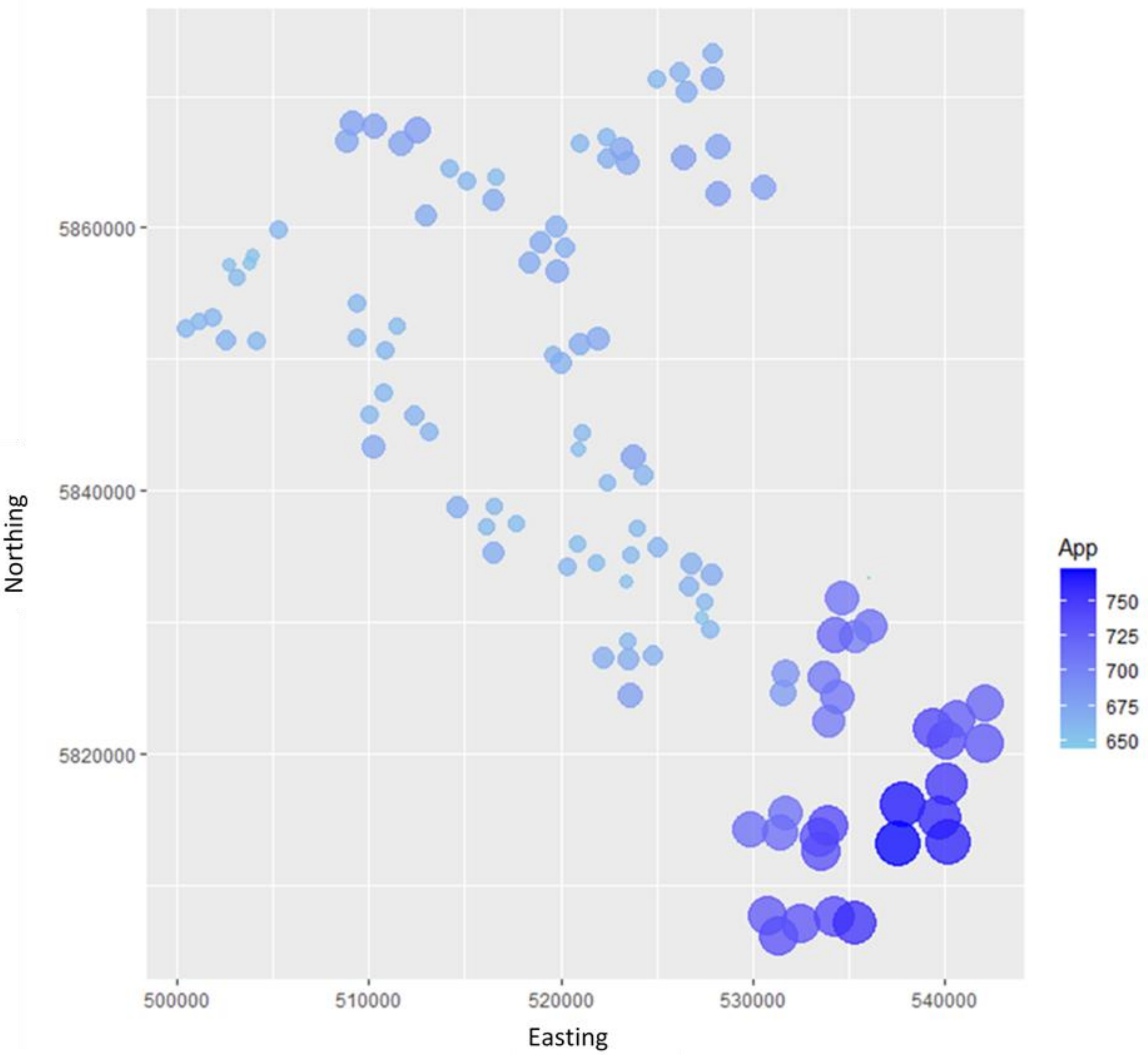
## A. Appendix A-Supplementary material for Chapter 2

