Fall 2019

From traps to snapshots: Examining the ecology of feral predators and native small mammals in southeastern Australia through case studies of two faunal sampling methods

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SIT Study Abroad

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Submitted in partial fulfillment of the requirements for Australia: Rainforest, Reef, and Cultural Ecology, SIT Study Abroad, Fall 2019

Abstract

The red fox (*Vulpes vulpes*) and feral cat (*Felis catus*) are introduced mesopredators that significantly threaten native small mammal species in Australia. For decades, environmental managers have attempted to mitigate the effects of these introduced species. However, ecosystems are highly complex, making it difficult to assess the impacts of feral predators on communities of native fauna independent of other disturbances such as fire regime and habitat fragmentation. Cost-effective ecological monitoring programs are imperative for evaluating threats to native species and informing environmental decisions. New technology has become increasingly present in wildlife monitoring, and camera trapping has provided an alternative to traditional live trapping methods such as the use of wire cages. This study evaluates the function of live trap and camera trap methods in the context of two case studies of faunal monitoring projects in Victoria, Australia. The advantages and limitations of each method were examined for their project and site-based applications and broader role in biodiversity conservation. The investigation revealed that both live trapping and camera trapping represent valuable tools for ecological monitoring in the context of each project. The principal difference between the choice of sampling method pertained to individual project aims and scale.

Keywords: camera trap, conservation, ecological monitoring, feral cat, live trap, introduced predator, potoroo, red fox, small mammal

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Acknowledgements

I would like to thank my advisor, Euan Ritchie, for connecting me with the two research projects in this paper, through which I got to experience so many different parts of southeastern Australia! My appreciation to Ange Pestell for sharing her experiences in conservation and genuine excitement about the plants and animals of the Victorian mallee. I would also like to thank Meg Farmer for sharing the background and process of her current research on French Island and for giving me insights about my own project. Many thanks to Tony Cummings and Jack Grant for their guidance during the outline and research phases of my ISP and through the entirety of this study abroad program. Finally, I want to express my deep gratitude and love for my family: to my sister, Caroline, and my parents, Linda and James. Thank you for your endless support and for always encouraging me to explore, learn, and do what I love.

I. INTRODUCTION

a. Impact of introduced mesopredators in Australia

Over the last 200 years, introduced predators have threatened Australia's native species (Radford *et al*. 2018). Specifically, the red fox *(Vulpes vulpes)* and feral cat *(Felis catus)* have had a significant impact on faunal distribution in Australian ecosystems. These species are mesopredators, medium-sized and middle trophic level predators that are smaller than Australia's apex predator, the dingo *(Canis lupus dingo)*. Following the removal of the dingo with the expansion of agriculture and urbanization, foxes and cats have significantly increased in their abundance and activity across Australian ecosystems (Payne *et al*. 2014). The two species are opportunistic predators, and their flexible diet and habitat range have contributed to the widespread decline of native fauna, including small mammals, reptiles, and birds (May and Norton 1996). Several studies have suggested that the presence of foxes and cats coincides with a decreased habitat range and activity of their selected prey species (Payne *et al*. 2014; Doherty *et al*. 2015). Without predation pressure from a higher-order predator, the populations of invasive predators can grow exponentially and have a devastating effect on the biodiversity of ecosystems (Radford *et al*. 2018).

b. Vulnerability of CWR mammal species

Australia is unique as a continent in its geographic isolation and relatively long period of evolutionary history without large predatory mammals (May and Norton 1996; Radford *et al*. 2018). As a result, Australia's native fauna is highly susceptible to introduced predators. Predation by foxes and cats has contributed to the extinction of at least 30 terrestrial mammal species at an estimated rate of one to two extinctions per decade since the 1850s (Radford *et al*. 2018). Significantly, small-bodied mammals within a critical weight range (CWR; 35-5500g) are the most at risk of local extinction when feral species are present (Burbidge and McKenzie 1989). CWR mammal species are the preferred prey size for foxes and cats, meaning that they are selectively targeted by these predators. Moreover, the small mammals within this threshold typically include marsupials and rodents with relatively slow rates of reproduction. Intense predation dramatically reduces the population viability of these species (Radford *et al*. 2018). Notably, many small mammal species that are the most vulnerable to extinction are endemic to Australia, existing nowhere else in the world (Radford *et al*. 2018).

c. Value of ecological monitoring programs

To date, the management of invasive predators has mainly involved the use of lethal control methods to directly reduce population density. Standard culling methods include 1080 poison baiting (sodium fluoroacetate), cage-trapping, and shooting of individual foxes and cats (Doherty *et al*. 2015). Along with the use of exclusion fencing, these projects aim to restore habitat biodiversity through reduced predation pressure on native prey. However, management programs using traditional culling methods are costly, at an estimated global cost of hundreds of millions of dollars annually, and their success has been variable. In many habitats where such programs were undertaken, the populations of native fauna continue to decline (Doherty *et al*. 2015). Therefore, directly targeting invasive populations proves questionable as an effective and sustainable solution.

Ecological interactions within an ecosystem are highly complex and interrelated. Multiple density-independent components, including natural and anthropogenic disturbances like fire and habitat fragmentation, significantly influence ecosystems and must be factored into the management equation (Doherty *et al*. 2015; Geary *et al*. 2018). Additionally, native mammal species will often vary in their degree of susceptibility to introduced predators (May and Norton

1996). Management programs must take all of these factors into account to inform the most advantageous and cost-effective decisions.

