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## **An investigation into the spatial distribution, habitat selection and resource usage of the red fox (*Vulpes vulpes*) inhabiting urban reserves within Perth, Western Australia**

Michael Thomas Main  
*Edith Cowan University*

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**An investigation into the spatial distribution,  
habitat selection and resource usage of the  
red fox (*Vulpes vulpes*) inhabiting urban reserves  
within Perth, Western Australia**

This thesis is presented for the degree of  
**Master of Science (Biological Sciences)**

**Michael Thomas Main**

Edith Cowan University

School of Science

2020

## Preliminary Summary

I attempted to track a population of urban foxes in Kings Park, but due to collar failure, only one collar was retrieved. The GPS telemetry data from this fox produced home range estimates for minimum convex polygon (MCP) and kernel density (KD) of 0.302 km<sup>2</sup> and 0.331 km<sup>2</sup>, respectively. The fox was predominantly active at night, with a ten-fold increase in movement during nocturnal periods when compared to daytime movements. Roads and man-made tracks were important for facilitating movement of the fox through its home range, with almost 97% of location fixes recorded within 100m of these features. The fox showed a preference for parrot bush *Banksia sessilis* shrubland and disturbed areas containing exotic weeds and revegetation, while avoiding woodlands and open spaces.

Monitoring programs aimed at assessing the abundance of invasive species, as well as the severity of their impacts to the environment, are crucial for designing and implementing effective control strategies. I investigated the relative occupancy and diet of foxes at the local scale. Thirty one fox scats taken from two urban reserves revealed that medium-sized mammals, particularly brush-tailed possums (*Trichosurus vulpecula*) and quenda (*Isodon fusciventer*), and black rats (*Rattus rattus*) comprised a large proportion of fox diet. Fruits and seeds, predominantly those produced by the Moreton Bay Fig (*Ficus macrophylla*), also contributed to a large portion of the diet of foxes. I used 21 motion cameras deployed across 10 monitoring sites to estimate fox occupancy within Kings Park. Seasonality had a significant influence on probability of occupancy and detection for foxes inhabiting Kings Park, with the highest rates of detection seen during the summer months (December-February). This spike in detections is consistent with the timing of dispersing juveniles, which are likely to be immigrating into the area in search of a suitable home range.

Improving the effectiveness of conservation strategies through collaborative research is a key outcome of the *Kings Park and Botanic Gardens Management Plan 2014-2019* strategic framework and implementing control measures for pest animals is a priority target for both this plan and the *Bold Park Management Plan 2011-2016*. Numerous methods have been used to control and/or mitigate their impacts within Australia, however, the success rates of these strategies vary. With the information gained from this investigation, it is my hope that future fox monitoring and control programs can be improved within the reserves and surrounding land uses.

## Declaration

*I certify that this thesis does not, to the best of my knowledge and belief:*

*i. incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;*

*ii. contain any material previously published or written by another person except where due reference is made in the text of this thesis; or*

*iii. contain any defamatory material;*

Signed: Mr. Michael Thomas Main

A solid black rectangular box used to redact the signature of the author.

Date: 21/09/2020

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Friends of Kings Park

## **Ethics**

This study was undertaken with approval from the Edith Cowan University Animal Ethics Committee (Permit #17589 BLAKE).

## **Research outputs**

Journal Article:

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\*Article is included as Chapter 2 in original Thesis.

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## Chapter 1: Introduction

### 1.1 Influence of urbanisation on wildlife

The biodiversity of a region is usually linked to characteristics of the surrounding landscape, with highly productive, heterogeneous landscapes supporting larger population densities and assemblages of species (Medley, McDonnell & Pickett, 1995). In contrast, urban environments, which have undergone extreme human-induced modifications, are characteristically seen as energy sinks, requiring vast amounts of imported resource while being poor primary producers (Adams, Van duff & Luniak, 2005). The rapid and extensive transformation seen in a landscape following urbanisation is catastrophic for native fauna, which can struggle to adapt to this newly formed ecosystem (Gortat *et al.*, 2014).