*Appendix A, Table 1 a-1 Results of testing for landscape variable that is representing the spatial clustering, two models were created for each species with a random effect (landscape) and without a random effect. AICc (Akaike's Information Criterion for small sample sizes) showed the most parsimonious model does not require random effects f*

| **Species** | **AIC without a random effect** | **AIC with a random effect** |
|---|---|---|
| Yellow-footed antechinus (*Antechinus flavipes*) | 144.1858 | 144.2373 |
| Bush rat (*Rattus fuscipes*) | 83.56264 | 83. 88668 |
| Heath mouse (*Pseudomys shortridgei*) | 54.17349 | 56.28668 |
| House mouse (*Mus musculus*) | 84.25014 | 86.1315 |



*Appendix A, Figure 1 a-3 Occurrence of the selected small mammals in the study area. The size of the filled black circles is determined by the number of individuals captured at each site small black dots are study sites where there were no individuals captured.*



*Appendix A, Figure 2 a-4 Annual precipitation of the study sites (sum of all total monthly precipitation values) (Fick and Hijmans, 2017)*

# B. Appendix B-Supplementary material for Chapter 3

*Appendix B, Table 1 b-1 Number of scat samples, unique number of ZOTUs and mean prey number per a scat sample for each species*

| **Species** | **Scat samples** | **Number of unique ZOTUs** | **mean prey number per a scat sample** | **Std. Error of Mean** |
|---|---|---|---|---|
| Bush rat<br>(*Rattus fuscipes*) | 49 | 101 | 11.5 | 0.72 |
| Heath mouse<br>(*Pseudomys shortridgei*) | 31 | 92 | 10.9 | 0.81 |
| Yellow-footed antechinus<br>(*Antechinus flavipes*) | 42 | 77 | 10.5 | 1.01 |
| All 3 species | 112 | 155 | 11.0 | 0.49 |

*Appendix B, Table 2 b-2 Pairwise analysis of the diets from PERMANOVA of three species for different post- fire growth*

**Bush rat**

| **Pairs** | **df** | **Sums of squares** | **Pseudo-*F*** | **$R^2$** | **P** |
|---|---|---|---|---|---|
| Late vs recent | 1 | 0.65 | 3.13 | 0.09 | 0.002* |
| Late vs mid | 1 | 0.49 | 2.13 | 0.06 | 0.023**.** |
| Recent vs mid | 1 | 1.08 | 5.20 | 0.15 | 0.001* |

**Yellow-footed antechinus**

| **Pairs** | **df** | **Sums of squares** | **Pseudo-*F*** | **$R^2$** | **P** |
|---|---|---|---|---|---|
| Mid vs late | 1 | 0.36 | 1.45 | 0.05 | 0.135 |
| Mid vs recent | 1 | 0.32 | 1.51 | 0.08 | 0.122 |
| Late vs Recent | 1 | 0.53 | 2.19 | 0.06 | 0.013**.** |

**Heath mouse**

| **Pairs** | **df** | **Sums of squares** | **Pseudo-*F*** | **$R^2$** | **P** |
|---|---|---|---|---|---|
| Mid vs late | 1 | 0.25 | 1.20 | 0.07 | 0.277 |
| Mis vs recent | 1 | 0.45 | 2.02 | 0.09 | 0.025. |
| Late vs recent | 1 | 0.29 | 1.47 | 0.07 | 0.115 |

*Appendix B, Table 3 b-3 List of food species detected for yellow-footed antechinus scat samples*

---

**Yellow-footed antechinus (***Antechinus flavipes***)**

**Scat samples = 42**

---

**List of arthropods detected from COI metabarcode (Unique ZOTUs = 38)**

---

| **Class** | **Order** | **Family** | **Genus/ Species** | **ZOTU ID** | **Sum of frequency of occurrence** |
|---|---|---|---|---|---|
| Insecta | Lepidoptera | | UNKNOWN | ZOTU57 | 7 |
| | | Limacodidae | *Doratifera oxleyi* | ZOTU28 | 16 |
| | | | *Doratifera* sp. | ZOTU29 | 2 |
| | | Geometridae | *Idiodes siculoides* | ZOTU23 | 13 |
| | | | *Idiodes apicata* | ZOTU22 | 2 |
| | | | UNKNOWN | ZOTU24 | 1 |
| | | Noctuidae | *Thoracolopha spilocrossa* | ZOTU35 | 12 |
| | | | *Agrotis porphyricollis* | ZOTU30 | 6 |
| | | | *Thoracolopha melanographa* | ZOTU34 | 5 |
| | | | *Agrotis* sp. | ZOTU31 | 2 |
| | | | *Persectania dyscrita* | ZOTU32 | 2 |
| | | | *Proteuxoa hypochalchis* | ZOTU33 | 1 |
| | | | UNKNOWN | ZOTU36 | 1 |
| | | Oecophoridae | *Prodelaca achalinella* | ZOTU43 | 4 |
| | | | *Prodelaca* sp. | ZOTU44 | 4 |
| | | | *Enoplidia simplex* | ZOTU37 | 2 |
| | | | *Eomichla* sp. | ZOTU38 | 1 |
| | | | *Garrha* sp. | ZOTU41 | 1 |
| | | | *Heliocausta oecophorella* | ZOTU42 | 1 |
| | | | UNKNOWN | ZOTU45 | 1 |
| | | Hepialidae | *Oxycanus sp.* | ZOTU26 | 5 |