Ecological monitoring programs aim to understand the environmental response of an event, such as a disturbance, on a target species or a community of species within a habitat (Leonard *et al*. 2018). Reliable monitoring data from these programs are valuable for informing more holistic management decisions and generating predictions about expected outcomes (Newey *et al*. 2015). Programs for invasive predator management have used population sampling methods, such as live trapping and camera trapping methods, to examine the demography and ecology of small mammal species and reveal the implications of predator disturbance in a habitat (Frankham *et al*. 2011; Dundas *et al*. 2019).

d. Live trapping

Traditionally, live trapping methods, including the use of wire cage traps or pitfalls, have been used to survey faunal populations. These direct sampling methods involve the physical capture of target fauna, which are evaluated for their condition and tagged with a GPS-microchip. Data analyses from live trapping surveys can reveal useful trends such as species richness, composition, and abundance (De Bondi *et al*. 2010). However, live trapping methods are limited by their labor-intensive and time-consuming nature, as set traps must be actively checked for the capture of species. Data collection is also reliant on the frequency that animals visit the traps, which may be lower for certain species that are "trap-shy," or hesitant to approach the foreign object (Welbourne *et al*. 2015).

e. Camera trapping

Many recent studies have shifted to the use of camera traps to assess faunal populations. Motion and temperature-sensitive flash-picture or infrared cameras are mounted near bait stations at study sites, and "trap" the image of the visiting creature (Dundas et al. 2019). After installation, camera traps are left in the field to operate and perform sampling for a set duration. The captured images are stored to an SD card, which is retrieved following the sampling period, and images are processed and classified for contents of interest. Camera traps have the advantage of being less invasive than live trapping methods, as they do not involve the physical capture and handling of species. However, the camera technology is expensive, and the sampling method has other drawbacks, including blank images captured by false triggers, technological failure, and potential theft (Dundas *et al*. 2019). Yet, when compared to live trapping, camera trapping may prove to be a more cost-effective and ethical sampling method, especially for long-term surveys in remote locations (De Bondi *et al*. 2010).

f. Aim of study

The aim of this study is to evaluate the function of live trap and camera trap methods in the context of two case studies of faunal monitoring projects in Victoria, Australia.

The case studies include:

1) Live trapping of the long-nosed potoroo *(Potorous tridactylus)* on French Island.

2) Camera trap deployment for faunal monitoring in mallee regions of semi-arid Victoria.

My study will assess the advantages and limitations of each faunal trapping method for examining ecological associations between feral predators and native small mammal species to inform environmental management decisions. The analysis and discussion will combine my direct observations, primary perspectives from the project researchers, and views from the scientific literature to evaluate the project and site-based applications of each trapping method and to investigate their role in future biodiversity conservation projects.

II. CASE STUDIES

Case Study 1: Live trapping of the long-nosed potoroo *(Potorous tridactylus)* on French Island.

A. OVERVIEW

Study region

French Island is Victoria's largest island, located about 75 km south-east of Melbourne in Western Port. The island has a mild climate, with an average annual temperature of 11ºC - 18.7°C and an average annual rainfall of 696.7 mm (V. Miritis unpubl.). Regionally, the island is situated near the Mornington Peninsula and Phillip Island, which collectively represent the most popular recreation area in Victoria. An estimated five million visitors come to the Western Port Region every year to participate in beach activities such as swimming, surfing, walking, and scuba diving. In contrast to nearby Phillip Island and the Mornington coastline, French Island has few beaches, limited commercial development, and a low standard of roads and tracks. Located about two kilometers from the mainland, the island is only accessible by ferry and barge transport (Parks Victoria 1998).

French Island National Park is the largest national park in the Central Coastal Region, covering 11,100 ha, or two-thirds of French Island. Due to its limited accessibility and recreational services, the park is the least visited in the Western Port Region. As a result, French Island National Park remains relatively undisturbed and contains one of the largest intact areas of native vegetation in the region (Parks Victoria 1998).

Classification and ecology of the long-nosed potoroo

The long-nosed potoroo (*Potorous tridactylus*) is a CWR mammal (~700-1,300 g) native to the woodland and pasture ecosystems of French Island (V. Miritis unpubl). Although the marsupial resembles a bandicoot with its pointed nose and grey-brown fur, the potoroo represents the smallest member of the rat-kangaroo (*Potoroidae*) family (Frankham *et al.* 2011). Much like their macropod cousins, potoroos have enlarged hind feet and powerful hind limbs that allow for high-speed hopping when threatened. Potoroos are generally solitary and nocturnal creatures, with peak activity in the first few hours after dusk (V. Miritis unpubl). During the day, they take shelter in areas with an understory of dense vegetation (Atlas of Living Australia 2019).

The long-nosed potoroo is an important 'ecosystem engineer' based on its specialized diet of sporocarps (truffles) of hypogeous fungi. The marsupial's foraging disperses fungal spores throughout the ecosystem, which grow on the roots of native plants and trees and help with nutrient uptake. Potoroos are one of the few known mammal species to provide this ecological service, which is critical to the health of native forests (Claridge *et al*. 1993).

Conservation status

Long-nosed potoroos are listed as 'Vulnerable' under the Commonwealth Environment Protection and Biodiversity Conservation Act of 1999 and 'Threatened' in Victoria under the Flora and Fauna Guarantee Act of 1988 (V. Miritis unpubl). The species breeds continuously, but females only give birth to a single newborn, contributing to a low reproductive potential at about 2.5 young per year (Atlas of Living Australia 2019). Previous research suggests that the French Island population exists at a low but stable density (0.33 ± 0.01 potoroos ha^{-1}) and is vulnerable to the pressures of predation by feral cats and habitat fragmentation (Frankham *et al.* 2011).