Urbanisation is recognised as a major driver in the global decline of mammals and is cited as the second biggest threat to biodiversity in the United States (Adams *et al.*, 2005; Hoffmann *et al.*, 2011). Studies have shown that the diversity of mammal species in an area decreases in response to an increase in human-induced disturbances (Gortat *et al.*, 2014). However, urban areas tend to have a high abundance and density of animals, particularly invasive species that are pre-adapted to human disturbances and are limited by few thresholds (Adams *et al.*, 2005). Invasive species commonly display ecological and behavioural plasticity, taking advantage of the new niches and anthropogenic food sources that people have created (Luniak, 1996).

Resource and habitat availability in urban environments differs greatly to that of the pre-existing landscape. Land clearing and fragmentation caused by the development of roads and buildings has contributed to the alteration of vegetation structures, with some remnant vegetation being restricted to small, isolated patches (Stenhouse, 2005). Native species that occur in these patches are also more vulnerable to other disturbances, including incursions by exotic species, increased competition and predation pressures, erosion, refuse dumping and loss of understory vegetation (Stenhouse, 2004). Mitigating some of the impacts caused by fragmentation and other disturbances can improve urban biodiversity.

The rate of species loss is lower for large patches of remnant vegetation when compared to smaller patches, and corridors connecting vegetation patches improves species richness and recolonization in urban areas (Collinge, 1998; Shanahan, Miller, Possingham & Fuller, 2011). Movement between patches can also be facilitated by corridors and greenways, further increasing the amount of habitat and

resources available to mobile species (Bryant, 2006). These remnant patches and wildlife corridors should be considered as high conservation assets, as they can support locally declining occurring fauna species. However, remnant vegetation is also be used by invasive species.

The introduction of exotic species is a common occurrence in urban centers throughout the world, either through deliberate release or by utilising habitat and/or resources that were inaccessible prior to human development (Tait, Daniels & Hill, 2005). Disturbances from people also benefit invasive species, with a positive correlation observed between the degree of urbanisation and invasive species abundance (Cadotte, Yasui, Livingstone & MacIvor, 2017). For instance, Grarock, Tidemann, Wood and Lindenmayer (2014) found that abundances of the common myna (*Acridotheres tristis*) increased three-fold in urban areas when compared to natural vegetation.

Pressures exerted by invasive species, including competition for resources and predation, can have severe impacts on native animals occurring in urban reserves. Impacts from invasive predators are exacerbated by the combined factors altering vegetation characteristics, such as changed fire regimes and land clearing, that reduce food and habitat availability, remove connectivity, increase competition and lower population sizes (Doherty, Dickman, Nimmo and Ritchie, 2015). Predation by feral predators is one of the leading causes of mammal extinctions in Australia, second to changed fire regimes (Woinarski, Burbidge & Harrison, 2015). An invasive mesopredator with known major impacts on native biodiversity in Australia is the European red fox (*Vulpes vulpes*).

## *1.2 Fox colonisation of Australia*

Inconsistencies in historical records have created uncertainties as to when foxes were first introduced into Australia, though initial findings suggest foxes have occurred on the mainland for the past 140 years (Short, Kinnear & Robley, 2002; Fleming *et al.*, 2014). The first records of fox introductions are from 1871 at Werribee near Geelong, Victoria, (Fairfax, 2019). The dispersal of foxes was rapid and by 1880 foxes had become common in areas between Geelong and Melbourne, occupying almost 13,000km<sup>2</sup> (Saunders, Gentle & Dickman, 2010; Fairfax, 2019). Foxes crossed the border of South Australia during the late 1880's and were established in Queensland by the early 1890's (Saunders *et al.*, 2010). In Western Australia, the first reports of fox sightings took place in an area west of Eucla in the year 1912, and foxes continued to expand in both distribution and abundance well into the mid-

twentieth century (Saunders, Coman, Kinnear & Braysher, 1995; Short *et al.*, 2002). Within 100 years, the fox had successfully colonised almost all of Australia's mainland, with the exception of the tropical regions of Queensland, the Northern Territory and Western Australia (Fleming *et al.*, 2014; Fairfax, 2019).

There are a number of factors that have contributed to the fox's rapid distribution and population expansion. Fox movements would have been greatly accelerated across areas of favourable habitat, with instances of individual foxes traversing distances of 140 to 160km per year (Short *et al.*, 2002; Saunders *et al.*, 2010). However, movements on this scale are rare, with studies into natal dispersal of fox cubs indicating annual movements ranging between 2 to 30 kilometres (Coman, Robinson & Beaumont, 1991; Saunders *et al.*, 1995). The dispersal of foxes was most likely accelerated by deliberate releases by people (Saunders *et al.*, 1995; Saunders *et al.*, 2010). Many regions of Australia have also experienced changes in land uses caused by agricultural and urban process, further aiding the dispersal and survival of foxes (Saunders *et al.*, 2010).