| | | | | | |
|---|---|---|---|---|---|
| | | Erebidae | *Castulo doubledayi* | ZOTU16 | 4 |
| | | | *Calamidia hirta* | ZOTU15 | 1 |
| | | | *Praxis aterrima* | ZOTU19 | 1 |
| | | Psychidae | *Cebysa leucotelus* | ZOTU46 | 2 |
| | | | *Lepidoscia retinochra* | ZOTU48 | 1 |
| | | Pyralidae | *Stericta carbonalis* | ZOTU51 | 3 |
| | | | *Endotricha pyrosalis* | ZOTU49 | 2 |
| | | Tineidae | *Tineola bisselliella* | ZOTU53 | 4 |
| | | Cosmopterigidae | *Macrobathra ceraunobola* | ZOTU12 | 1 |
| | Blattodea | Blaberidae | *Calolampra sp.* | ZOTU3 | 10 |
| | Coleoptera | Carabidae | UNKNOWN | ZOTU4 | 7 |
| | | Dermestidae | UNKNOWN | ZOTU6 | 4 |
| | | Cleridae | *Eleale* sp. | ZOTU5 | 1 |
| | Diptera | | UNKNOWN | ZOTU11 | 1 |
| | | Phoridae | *Megaselia* sp. | ZOTU9 | 2 |
| | Neuroptera | Hemerobiidae | *Micromus tasmaniae* | ZOTU58 | 2 |
| Arachnida | Araneae | Miturgidae | *Cheiracanthium* sp. | ZOTU2 | 1 |

**List of plants detected from trnL metabarcode (Unique ZOTUs = 54)**

| **Class** | **Order** | **Family** | **Genus/ Species** | **ZOTU ID** | **Sum of frequency of occurrence** |
|---|---|---|---|---|---|
| Streptophyta | | | UNKNOWN | ZOTU162 | 37 |
| Magnoliopsida | | | UNKNOWN | ZOTU154 | 14 |
| | Myrtales | | UNKNOWN | ZOTU114 | 37 |
| | | Myrtaceae | UNKNOWN | ZOTU115 | 30 |
| | Fabales | Fabaceae | UNKNOWN | ZOTU99 | 15 |
| | | | *Acacia* sp. | ZOTU93 | 9 |
| | | | *Kennedia* sp. | ZOTU95 | 2 |