Threatening processes

Predation by feral cats

Apart from feral cats, French Island lacks any medium to large-sized terrestrial mammalian predators (V. Miritis unpubl). Small mammal species on the island are especially vulnerable because they evolved independently of feral cats and exhibit a naivety to predation (Banks and Dickman 2007). The absence of larger predators on the island also permits the unchecked growth of the feral cat population. The preferred prey species of the mesopredator, including rabbits (*Oryctolagus cuninculus*) and rodents, have also been introduced to French Island and support cat populations (Doherty *et al.* 2015). As opportunistic predators, feral cats prey selectively and aggressively on CWR mammal species like the long-nosed potoroo (May and Norton 1996).

Habitat fragmentation

Although once widespread throughout southern Victoria, much of the preferred habitat of the long-nosed potoroo has been fragmented or cleared for agriculture and urbanization (Atlas of Living Australia 2019). The potoroo relies on thick groundcover for protection and nesting material, and light soils to dig for underground fungi and roots (Atlas of Living Australia 2019). French Island National Park represents a fragmented landscape of forest remnants. The potoroo populations within these remnants are isolated due to limited dispersal pathways, which may restrict population growth and genetic diversity of the species (V. Miritis unpubl).

B. PROJECT AIMS

The present research study on French Island is being undertaken by Meg Farmer, an honors student at Deakin University. Using live trapping methods, Farmer aims to:

- quantify the distribution, abundance and behavior of long-nosed potoroos on French Island.
- assess fine-scale habitat use and investigate interactions with feral cats.
- gain an understanding of the factors that enable native wildlife to survive in the presence of feral cats (M. Farmer pers. comm.).

C. METHODS

Site establishment

The study takes place in 'Bluegums,' a 3 km^2 area located within French Island National Park (-38.398, 145.378). The vegetation types in the study area were classified into two categories: closed sites, including woodland, heath, saltmarsh and mangrove; and open sites, including retired grassland pastures with prickly tea tree *(Leptospermum continentale)* and dense regions of blackberry *(Rubus fruticosus).* Study sites were established in the same areas as research undertaken during the previous year that analyzed island cat ecology and relationships with the long-nosed potoroo (V. Miritis unpubl).

Forty soft-set wire cage traps (36 x 21 x 17 cm) were deployed in a loosely gridded pattern, ~50 m apart within the study area (**Figure 1**). The trapping stations were distributed as uniformly as possible, accounting for the thick and sometimes impenetrable vegetation in the study area. Live traps were baited with a mixture of rolled oats, peanut butter, golden syrup, and vanilla essence rolled into a ball and placed in the bait holder at the back of the trap. KFC popcorn chicken was also included in traps, as this bait was observed to increase potoroo activity (M. Farmer pers. comm.). Before trapping sessions, cage traps were set up on-site, wired open with cable ties, and pre-baited to increase trapping success (**Figure 1**).

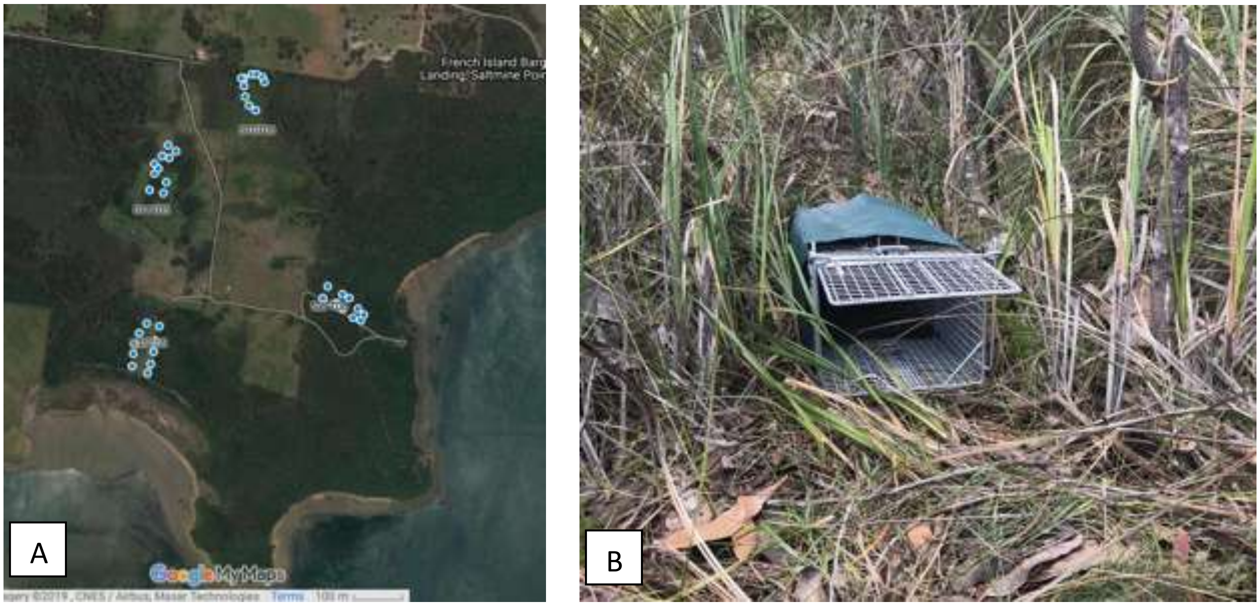

Figure 1. A*)** Map of ‘Bluegums’ study area in French Island National Park. Each blue pin represents the placement of a cage trap (M. Farmer pers. comm.). ***B) the completed set-up for a baited wire cage trap.