It is likely that the spread of foxes throughout the mainland coincided with that of rabbits, as the incursion of both species throughout Australia occurred almost simultaneously (Jackson, 2003; Kordes, 2004). Rabbits were first introduced into mainland Australia in 1859 and began to disperse throughout the country at an annual rate of 10 to 100 kilometres, depending on habitat structure and climate (Kordes, 2004). Like foxes, rabbits inhabit most regions of Australia, with the exception of the northern tropics. Rabbits are a common prey species targeted by foxes and make up a staple part of their diet (Saunders *et al.*, 2004), thus, the spread of rabbits would have sustained newly formed fox population and facilitated their dispersal throughout Australia. This is supported by studies that investigated the diet of foxes in Australia (Risbey, Calver & Short, 1999; Saunders *et al.*, 2004; Mitchell & Banks, 2005), as well as a positive correlation seen in fox densities when compared to rabbit densities.

### *1.3 Impact of foxes on Australia's biodiversity*

Predation by feral predators is one of the leading causes of mammalian extinctions in Australia, second to changed fire regimes (Woinarski *et al.*, 2015). A majority of fauna species are at risk of predation by foxes, including 51 threatened species recorded in the *Environmental Protection and Biodiversity*

*Conservation Act 1999*. Native species that have been impacted the most by foxes include mammals within the critical weight range (CWR; 35-5500g) (Burbidge & McKenzie, 1989), as well as non-arboreal mammals and ground-nesting birds (Reaveley, Bettink & Valentine, 2009). In south-western Australia, five marsupial species, the brushtail bettong/woylie (*Bettongia penicillata*), quokka (*Setonix brachyurus*), numbat (*Myrmecobius fasciatus*), and western ringtail (*Pseudocheirus occidentalis*) and brushtail (*Trichosurus vulpecula*) possum, all suffered severe population and distribution declines shortly after the first confirmed fox sighting (Dickman, 1996). Furthermore, foxes have been found to demonstrate behaviours of surplus killing, with prey species being targeted in mass numbers but are not consumed or cached. There is evidence that suggests foxes were responsible for the surplus killing of three macropod species, the burrowing bettong (*Bettongia lesueur*), black-flanked rock-wallaby (*Petrogale lateralis*) and tammar wallaby (*Macropus eugenii*) (Short *et al.*, 2002), and are suspected in the mass deaths of black swans (*Cygnus atratus*) at Lake Muir, Western Australia (Sedgwick, 1936).

#### 1.4 Influence of urbanisation on fox ecology

Interactions between species in a densely populated region is likely to differ to that seen in rural environments, as the distribution of habitat patches, the different nature of the urban matrix and the changed species composition in urban ecosystems can alter the availability of, and competition for, resources (Mitchell & Powell, 2004). Wildlife occupying urban landscapes display different ecological and behavioural traits to those inhabiting rural and sparsely-populated regions, most likely due to the differences in environmental conditions and stresses caused by urbanisation (Ditchkoff, Saalfeld & Gibson, 2006; Bateman & Fleming, 2012).

As such, we would expect to see differences in the life-history traits for foxes when comparing between environments with varying degrees of human disturbance. For instance, foxes inhabiting Bristol showed little avoidance to the presence of people, frequently visiting residences and public areas either in search of an appropriate place to shelter or to scavenge for food (Saunders, White, Harris & Rayner, 1993). The density of foxes can also vary dramatically between areas, ranging from 0.2 individuals per km<sup>2</sup> in rural regions to up to 16 individuals per km<sup>2</sup> in urban areas (Dickman, 1996; White, Gubiani, Smallman, Snell & Morton, 2006). The composition of vegetation patches in urban environments may contribute to the abundance of foxes, with several studies indicating fox occurrences to be higher in

landscapes that have a greater degree of edge habitats and cleared land (Graham, Maron & McAlpine, 2013; Towerton, Penman, Kavanagh & Dickman, 2011).