| | | | | |
|---|---|---|---|---|
| Asterales | Asteraceae | UNKNOWN | ZOTU78 | 14 |
| | | *Aster* sp. | ZOTU77 | 6 |
| Proteales | Proteaceae | *Persoonia* sp. | ZOTU141 | 11 |
| | | UNKNOWN | ZOTU133 | 1 |
| Oxalidales | Elaeocarpaceae | *Tetratheca* sp. | ZOTU117 | 7 |
| | Oxalidaceae | *Oxalis* sp. | ZOTU118 | 2 |
| Poales | Poaceae | *Cenchrus* sp. | ZOTU129 | 7 |
| | | *Microlaena* sp. | ZOTU132 | 3 |
| | | *Stipa* sp. | ZOTU134 | 2 |
| | | UNKNOWN | ZOTU135 | 2 |
| | | *Holcus* sp. | ZOTU130 | 1 |
| | | *Rytidosperma* sp. | ZOTU133 | 1 |
| | Restionaceae | *Hypolaena* sp. | ZOTU137 | 2 |
| | | *Leptocarpus* sp. | ZOTU138 | 2 |
| | Cyperaceae | *Lepidosperma tortuosum* | ZOTU120 | 1 |
| | | *Schoenus apogon* | ZOTU124 | 1 |
| Apiales | Araliaceae | *Hydrocotyle* sp. | ZOTU66 | 6 |
| | Apiaceae | UNKNOWN | ZOTU65 | 2 |
| Asparagales | Asphodelaceae | *Xanthorrhoea* sp. | ZOTU74 | 6 |
| Gentianales | Rubiaceae | UNKNOWN | ZOTU104 | 5 |
| Brassicales | Brassicaceae | *Brassica* sp. | ZOTU83 | 3 |
| | | UNKNOWN | ZOTU84 | 1 |
| Caryophyllales | Polygonaceae | UNKNOWN | ZOTU88 | 3 |
| Fagales | Juglandaceae | UNKNOWN | ZOTU101 | 3 |
| Geraniales | Geraniaceae | *Geranium* sp. | ZOTU105 | 3 |
| Solanales | Solanaceae | *Solanum* sp. | ZOTU151 | 3 |
| | | *Capsicum* sp. | ZOTU150 | 2 |
| Zingiberales | Musaceae | UNKNOWN | ZOTU153 | 3 |
| Malpighiales | Euphorbiaceae | *Amperea xiphoclada* | ZOTU109 | 2 |
| Arecales | Arecaceae | UNKNOWN | ZOTU70 | 1 |
| Fagales | Casuarinaceae | *Casuarina* sp. | ZOTU100 | 1 |
| Lamiales | Oleaceae | *Ligustrum* sp. | ZOTU106 | 1 |
| | Plantaginaceae | *Plantago* sp. | ZOTU107 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| | | Scrophulariaceae | *Leucophyllum mojinense* | ZOTU108 | 1 |
| | Rosales | Rhamnaceae | UNKNOWN | ZOTU143 | 1 |
| | | Rosaceae | *Rosa* sp. | ZOTU144 | 1 |
| | | | UNKNOWN | ZOTU145 | 1 |
| | | Ulmaceae | UNKNOWN | ZOTU146 | 1 |
| | Sapindales | Rutaceae | UNKNOWN | ZOTU148 | 1 |
| | Vitales | Vitaceae | UNKNOWN | ZOTU152 | 1 |
| Pinopsida | Pinales | Pinaceae | UNKNOWN | ZOTU157 | 16 |
| | Cupressales | Cupressaceae | *Callitris* sp. | ZOTU155 | 5 |
| | | | *Hesperocyparis* sp. | ZOTU156 | 4 |
| Polypodiopsida | Polypodiales | Dennstaedtiaceae | UNKNOWN | ZOTU160 | 16 |
| | Cyatheales | Dicksoniaceae | *Calochlaena* sp. | ZOTU158 | 2 |
| | | | *Dicksonia* sp. | ZOTU159 | 1 |
| Bryopsida | Hypnodendrales | Racopilaceae | *Racopilum* sp. | ZOTU61 | 2 |