Live trapping and handling

Because potoroos are a nocturnal species, live trapping sessions start at 4:00 pm, when cage traps are opened, baited, and left undisturbed for a minimum of five hours. Trap checks begin at 9:30 pm by walking the transects of trap lines and checking if any have closed. The status of each trap (open/closed) and bait (present/absent) is recorded (M. Farmer pers. comm.).

Potoroos are processed at the point of capture. Upon initial capture, the individual is carefully removed from the trap and placed in a handling bag. The potoroo is checked for a GPS-microchip. If a microchip is not present, the animal is marked with an 11 x 2 mm passive induction transponder tag (Trovan, Microchips Australia, Keysborough, Victoria) injected under the skin between the shoulder blades. The sex of the animal is determined, and the individual is weighed using a spring balance. Condition of the eyes, nails, and tail are also noted. Morphometric measurements, including head and pes (foot) length, are recorded using a Vernier caliper (to the nearest 0.1 mm). For females, the condition of the pouch and teats is noted. If a pouch-young is present, morphometric measurements such as head length are recorded when possible. All animals are released at the site of capture. Traps are closed after they have been checked to avoid the capture of more individuals in the same trapping session (Frankham 2011; M. Farmer pers. comm.).

D. ANALYSIS OF LIVE TRAPPING

Advantages

Direct sampling of qualitative data

Live trapping allows for the researcher to directly capture and handle organisms of a target species of interest, from which they can generate unambiguous observations about population dynamics based on individuals' sex, age, and condition (De Bondi *et al.* 2010). These data are valuable for further analysis of species richness, composition, and abundance. In the present study, trapped potoroos are also tagged with a GPS-transponder microchip, which will allow for the collection of fine-scale spatial and temporal data based on their movement and habitat use (M. Farmer pers. comm.).

Standardization of method

Live trapping is a well-established sampling method that has been used for many decades in ecological and conservation research (Dundas *et al.* 2019). Given the ethical considerations of the method, all elements are highly standardized, including the type of cage trap, the trapping session protocol, animal handling, and the data collection and analysis process (M. Farmer pers. comm.; DBCA 2018). Such standardization is critical to support the collection of reliable data and allow for future replication studies (Meek *et al.* 2014).

Limitations

Ethical considerations

Because animals are physically detained in the cage trap and handled upon capture, live trapping is a fairly invasive sampling method. Although researchers using this method must be licensed and trained in proper protocol before performing any sampling, live trapping remains stressful for the organism (De Bondi *et al.* 2010). Moreover, unexpected injury or death of the captured organism may occur through uncontrollable factors such as trauma, predation, hypothermia, dehydration, or heat stroke (DBCA 2018).

Time and labor costs

As a 'single-catch' system, the fieldwork component of live trapping is extremely time-consuming and labor-intensive (Wearn and Glover-kapfer 2019). All traps within the study area must be systematically checked during a trapping session and manually reset and rebaited after a capture. In the present study, 40 cage traps are deployed 50 m apart in a 3 km^2 study area and performing checks for all traps takes approximately four hours (M. Farmer pers. comm.). The amount of time required to complete a trapping session limits the researcher in the number of replications that they can achieve, along with additional uncontrollable factors such as weather conditions. Therefore, the extent and duration of a live trapping study is often determined by the costs of time and labor required for each trapping session (De Bondi *et al.* 2010).

Detection shortcomings

Cage traps do not discriminate in the organism that is captured, and baits in live traps may attract organisms other than the focal species. In addition, researchers face low detection probabilities for species that are "trap-shy," or hesitant to approach the foreign traps (Welbourne *et al*. 2015). In the present study, Farmer was having trouble luring and capturing potoroos successfully. Previous data suggest trap shyness is common in potoroo species, with live capture success ranging from 0.05% to 10% (Frankham *et al.* 2011). In contrast, the local eastern barred bandicoots (*Perameles gunnii*) were much more curious to check out the traps, and these creatures were often found captured instead of potoroos (M. Farmer pers. comm.).

Case Study 2: Camera trap deployment for faunal monitoring in semi-arid Victoria.

A. OVERVIEW

Study region

Big Desert Wilderness Park is a protected area of 142,300 ha located in the Mallee district of northwest Victoria near the South Australian border (between latitudes 35°15'S and 36°15'S; **Figure 2**). The park was the first declared wilderness area in Victoria and remains one of the most remote and least disturbed regions in the state. The closest towns are an average distance of 150 km from the area, including Murrayville to the north and Nhill and Yanac to the south. Big Desert is a dedicated wilderness area with no vehicle access into the park, public facilities, or defined walking tracks. Four-wheel drive is required to access the area by the Murrayville-Nhill Track, which runs 5 km to the east of the park and becomes rough and slippery during and after bad weather. Given the park's remote location, visitors who plan to hike or camp need to be equipped with sufficient supplies, including plenty of food and water (Parks Victoria 2011).

Little Desert National Park is located 375 km west of Melbourne in the Wimmera region and 150 km south of Big Desert (between latitudes 36°25's and 36°42'S; **Figure 2**). As the second-largest national park in Victoria, Little Desert covers 132,647 ha of land, extending from the South Australian border to the Wimmera River. The closest towns are Dimboola, Nhill and

Kaniya at about 50 km distance, making the region much more accessible than Big Desert. Little Desert attracts about 50,000 visitors a year for camping, birdwatching, and bush walking. Four-wheel drive is still recommended to traverse the unsealed tracks of the park (Earthwatch Institute 2019).