The success of foxes in urban environments can be attributed to increased amounts and closer proximity of natural and anthropogenic food resources. Scavenged food, either taken from refuse or by deliberate feeding, constitutes to a large proportion of the diet of urban foxes (Saunders *et al.*, 1993; White, Saunders & Harris, 1996), while foxes in remote areas scarcely encounter food from anthropogenic sources. Urban foxes also experience less competition and predation pressures from larger predators, such as dingoes (*Canis dingo*) and wild dogs (*Canis lupus familiaris*), which are persecuted by people (Davis *et al.*, 2015). Furthermore, roads and other cleared features can facilitate the movement of predators between remnant vegetation and provide ideal hunting grounds, thereby increasing predation success of foxes inhabiting urban areas (Doherty *et al.*, 2015).

### *1.5 Implications of controlling urban foxes*

The increased interaction between people and foxes in urban areas is potentially problematic, as foxes pose a direct threat to the health of people and domestic animals and can act as vectors for disease, such as mange and rabies (Saunders, White & Harris, 1997). Deploying poisoned baits has been a highly effective control measure for eliminating foxes and reducing impacts to native wildlife (Saunders *et al.*, 1995; Saunders *et al.*, 2010). However, the higher density of people living in urban areas makes mortality-based control measures less practical, as there is an increased risk of exposure to non-target species and people (Jackson, 2003; Jackson, Moro, Mawson, Lund & Mellican, 2007). Due to this, the most common forms of fox control seen in urban environments are those that present minimal risk to non-target species, such as den fumigation (White *et al.*, 2006) and trapping (Fleming *et al.*, 2014). While effective at the local scale, the tasks of locating den sites and setting and checking traps are time consuming and labour intensive (Saunders *et al.*, 2010). For these reasons, finding an alternative method for monitoring foxes and mitigating their impacts to biodiversity and people should be an essential focus of future management programs.

When planning management or conservation programs for a certain species, it is necessary to have accurate data relating to the space and resources used by that animal, as well as an understanding of how the characteristics of the surrounding landscape influence the distribution of individuals and populations (Gough & Rushton, 2000; Benhamou & Corn  lis, 2010). When dealing with pest species,

understanding how animals perceive and utilise their surroundings is necessary for implementing an effective management strategy (Bengsen *et al.*, 2016). Identifying key characteristics, including home range size and formation, time taken to traverse the home range area and composition and visitation frequency of habitats within the home range, for the target species can aid in the planning of control or monitoring strategies (Moseby, Scott & Crisp, 2009; Bengsen, Butler & Masters, 2011; Bengsen, Butler & Masters, 2012).

### *1.6 Defining the home range*

Non-nomadic animal species demonstrate site fidelity for an area or habitat by establishing home ranges. A conceptual definition, provided by Burt (1943), describes home ranges as the total area in which animals forage, reproduce and nurture offspring. Animals may travel beyond the boundary of their home range when seeking potential mates or food sources; such excursions are separate from the home range area (Burt, 1943). However, extrapolating ecological and behavioural information from home range data is achievable only when quantifiable components are analysed (Powell & Mitchell, 2012). In response to this, several recent publications have attempted to identify the underlying conceptual framework of ranging behaviours observed in animals (Powell, 2000; Mitchell & Powell, 2004; Börger, Dalziel & Fryxell, 2008; Mitchell & Powell, 2012; Powell & Mitchell, 2012; Spencer, 2012). Though it is not completely certain, it is believed that a home range represents the total area of which an animal, through frequent visitations, has gathered collective knowledge of the spatial distribution and availability of resources occurring within its habitat that are needed to satisfy its biological requirements (Mitchell & Powell, 2012; Spencer, 2012).

Animal home ranges are not constructed randomly, as resources (food, water, shelter) do not occur randomly in space (Johnson, Kays, Blackwell & Macdonald, 2002). An animal's home range may vary throughout its lifetime (Berghout, 2000), changing in size and structure in response to seasonal variations (Henry, Poulle & Roeder, 2005; Bengsen *et al.*, 2016) and occupation of adjoining areas that were recently vacated (White *et al.*, 1996; Baker, Funk, Harris & White, 2000; Meek & Saunders, 2000; Bengsen, 2014). Changes in home range characteristics vary, ranging from minor fluctuations in size and shape to forming a completely new home range several kilometres from the previous boundary (Meek & Saunders, 2000). The availability of food is thought to be a limiting factor influencing the characteristics of an individual's home range (Lucherini & Lovari, 1996), with several studies attributing the spatial

distribution and social organisation of animal groups to the richness and spatial distribution of food resources within an area (Macdonald, 1983; Creel & Macdonald, 1995; Powell *et al.*, 1997). Typically, animals establish smaller home ranges in highly productive environments, as these areas are associated with high quality resources (Reiss, 1988; Powell, Zimmerman & Seaman, 1997; Johnson *et al.*, 2002). Home range may also be influenced by intraspecific and interspecific interactions, with an individual's home range changing in response to how others utilise and defend resources that occur within the landscape (Mitchell & Powell, 2004).