## *Appendix B, Table 4 b-4 List of food species detected for bush rat scat samples*

**Bush rat (**Rattus *fuscipes***)**

**Scat samples = 49**

**List of arthropods detected from COI metabarcode (Unique ZOTUs = 36)**

| **Class** | **Order** | **Family** | **Genus/ Species** | **ZOTU ID** | **Sum of frequency of occurrence** |
|---|---|---|---|---|---|
| Insecta | Coleoptera | Carabidae | UNKNOWN | ZOTU4 | 21 |
| | | Dermestidae | UNKNOWN | ZOTU6 | 7 |
| | | Cleridae | *Eleale* sp. | ZOTU5 | 1 |
| | Diptera | Phoridae | UNKNOWN | ZOTU10 | 11 |
| | | | UNKNOWN | ZOTU11 | 4 |
| | | | *Megaselia* sp. | ZOTU9 | 2 |
| | | Ceratopogonidae | UNKNOWN | ZOTU7 | 2 |
| | | Chironomidae | *Polypedilum* sp. | ZOTU8 | 1 |
| | Lepidoptera | | UNKNOWN | ZOTU57 | 3 |
| | | Hepialidae | *Elhamma australasiae* | ZOTU25 | 6 |
| | | | *Oxycanus* sp. | ZOTU26 | 2 |
| | | Limacodidae | *Doratifera oxleyi* | ZOTU28 | 6 |
| | | Zygaenidae | *Myrtartona coronias* | ZOTU55 | 4 |
| | | Oecophoridae | *Heliocausta oecophorella* | ZOTU42 | 3 |
| | | | *Ericrypsina* sp. | ZOTU39 | 1 |
| | | | *Eulechria suffusa* | ZOTU40 | 1 |
| | | Erebidae | *Philenora omophanes* | ZOTU18 | 2 |
| | | | *Praxis aterrima* | ZOTU19 | 2 |
| | | Geometridae | *Idiodes apicata* | ZOTU22 | 2 |
| | | | *Chrysolarentia trygodes* | ZOTU21 | 1 |
| | | | *Idiodes siculoides* | ZOTU23 | 1 |
| | | Noctuidae | *Thoracolopha spilocrossa* | ZOTU35 | 2 |
| | | | *Agrotis porphyricollis* | ZOTU30 | 1 |
| | | Tortricidae | *Bathrotoma constrictana* | ZOTU54 | 2 |
| | | Cosmopterigidae | *Macrobathra chrysotoxa* | ZOTU13 | 1 |
| | | Elachistidae | *Agriophara platyscia* | ZOTU14 | 1 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
|  |  | Erebidae | *Phaeophlebosia furcifera* | ZOTU17 | 1 |
|  |  |  | *Praxis difficilis* | ZOTU20 | 1 |
|  |  | Lasiocampidae | *Porela albifinis* | ZOTU27 | 1 |
|  |  | Psychidae | *Clania ignobilis* | ZOTU47 | 1 |
|  |  |  | *Lepidoscia retinochra* | ZOTU48 | 1 |
|  |  | Tineidae | *Opogona stereodyta* | ZOTU52 | 1 |
|  |  |  | *Tineola bisselliella* | ZOTU53 | 1 |
|  | Blattodea | Blaberidae | *Calolampra sp.* | ZOTU3 | 1 |
|  | Neuroptera | Osmylidae | *Stenosmylus tenuis* | ZOTU59 | 1 |
| Malacostraca | Decapoda | Parastacidae | *Geocharax gracilis* | ZOTU60 | 2 |

**List of plants detected from trnL metabarcode (Unique ZOTUs = 65)**

| Class | Order | Family | Genus/ Species | ZOTU ID | Sum of frequency of occurrence |
|---|---|---|---|---|---|
| Streptophyta |  |  | UNKNOWN | ZOTU162 | 39 |
| Magnoliopsida |  |  | UNKNOWN | ZOTU154 | 29 |
|  | Myrtales | Myrtaceae | UNKNOWN | ZOTU115 | 38 |
|  |  |  | UNKNOWN | ZOTU114 | 37 |
|  | Asterales | Asteraceae | UNKNOWN | ZOTU78 | 30 |
|  |  |  | *Aster* sp. | ZOTU77 | 22 |
|  |  | Campanulaceae | *Lobelia anceps* | ZOTU79 | 7 |
|  |  |  | UNKNOWN | ZOTU81 | 6 |
|  |  |  | *Wahlenbergia marginata* | ZOTU80 | 3 |
|  |  | Goodeniaceae | *Goodenia rosulata* | ZOTU82 | 1 |
|  | Fabales | Fabaceae | UNKNOWN | ZOTU99 | 21 |
|  |  |  | *Acacia* sp. | ZOTU93 | 17 |
|  |  |  | *Pultenaea* sp. | ZOTU96 | 4 |
|  |  |  | *Viminaria juncea* | ZOTU98 | 2 |
|  |  |  | *Templetonia egena* | ZOTU97 | 1 |
|  | Poales | Restionaceae | *Leptocarpus* sp. | ZOTU138 | 17 |
|  |  |  | *Hypolaena* sp. | ZOTU137 | 11 |
|  |  |  | *Centrolepis monogyna* | ZOTU136 | 4 |
|  |  |  | UNKNOWN | ZOTU139 | 3 |