Big Desert has a semi-arid climate with an average annual temperature of 7.8ºC to 23.0ºC and an average annual rainfall of ~330-400 mm. Little Desert has a similar climate, although the average yearly rainfall is about 200 mm greater (Australian Bureau of Meteorology 2019). Low rainfall in the two regions produces the characteristic sandy soils and dunes that are unsuitable for agriculture. However, a wide variety of native plant species have adapted to the climate (Conn 1993). Specifically, the desert regions host two distinct vegetation types. "Lowan mallee" vegetation with a mallee eucalypt canopy and healthy shrub understory, while "heathland sands" vegetation lacks eucalypt trees and is composed of a mixed layer of small heathy shrubs (Geary *et al.* 2018).

Figure 2. Map of Big Desert Wilderness Area and Little Desert National Park.

Ecology of small mammals in semi-arid Victoria

To date, there has been minimal research on the small mammal species that inhabit semi-arid Victoria. Past live-trapping studies have identified at least nine species in the mallee region, including four species of dasyurids, two pygmy possums, two rodents, and a species of feathertail glider (Clemann *et al*. 2005; Bennett, Lumsden, and Menkhorst 2006). These small terrestrial vertebrates represent CWR species of marsupials and rodents that are well-adapted to the semi-arid climate and dependent on the structure of heathland vegetation for shelter and food.

Conservation status

Past research suggests that over half of all small native terrestrial mammal species that once occurred in the mallee region are no longer present (Bennett, Lumsden and Menkhorst 2006). Extant species are highly sensitive to changes in habitat structure and availability of vegetation, which area influenced by fire regimes and the range of introduced predators such as the red fox. As a result, the small mammals in this region are classified as either "Near Threatened" or "Vulnerable" (DSE 2014; species listed in **Appendix 1**). More research in the semi-arid mallee is necessary to better understand the processes that influence the distribution and abundance of these cryptic species (Bennett, Lumsden, and Menkhorst 2006).

Threatening processes

Bushfires and fire management

The mallee is an extremely fire-prone region due to its low rainfall and expansive dry heathy vegetation. Large wildfires occur in the area about every 20 years, with most spontaneously ignited by lightning strikes (Payne *et al.* 2014). Fire dramatically shapes mallee ecosystems, altering the structure of vegetation and influencing species distribution and abundance. Consequently, wildfire management, through planned burns at pre-determined scopes and time intervals, is an essential conservation tool. Planned burns reduce the fuel load and can help to reinstate early successional vegetation that many small mammal species require for habitat (A. Pestell pers. comm.) However, research suggests that CWR mammals vary in their tolerance of frequent large-scale burns, so current fire management programs may be doing more harm than good for these species (Geary *et al.* 2018).

Predation by feral foxes

As one of the world's most widely distributed mesopredators, feral foxes are especially problematic to the diversity of small mammal species in the semi-arid mallee (Payne *et al.* 2014). Although red foxes will prey on a variety of native mammals, reptiles, and birds, they focus mainly on ground-dwelling vertebrates, and are capable of prey-switching to target the most abundant source of prey (Radford *et al.* 2018; Payne *et al.* 2014). Red foxes are also habitat generalists, meaning that they are flexible in the range and structure of environments that they inhabit. However, the invasive species prefers to hunt in open areas with structurally simple vegetation. Foxes may benefit from the clearing of the bush through frequent burns, which reduce vegetation cover for native prey, exposing them to the invasive mesopredator for more accessible hunting (Payne *et al.* 2014).

B. PROJECT AIMS

The present survey in semi-arid Victoria is being undertaken by Ange Pestell, a Ph.D. candidate funded by Deakin University. Using camera trapping methods, Pestell aims to:

- investigate faunal assemblages across a range of fire age-classes in two major vegetation types (mallee eucalypt and heathland sands) in the Victorian mallee.
- understand approaches to increasing the effectiveness and cost-efficiency of wildlife surveys in remote landscapes.
- improve fire management outcomes for biodiversity in the Victorian Mallee and Wimmera regions.

- contribute to the development of machine learning processes that automate species identification from camera trap data for small vertebrates (as part of a larger project for biodiversity monitoring with partners from La Trobe University the Bushfire and Natural Hazards Cooperative Research Centre, and the Department of Environment, Land, Water and Planning.) (DELWP 2018; A. Pestell pers. comm.).

C. METHODS

Site establishment

The present study uses a "whole-of-landscape" design, with sampling sites selected across representative gradients for vegetation structure (mallee eucalypt or heathland sands), fire age (time since last burn), and fire interval (the tolerable period between burns for the ecosystem). Current sites were selected as the baseline for planned long-term biodiversity monitoring in the region (R. McIntosh pers. comm; see **Appendix 2** for sample map).

We deployed a total of 44 camera traps across 22 sites (17 sites in Little Desert; 5 sites in Big Desert) for the first two weeks of November 2019, spanning a study area of approximately 966 km^2 across the two regions **(Figure 3).** Pestell was at the start of her Ph.D. research, so this was the first of several upcoming trips to establish camera traps across all designated study sites. (A. Pestell pers. comm.)