### *1.7 Factors influencing fox home range characteristics and space use*

The space use and resource requirements of the European red fox have been the focus of numerous investigations. Most studies report a negative relationship existing between home range size and productivity in foxes (Lucherini & Lovari, 1996; Meia & Weber, 1996; Macdonald, Courtenay, Forbes & Mathews, 1999; Baker *et al.*, 2000). Foxes occurring in productively-poor environments must maintain significantly larger home ranges compared to foxes inhabiting resource-rich habitats. Changes to the metabolic requirements and behaviour during critical biological time periods, such as gestation and lactation, have also been linked to temporal home range shifts in reproductive vixens (Lindstedt, Miller & Buskirk, 1986). There appears to be a trend in the size of a fox's home range along the natural-urban gradient, with foxes occurring near urban areas having significantly smaller home ranges than those inhabiting natural areas (Moseby *et al.*, 2009; Šálek, Drahníková & Tkadlec, 2015).

Landscape characteristics, particularly vegetation type and density, have a strong influence on habitat selection by foxes. White *et al.* (2006) identified that the core areas of foxes occurring in riparian zones contained proportionally more blackberry and gorse vegetation than that which was available in their home range. Similar patterns have been observed in other studies (Marks & Bloomfield, 2006), suggesting that the structure of these vegetation types are preferred by foxes. Habitat selection displayed by foxes can also be influenced by the individual's characteristics, such as dispersal stage and response to time of day. Towerton, Kavanagh, Penman & Dickman (2016) found that foxes would venture into cleared areas near the forest edge at night, presumably because hunting is more successful in these areas, and retreated to forest patches during the day. There also appeared to be a difference in preferred habitat for pre-dispersed and post-dispersed foxes, though habitats selected varied between

individuals (Towerton *et al.*, 2016). However, the influence of urban processes on the ranging behaviour and spatial usage of foxes has been relatively unexplored in Australia.

### *1.8 Fox home range studies in Australia.*

Several studies have investigated home ranges of foxes occurring in different landscape conditions across Australia, including arid (Moseby *et al.*, 2009), forests and agricultural (Carter, Luck & McDonald, 2012; Towerton *et al.*, 2016), coastal (Phillips & Catling, 1991), and peri-urban (Meek & Saunders, 2000; White *et al.*, 2006) and urban environments (Marks & Bloomfield, 2006). Reported home range sizes of foxes in Australia varies between studies, ranging from 0.6km<sup>2</sup> to 103.1km<sup>2</sup> (Meek & Saunders, 2000; Towerton *et al.*, 2016). The extensive difference seen between home range sizes is likely reflective of the conditions of the prevailing landscape in which the foxes occur. For instance, Coman *et al.* (1991) compared the home ranges of foxes inhabiting rural regions to those existing in the peri-urban areas in central Victoria. Foxes that occurred in remotely populated grazing and woodland areas had larger home ranges than those occurring along the peripheral landscape surrounding the city of Bendigo, with home ranges up to 7 km<sup>2</sup> and 1.3 km<sup>2</sup>, respectively. The home range estimates, as well as density and dispersal distance, calculated for foxes were similar to those described in other studies (Adkins & Stott, 1998; Iossa *et al.*, 2008). However, Coman *et al.* (1991) only interpreted variations between home ranges, and failed to analyse the underlying factors influence spatial use and movement patterns of foxes.

### *1.9 Aims and objectives of this study*

The aims of this investigation are to i) determine how fox home range sizes are influenced by productivity and human disturbances via a comprehensive review of relevant literature; ii) identify key factors influencing spatial distribution and movement of foxes occurring within Perth's urban reserves; iii) determine which habitat and land-use types are most likely to be utilised by foxes; iv) identify the different prey and food items that occur in the diet of foxes; and, v) determine how seasonality and habitat influence fox occupancy. Given the importance of urban reserves in supporting biodiversity and the threat foxes present to native fauna, it is my hope that the information gained from this investigation can aid wildlife managers in the planning and development of future conservation efforts and fox control programs.