| | | | | |
|---|---|---|---|---|
| | Poaceae | *Microlaena* sp. | ZOTU132 | 8 |
| | | UNKNOWN | ZOTU135 | 3 |
| | | *Cenchrus* sp. | ZOTU129 | 1 |
| | Cyperaceae | *Gahnia* sp. | ZOTU119 | 4 |
| | | *Lepidosperma tortuosum* | ZOTU120 | 2 |
| | | *Machaerina* sp. | ZOTU123 | 1 |
| | Juncaceae | *Juncus* sp. | ZOTU126 | 2 |
| | | *Luzula* sp. | ZOTU127 | 2 |
| Fagales | Juglandaceae | UNKNOWN | ZOTU101 | 4 |
| | Casuarinaceae | *Casuarina* sp. | ZOTU100 | 15 |
| Proteales | Proteaceae | *Persoonia* sp. | ZOTU141 | 15 |
| | | UNKNOWN | ZOTU142 | 3 |
| | | *Isopogon anemonifolius* | ZOTU140 | 1 |
| Asparagales | Asphodelaceae | *Xanthorrhoea* sp. | ZOTU74 | 10 |
| | Iridaceae | UNKNOWN | ZOTU75 | 10 |
| | Orchidaceae | UNKNOWN | ZOTU76 | 4 |
| | Asparagaceae | *Lomandra multiflora* | ZOTU73 | 3 |
| Gentianales | Rubiaceae | UNKNOWN | ZOTU104 | 10 |
| | Loganiaceae | *Mitrasacme pilosa* | ZOTU102 | 6 |
| Apiales | | UNKNOWN | ZOTU69 | 7 |
| | Araliaceae | *Hydrocotyle* sp. | ZOTU66 | 7 |
| | | *Panax* sp. | ZOTU68 | 2 |
| | | *Macropanax dispermus* | ZOTU67 | 1 |
| | Apiaceae | *Centella* sp. | ZOTU63 | 3 |
| | | UNKNOWN | ZOTU65 | 2 |
| | | *Mackinlaya* sp. | ZOTU64 | 1 |
| Sapindales | Rutaceae | *Boronia* sp. | ZOTU148 | 5 |
| | | UNKNOWN | ZOTU149 | 1 |
| Dilleniales | Dilleniaceae | *Tetracera* sp. | ZOTU91 | 4 |
| | | *Tetracera nordtiana* | ZOTU90 | 3 |
| Malpighiales | Violaceae | *Melicytus dentatus* | ZOTU111 | 3 |
| Rosales | Rosaceae | *Rosa* sp. | ZOTU144 | 2 |
| Solanales | Solanaceae | *Solanum* sp. | ZOTU151 | 2 |

| | | | | | |
|---|---|---|---|---|---|
| | Zingiberales | Musaceae | UNKNOWN | ZOTU153 | 2 |
| | Brassicales | Brassicaceae | *Brassica* sp. | ZOTU83 | 1 |
| | Caryophyllales | Droseraceae | *Drosera erythrorhiza* | ZOTU86 | 1 |
| | Celastrales | Celastraceae | *Stackhousia* sp. | ZOTU89 | 1 |
| | Ericales | Theaceae | UNKNOWN | ZOTU92 | 1 |
| | Lamiales | Plantaginaceae | *Plantago* sp. | ZOTU107 | 1 |
| | Malpighiales | Euphorbiaceae | *Amperea xiphoclada* | ZOTU109 | 1 |
| | Malvales | Thymelaeaceae | *Pimelea* sp. | ZOTU113 | 1 |
| | Oxalidales | Elaeocarpaceae | *Tetratheca* sp. | ZOTU117 | 1 |
| | Santalales | Loranthaceae | *Muellerina eucalyptoides* | ZOTU147 | 1 |
| Polypodiopsida | Polypodiales | Dennstaedtiaceae | UNKNOWN | ZOTU160 | 9 |
| Pinopsida | Pinales | Pinaceae | UNKNOWN | ZOTU157 | 4 |
| Lycopodiopsida | Isoetales | Isoetaceae | *Isoetes* sp. | ZOTU62 | 2 |