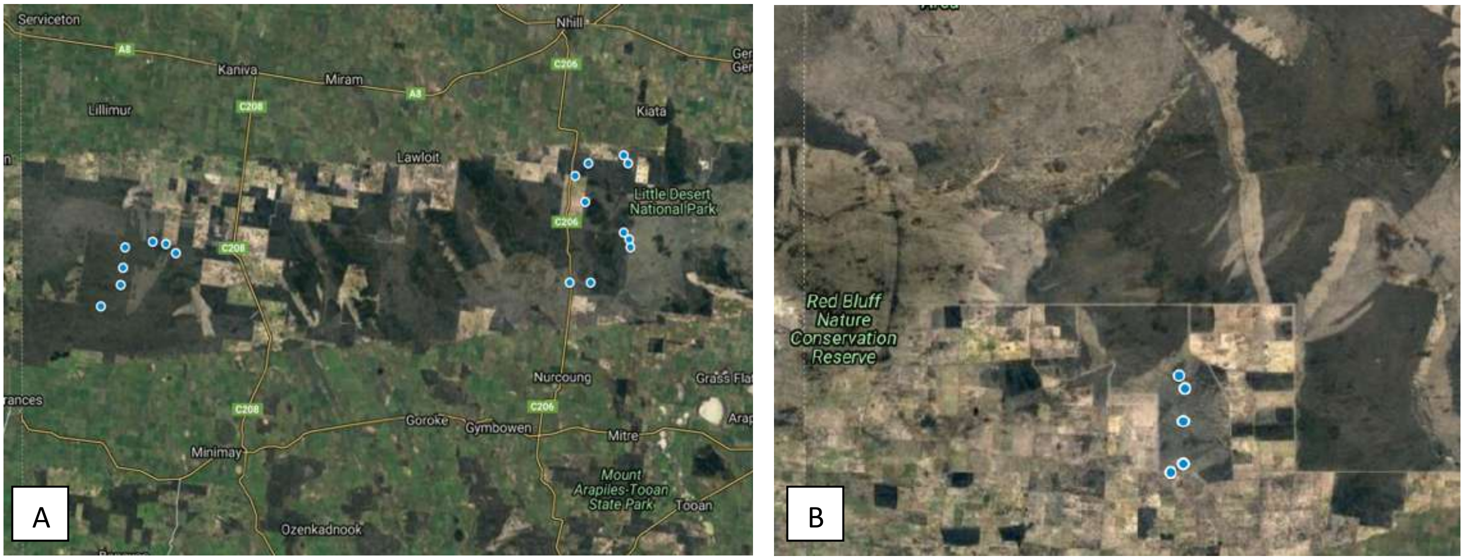

Figure 3. Map of ***A)*** Little Desert and ***B)*** Big Desert study sites completed November 2019. Each blue pin represents the placement of two motion-detecting camera traps.

Deployment of Camera Traps

Two motion-detecting camera traps (Reconyx Hyperfire HC500/550) per site were set up to survey for predator and small mammal species. The cameras were placed at 0 m (point 1) and 100 m (point 2) points of a transect previously established for vegetation and floristic surveys. Camera placement was offset 20 m to the left of the transect, looking from 0 – 100 m. The camera at point 1 was baited to attract small herbivorous mammals while the camera at point 2 was baited to attract predators **(Figure 4)**.

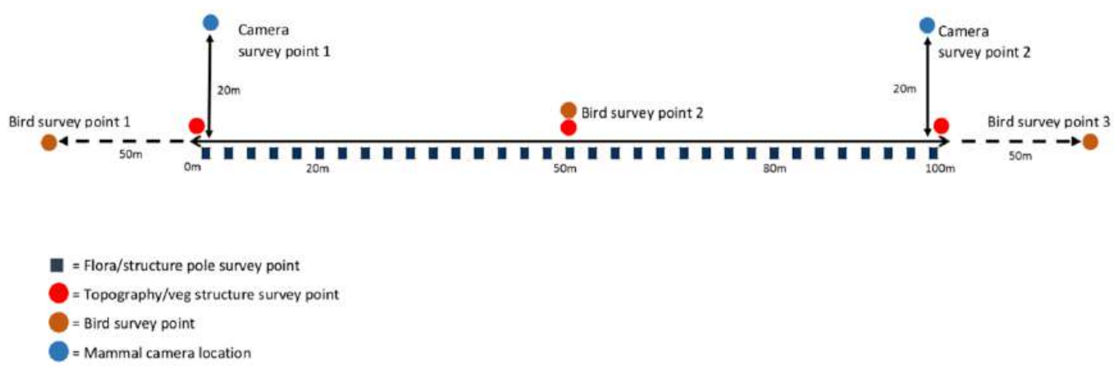

Figure 4. Schematic depicting camera trap set-up across a transect at a given study site (Leonard *et al.* 2018).

To survey for predators (dingoes, foxes), we deployed infrared motion-detecting camera traps (Reconynx Hyperfire HC500). Camera traps were set on the highest sensitivity and resolution and programmed to take a series of five photos every time the camera was triggered by motion, with no time interval between photos or triggers. Cameras work both day and night, allowing for capture of nocturnal activity. Oriented south to reduce false triggers from direct sunlight, cameras were mounted with a zip tie onto a wooden stake, which was driven into the ground until stable with a rubber mallet. Cameras were positioned 1 m above the ground and angled slightly downward, with bait stations in the middle of frame **(Figure 5).** Predator camera traps were baited with a mixture of 'Blood and Bone' fertilizer and tuna oil secured within a PVC pipe bait canister. Bait was attached to a wooden stake at approximately 1 m above the ground and 3 m in front of the camera. This bait mixture has been successful in previous surveys for red foxes in Mallee ecosystems (Geary *et al.* 2018).

To survey for small mammal species, we deployed white-flash LED motion-detecting camera traps (Reconyx Hyperfire HC550) in a similar manner as the predator camera traps. To attract small mammals, cameras were baited with a mixture of rolled oats, peanut butter, golden syrup, and vanilla essence secured in a PVC pipe bait canister. Bait was attached to a wooden stake at approximately 40 cm above the ground and 1.7 m in front of the camera (**Figure 5**). For both small mammal and predator cameras, vegetation was cleared from each camera's field of view to reduce false triggers.