### *1.10 Thesis structure*

The structure of the thesis is as follows: Chapter 2 is a global review of fox home range studies, focusing on changes in home range size in response to environmental productivity and anthropogenic disturbances. Chapter 3 describes the movement patterns, home range characteristics and habitat use of foxes in Kings Park from data collected by GPS collars, including comparisons to similar studies conducted within Australia and internationally. Chapter 4 concentrates on the practicality of camera traps and dietary analysis as non-invasive methods of monitoring the extent and potential impacts of foxes occurring in urban reserves. Chapter 5 discusses the potential management of foxes in Perth's urban reserves, focusing on different methods of controlling foxes and monitoring the effects of such methods, based on the findings of this study.

## **Chapter 2: Human impact overrides bioclimatic drivers of red fox home range size globally**

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## **Chapter 3: Seasonal home range, habitat selection and movement patterns of foxes inhabiting an urban reserve.**

### *3.1 Introduction*

As outlined in chapter 1, the red fox is an introduced predator to Australia that presents a significant risk to economic and environmental assets (Saunders *et al.*, 1995; Baltrunaite, 2010; Saunders *et al.*, 2010). Predation by foxes has contributed to the decline of many native species, particularly ground-dwelling mammals (Woinarski *et al.*, 2015). Predation pressure from foxes presents a significant threat to populations of native fauna inhabiting urban reserves, which are vulnerable to disturbances such as fragmentation, habitat loss and increased competition (Stenhouse, 2004). Additionally, foxes may introduce or facilitate the spread of diseases, including sarcoptic mange and rabies, to native fauna (Saunders *et al.*, 1997). The risk of foxes transmitting diseases to people and domestic pets is greater in urban areas, due to their proximity and more frequent interactions (Saunders *et al.*, 1995).

Unlike other species that experience population declines and other negative impacts following urbanisation, foxes seem to thrive in areas with high human densities. When compared to counterparts inhabiting natural environments, foxes occurring in urban areas maintain smaller home ranges and have higher population densities (Šálek *et al.*, 2015). The success of foxes in these areas can be linked to greater resource availability, as well as the behavioural plasticity of the animal. Urban and agricultural areas provide anthropogenic sources of food (i.e. livestock; refuse; pet food; etc.), which foxes advantageously forage from (Doncaster *et al.*, 1990; Saunders *et al.*, 1993). Furthermore, as anthropogenic food sources are likely to have a low spatiotemporal variability, foxes are likely to expend less time and effort acquiring food.

Foxes are known to inhabit agricultural areas and suburban residences in several Australian cities, including the inner suburbs and metropolitan areas of Perth (Marks & Bloomfield, 1999). However, there is limited understanding of how urban processes have influenced ecological and behavioural responses of foxes occurring in these metropolitan areas. Effective control programs for pest species are reliant on wildlife managers having a clear understanding of those species ecological and behavioural traits, particularly movement patterns, spatial distribution and habitat use (Saunders *et al.*, 1995; Saunders *et al.*, 2010).

There are numerous methods that can be used to determine the location of animals within a landscape, each having their own applications and limitations. Indirect observations, including track and scat identification (Goszczyński, 1989; Cagnacci, Meriggi & Lovari, 2004), den locations (Dell'Arte & Leonardi, 2008) and camera traps (Petrov, Popova & Zlatanova, 2016), can be used to identify space use for populations or groups of animals within a defined landscape. For instance, Frafjord (2004) recorded the location of snow tracks made by foxes to determine the group home range size. These methods do not distinguish between individuals, however, preventing researchers from determining the space use and movement patterns of individuals. Fortunately, advances in technologies have allowed free-ranging animals to be tracked remotely through the use of radio-telemetry (Fuller, Millspaugh, Church & Kenward, 2005). Radio-telemetry is a versatile tool used by researchers and wildlife managers to record the distribution of animals and track their movements through the environment (Harris *et al.*, 1990). It is more advantageous than other methods of determining animal distributions, as there is less effort required and greater success of relocating and observing individuals (Fuller *et al.*, 2005). From radio-tracking animals, wildlife researchers and managers can better address ecological and conservational matters related to movement, behaviour, resource usage and activity patterns (Ramanzin, Sturo & Zanon, 2007; Gutema, 2015). There are three methods of radiotracking animals, very high frequency (VHF) and two methods of satellite positioning: global position system (GPS) and global navigation satellite system (GNSS) (Gutema, 2015).