## *Appendix B, Table 5 b-5 List of food species detected for heath mouse scat samples*

**Heath mouse (*Pseudomys shortridgei*)**

**Scat samples = 31**

**List of arthropods detected from COI metabarcode (Unique ZOTUs = 15)**

| **Class** | **Order** | **Family** | **Genus/ Species** | **ZOTU ID** | **Sum of frequency of occurrence** |
|---|---|---|---|---|---|
| Insecta | Coleoptera | Carabidae | UNKNOWN | ZOTU4 | 4 |
| | | Dermestidae | UNKNOWN | ZOTU6 | 2 |
| | Diptera | Phoridae | UNKNOWN | ZOTU10 | 3 |
| | Lepidoptera | | UNKNOWN | ZOTU57 | 2 |
| | | Psychidae | *Clania ignobilis* | ZOTU47 | 2 |
| | | Erebidae | *Phaeophlebosia furcifera* | ZOTU17 | 1 |
| | | | *Praxis aterrima* | ZOTU19 | 1 |
| | | Limacodidae | *Doratifera oxleyi* | ZOTU28 | 1 |
| | | Oecophoridae | *Garrha* sp. | ZOTU41 | 1 |
| | | | UNKNOWN | ZOTU45 | 1 |
| | | Pyralidae | *Plodia interpunctella* | ZOTU50 | 1 |
| | | Tineidae | *Tineola bisselliella* | ZOTU53 | 1 |
| | | Zygaenidae | *Myrtartona coronias* | ZOTU55 | 1 |
| | | | *Pollanisus viridipulverulenta* | ZOTU56 | 1 |
| Arachnida | Araneae | Araneidae | *Argiope protensa* | ZOTU1 | 1 |

**List of plants detected from trnL metabarcode (Unique ZOTUs = 62)**

| **Class** | **Order** | **Family** | **Genus/ Species** | | **Sum of frequency of occurrence** |
|---|---|---|---|---|---|
| Streptophyta | | | UNKNOWN | ZOTU162 | 27 |
| Magnoliopsida | | | UNKNOWN | ZOTU154 | 5 |
| | Poales | Restionaceae | *Hypolaena* sp. | ZOTU137 | 23 |
| | | | *Leptocarpus* sp. | ZOTU138 | 23 |
| | | | *Centrolepis monogyna* | ZOTU136 | 1 |
| | | | UNKNOWN | ZOTU139 | 1 |
| | | Cyperaceae | *Schoenus apogon* | ZOTU124 | 6 |

| | | | | |
|---|---|---|---|---|
| | | *Lepidosperma* sp. | ZOTU121 | 3 |
| | | *Lepidosperma tortuosum* | ZOTU120 | 3 |
| | | *Machaerina gunnii* | ZOTU122 | 2 |
| | | *Machaerina* sp. | ZOTU123 | 1 |
| | | *Schoenus lepidosperma* | ZOTU125 | 1 |
| | Poaceae | *Stipa* sp. | ZOTU134 | 5 |
| | | *Microlaena* sp. | ZOTU132 | 3 |
| | | UNKNOWN | ZOTU135 | 2 |
| | | *Holcus* sp. | ZOTU130 | 1 |
| Gentianales | Rubiaceae | UNKNOWN | ZOTU104 | 20 |
| | Rubiaceae | *Lasianthus* sp. | ZOTU103 | 1 |
| | Loganiaceae | *Mitrasacme pilosa* | ZOTU102 | 4 |
| Myrtales | | UNKNOWN | ZOTU115 | 17 |
| | Myrtaceae | UNKNOWN | ZOTU114 | 19 |
| | Fabaceae | UNKNOWN | ZOTU99 | 16 |
| | | *Acacia* sp. | ZOTU93 | 4 |
| | | *Daviesia* sp. | ZOTU94 | 2 |
| | | *Pultenaea* sp. | ZOTU96 | 1 |
| Fagales | Casuarinaceae | *Casuarina* sp. | ZOTU100 | 13 |
| | Juglandaceae | UNKNOWN | ZOTU101 | 3 |
| Asterales | Asteraceae | UNKNOWN | ZOTU78 | 12 |
| | | *Aster* sp. | ZOTU77 | 9 |
| | Campanulaceae | *Wahlenbergia marginata* | ZOTU80 | 2 |
| | | UNKNOWN | ZOTU81 | 2 |
| | Goodeniaceae | *Goodenia rosulata* | ZOTU82 | 1 |
| Proteales | Proteaceae | *Isopogon anemonifolius* | ZOTU140 | 10 |
| | | *Persoonia* sp. | ZOTU141 | 9 |
| | | UNKNOWN | ZOTU142 | 4 |
| Asparagales | Asphodelaceae | *Xanthorrhoea* sp. | ZOTU74 | 9 |
| | Asparagaceae | *Lomandra multiflora* | ZOTU73 | 4 |
| | Iridaceae | UNKNOWN | ZOTU75 | 4 |
| | Amaryllidaceae | *Allium* sp. | ZOTU72 | 1 |
| | Orchidaceae | UNKNOWN | ZOTU76 | 1 |