Predator cameras are to be deployed for a minimum of 60 days before SD card recovery, and small mammal cameras a minimum of 30 days. Once SD cards are collected, photo identification and data analysis will take place in the lab.

Figure 5. Camera trap set-up for ***A)*** predator surveys and ***B)*** small mammal surveys across Big and Little Desert study sites.

D. ANALYSIS OF CAMERA TRAPPING

Advantages

Spatial and temporal benefits

The labor-intensive initial phase of set-up for camera trap surveys allows for the simultaneous collection of data across many study sites. Cameras can run day and night continuously for long periods of time, withstand extreme weather conditions, and capture images of rare and elusive species (De Bondi *et al.* 2010). When a specified sampling period is complete, SD cards are recovered, and photo identification and data analysis can take place in the comfort of the research lab. These characteristics make the camera trap method especially suitable for the present study, which has a survey area covering more than 275,000 ha in the mallee, an extremely remote and inaccessible region of Victoria (A. Pestell pers. comm.)

Moreover, because this study aims to investigate the distribution of many faunal species, the use of camera traps makes this goal more attainable, considerably reducing fieldwork costs of time and labor. Camera traps also eliminate the need for specialized techniques to trap different faunal species that would need to be employed with traditional live-capture methods (De Bondi *et al.* 2010).

Minimally invasive method

When accounting for the disturbance to the habitat during camera set-up and SD card retrieval, the presence of the camera and bait, and the emission of sound and light when a picture is taken, camera traps provide a minimally invasive method to sampling (Meek *et al.* 2014; A. Pestell pers. comm.). Cameras only "trap" a digital photo of the species that passes its detection zone, which does not physically impact the animal. Therefore, camera traps may provide a more sustainable and ethical option for wildlife sampling across a broader scale. This factor is especially relevant when considering vulnerable species already at risk in ecosystems, such as many of the small mammal species in the present study that inhabit the mallee region (De Bondi *et al.* 2010; Meek *et al.* 2014; A. Pestell pers. comm.).

Economically advantageous

Although the initial cost of professional-grade cameras is more expensive than most live trap systems, camera traps are much more cost-effective for long-term surveys (Welbourne *et al.* 2015). After preliminary set-up, camera traps become a self-automated "multi-catch" system. allowing for the 'hands-off' detection of many species over an extended period. This characteristic significantly reduces the amount of time and expense associated with fieldwork, including travel and labor costs, and provides opportunities for sampling across larger scales (De Bondi *et al.* 2010; A. Pestell pers. comm.).

Limitations

Technological shortcomings

The present study was in its first phase of set-up, and we did not encounter any technological issues. However, past studies using camera traps have reported numerous problems with the functionality of the technology. These include challenges with the camera unit overheating, malfunction of camera batteries, and distorted photos due to glare or impeding vegetation (Newey *et al.* 2015; Dundas *et al.* 2019). Reports also mentioned the theft of camera units, as units are expensive and professional models that are useful to recreational hunters and wildlife enthusiasts (Dundas *et al.* 2019; A. Pestell pers comm.). Because camera traps are deployed for one- or two-month sampling periods, these issues are usually not discovered by the researcher until long after they occur, which unfortunately results in a great deal of lost data and time.

Issue of standardization

Camera trapping is a relatively new method for wildlife sampling and monitoring. The field of camera trap research currently lacks a standardized protocol for undertaking surveys. Previous studies have used a range of camera models and settings, sampling designs, and data analyses (De Bondi *et al.* 2010; Newey *et al.* 2015). Ecologists have raised concerns about this variability, which may have contributed to bias and influenced the validity of results and inferences from past studies (Meek *et al.* 2015; A. Pestell pers. comm.). Reliable monitoring data from camera trap studies requires the standardization of survey protocol to enable future replication. In addition, camera trap studies need to account for the issue of "imperfect detection," meaning that the camera trap does not always detect individual animals with a sampling area. The detection zone of a camera trap is small, and the animal must pass in front of the camera to be detected. Therefore, researchers need to account for this bias to sampling through appropriate statistical analyses before they generate inferences about species distribution and abundance (Burton *et al.* 2015).

Challenges with data analysis

Previous studies have revealed that the majority of wildlife species are not easily identifiable from photos, which is especially true for species that lack uniquely patterning or closely resemble another species (Burton *et al.* 2015). During the photo analysis process, the researcher must take care not to misidentify species, which can lead to ineffective recommendations for the conservation and management of threatened species (Meek *et al.* 2015).

Camera traps may generate a large number of false positive detections that produce blank images. Because camera traps are motion-triggered, the high-sensitivity sensors may be set off for a variety of reasons other than an animal passing through the detection zone (Meek *et al.* 2015). As a result, the researcher must process through large numbers of images, which is already very time-consuming due to challenges with species identification, and further delayed by a mass of blank images. Data storage proves another challenge. Captured images represent raw data and should not be deleted, but consequently, they can fill hundreds of megabytes of storage space (Meek *et al.* 2014; A. Pestell pers. comm.).

III. DISCUSSION

a. Camera trapping as the future of wildlife monitoring?

Global biodiversity is declining at a startling rate, driven by climate change and natural and anthropogenic disturbances (Steenweg *et al.* 2016). Threatened species are incredibly vulnerable to these pressures, and many are on the brink of extinction. Introduced predators such as feral foxes and cats have a significant impact on faunal population density and the diversity of ecosystems. There is an increasing need for reliable monitoring data on faunal interactions to inform effective environmental management decisions (Meek *et al.* 2014). Given the limited funds of a research project, camera traps appear to provide a more economical and ethical option for long-term sampling projects of this nature (Welbourne *et al.* 2015).