| | | | | | |
|---|---|---|---|---|---|
| | Sapindales | Rutaceae | *Boronia* sp. | ZOTU148 | 7 |
| | | | UNKNOWN | ZOTU149 | 2 |
| | Dilleniales | Dilleniaceae | *Tetracera nordtiana* | ZOTU90 | 4 |
| | | | *Tetracera* sp. | ZOTU91 | 4 |
| | Apiales | | UNKNOWN | ZOTU69 | 3 |
| | | Apiaceae | UNKNOWN | ZOTU65 | 1 |
| | | Araliaceae | *Panax* sp. | ZOTU68 | 1 |
| | Malvales | Thymelaeaceae | *Pimelea* sp. | ZOTU113 | 2 |
| | Solanales | Solanaceae | *Capsicum* sp. | ZOTU150 | 2 |
| | Pinales | Pinaceae | UNKNOWN | ZOTU157 | 2 |
| | Isoetales | Isoetaceae | *Isoetes* sp. | ZOTU62 | 1 |
| | Caryophyllales | Droseraceae | *Drosera erythrorhiza* | ZOTU86 | 1 |
| | | Polygonaceae | *Persicaria* sp. | ZOTU87 | 1 |
| | Lamiales | Plantaginaceae | *Plantago* sp. | ZOTU107 | 1 |
| | Malpighiales | Euphorbiaceae | *Amperea xiphoclada* | ZOTU109 | 1 |
| | Oxalidales | Elaeocarpaceae | *Tetratheca* sp. | ZOTU117 | 1 |
| | Rosales | Rosaceae | *Rosa* sp. | ZOTU144 | 1 |
| | | Ulmaceae | UNKNOWN | ZOTU146 | 1 |
| | Santalales | Loranthaceae | *Muellerina eucalyptoides* | ZOTU147 | 1 |
| | Zingiberales | Musaceae | UNKNOWN | ZOTU153 | 1 |
| Pinopsida | Cupressales | Cupressaceae | *Hesperocyparis* sp. | ZOTU156 | 1 |
| Polypodiopsida | Schizaeales | Schizaeaceae | *Schizaea elegans* | ZOTU161 | 1 |

# C. Appendix C -Supplementary material for Chapter 4

*Appendix C, Table 1 c-1 Elliott trapping capture results*

| Site ID | Individual ID | M/F | Radio transmitter attached (Y/N) | Collar lost | Animal missing before enough tracking points obtained | Enough tracking points obtained | Number of fixes |
|---|---|---|---|---|---|---|---|
| 27 | YFA/27/01 | F | Y | - | - | ✓ | 28 |
| 29 | YFA/29/01 | M | Y | ✓ | ✓ | - | NA |
| 29 | YFA/29/02 | F | Y | - | ✓ | - | NA |
| 29 | YFA/29/03 | M | Y | - | ✓ | - | NA |
| 29 | YFA/29/04 | F | Y | ✓ | ✓ | - | NA |
| 29 | YFA/29/05 | F | Y | - | ✓ | - | NA |
| 29 | YFA/29/06 | M | Y | - | ✓ | - | NA |
| 66 | YFA/66/01 | M | Y | - | - | ✓ | 16 |
| 66 | YFA/66/02 | F | N | - | - | ✓ | 14 |
| 66 | YFA/66/03 | F | Y | - | - | ✓ | 15 |
| 66 | YFA/66/04 | M | Y | - | - | ✓ | 15 |
| 66 | YFA/66/05 | F | Y | - | - | - | NA |
| 66 | YFA/66/06 | F | N | - | - | - | NA |
| 66 | YFA/66/07 | F | N | - | - | - | NA |
| 66 | YFA/66/08 | F | N | - | - | - | NA |