Based on these factors, will camera traps ever completely replace live trapping methods in the future of wildlife monitoring? Most ecologists suggest this will not be the case because camera trapping is not a fully refined sampling method and is limited by inherent bias (Meek *et al.* 2015). While cameras provide a useful record of sampled fauna at a specific location and time, they lack the ability of live trapping methods to capture fine-scale data on animal demographics and movement across habitats (M. Farmer pers. comm.). Therefore, it is critical for researchers to clearly define the aims of an ecological survey before selecting a sampling method (Dundas *et al*. 2019). The sampling design of the study should directly reflect its ecological objectives. Researchers should also recognize the limitations of the chosen sampling method and account for them in their sampling design and data analyses (Burton *et al.* 2015). As reviewed in the two case studies of this paper, both live trap and camera trap methods are valuable tools for conservation in the context of monitoring projects for introduced predator management. The major difference between the choice of method pertained to the research aims and project scale.

b. Live trapping reveals data on fine-scale movements to infer between-species interactions

Captured potoroos are tagged with a GPS-microchip, which will provide valuable temporal and spatial information about the habitat use of individuals within a population. Comparing these data to microchipped feral cats on the island will allow for Farmer to better understand the nature of interactions between the two species (M. Farmer. pers. comm). A camera trap survey conducted the previous year in the same area revealed overlap in the temporal activity between potoroos and feral cats but found a significant difference between their peak activity times. Cats were mainly active around twilight, while potoroos exhibited nocturnal activity (V. Miritis unpubl.) Analysis from the current study can be compared to this finding, which may explain the marsupial's apparent coexistence with the invasive predator (M. Farmer pers. comm.). This information will be useful to wildlife managers on French Island, including Parks Victoria and the volunteer-run Landcare Group, who have been working for over a decade to try to eradicate feral cats from the island (M. Farmer pers. comm.).

c. Camera trapping enables broader surveys to support biodiversity modeling

Camera traps significantly reduce the amount of time and labor for the fieldwork component associated with traditional live trapping methods. As a result, the use of camera traps increases the scale of faunal monitoring across space and time and allows for a broader, multi-species survey (Welbourne *et al.* 2015; Wearn *et al.* 2019). These characteristics make camera trapping especially valuable for the present study in the Victorian mallee (A. Pestell pers. comm.). Previous research in the region suggests that existing fire management regimes may harm vulnerable CWR mammals and increase the range of invasive mesopredators such as the red fox (Geary *et al.* 2018; Payne *et al.* 2014). Ongoing ecological monitoring projects in the Victorian mallee aim to understand the impact of fire on the native plants and animals and assess biodiversity across a range of habitats with varying levels of fire-exposure to inform more sustainable fire management decisions (Leonard *et al.* 2018).

The present study will contribute monitoring data to a biodiversity modeling software called FAME (Fire Analysis Module for Ecological values). This database will combine the records of past planned fires with current ecological indicators for habitat biodiversity. FAME will allow fire planners to model different fire management strategies and evaluate their outcomes and ecological impact (Arthur Rylah Institute 2019; A. Pestell pers. comm.).

Significantly, this tool could help wildlife managers to suppress feral fox populations in collaboration with fire managers. Geary *et al.* 2018 reported that dingoes were drawn to recently burned areas in the Victorian mallee, while feral foxes subsequently avoided these regions due to the higher prevalence of the apex predator. Consequently, the researchers suggested that dingoes can provide refuge for native species from foxes after wildfire. Using biodiversity modeling software such as FAME, wildlife managers could coordinate carefully managed fires that suppress red fox populations and support CWR mammals in the Victorian mallee.

IV. CONCLUSION

Overall, live trap and camera trap methods have inherent advantages and limitations for faunal monitoring projects. However, if fit for the purpose of the research question and study aims, both methods can represent valuable tools for biodiversity conservation. Specifically, the broader application of these sampling methods to ecological monitoring programs can help wildlife managers better understand and mitigate the threat of introduced predators to native small mammals in Australia.

Future directions in monitoring will readily incorporate new technology to address imminent global biodiversity declines. Current examples include digital volunteer-based citizen science platforms and machine learning programs developed to streamline the photo identification and analysis processes of camera trapping (Steenweg *et al.* 2016; Caravaggi *et al.* 2017). Integrating these new techniques alongside traditional live sampling methods will ideally enable more extensive, reliable, and cost-effective data collection and support the foundation of a global biodiversity monitoring network.

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Personal Communication

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Appendix 1. Conservation status of identified small mammals in the Victorian mallee.

Vulnerable: facing a high risk of extinction in the wild.
Near Threatened: close to qualifying for a threatened category in the near future (Critically Endangered, Endangered, Vulnerable) (DSE 2014).

Vulnerable	
Common Dunnart	*Smithopsis murina murina*
Near Threatened	
Fat-tailed Dunnart	*Sminthopsis crassicaudata*
Gile's Planigale	*Planigale gilesi*
Little Pygmy Possum	*Cercatetus lepidus*
Mallee Ningaui	*Ningaui yvonneae*
Mitchell's Hopping Mouse	*Notomys mitchelli*
Silky Mouse	*Pseudomys apodemoides*
Western Pygmy Possum	*Cercatetus concinnus minor*

Appendix 2. Sample site map depicting fire-age classes and vegetation type in Little Desert National Park.

Fire-age class referred to by TSF = “time-since-fire” with ‘1’ indicating a recent burn and ‘8’ representing a long time since fire (R. McIntosh pers. comm.).