GPS systems are been used more regularly in recent years, due to the development of smaller, more efficient transmitters and increased capabilities of retrieving data (Tomkiewicz, Fuller, Kie & Bates, 2010). GPS system have also been found to out-perform VHF triangulation and tracking techniques, producing less associated distance error (Haller, Filli & Imfeld, 2001). The behavior of animals and their interactions with the environment can also be more accurately monitored with GPS, as locations can be recorded with high temporal frequency (Handcock *et al.*, 2009). Recent advances in GPS-telemetry technologies have enabled highly accurate spatiotemporal data to be taken from animals (Tomkiewicz *et al.*, 2010), thus improving the accuracy of home range estimates and movements seen in various species (Towerton *et al.*, 2016). For instance, Coelho, de Melo, Sábato, Rizel & Young (2007) tested the efficiency of data retrieval from GPS collars by tracking the position of three maned wolves (*Chrysocyon brachyurus*) at Galheiros Environmental Station, Brazil. Coelho *et al.* (2007) reported that efficiency of

retrieving data reach up to 90%, though this varied with the time of the day and activity patterns of the wolves.

The results of chapter 2 revealed that fox home ranges varied considerably in size in response to changes in seasonality and human disturbances. This demonstrates how the prevailing landscape conditions influence the ranging behaviours of this predator. Several studies have investigated home ranges of foxes occurring in different landscape conditions across Australia, including arid (Moseby *et al.*, 2009), forests and agricultural (Carter *et al.*, 2012; Towerton *et al.*, 2016), coastal (Phillips & Catling, 1991), as well as in highly populated cities (Marks & Bloomfield, 2006) and along urban fringes (Meek & Saunders, 2000; White *et al.*, 2006). In a comparative study of foxes inhabiting different landscapes in central Victoria, Coman *et al.* (1991) found that home range sizes of foxes in rural and peri-urban landscapes was up to 7km<sup>2</sup> and 1.3km<sup>2</sup>, respectively. While there was a significant difference for fox home ranges between the landscapes, however, Coman *et al.* (1991) only provide an arbitrary explanation that climate, land use and degree of human disturbance are the likely factors influencing size. Given the poor knowledge of urban fox movements in Australia, I propose to use GPS collars to understand the locations and movements of foxes in Kings Park, Perth.

In this chapter, I will identify key factors influencing spatial distribution and movement of foxes occurring within the study area and determine what factors influence habitat selection, including vegetation assemblages and physical structures, by foxes. Specifically, I aim to:

1. Determine the minimum daily movement (MDM) traversed by foxes and changes in movement rates during different time periods.
2. Identify the importance of roads, tracks and walking trails in facilitating fox movements and likelihood for foxes to use them.
3. Investigate the spatial distribution of foxes by estimating their home ranges.
4. Understand which habitat and land-use types are most likely to be utilized by foxes in the study area.

I predict that foxes inhabiting these reserves will maintain small home ranges with weak territorial boundaries, as is associated with carnivores inhabiting highly productive environments (Herfindal *et al.*, 2005; Nilsen *et al.*, 2005; Duncan *et al.*, 2015). The following hypothesis was tested:

H1: Movement rates change in response to the diurnal rhythm of foxes, with higher movement rates seen during dusk, dawn and night and lower movement observed during the day (Diaz-Ruiz, Caro, Delibes-Mateos, Arroyo & Ferreras, 2016).

The home range of foxes will likely consist of habitat types that are selected disproportionately to those occurring within the study area. Foxes are predicted to demonstrate selection processes for different habitats that occur within their home ranges, which will change in response to the animal's behaviour at different rhythmic cycles. Hypothesis for habitat selection by foxes are provided below:

H1: Preference and avoidance for different habitats by foxes was influenced by vegetation assemblages and characteristics .

### 3.2 Methods

#### Study area description

This study was conducted across two large remnant reserves, Kings Park and Bold Park, which occur within the Perth Metropolitan Area (PMA) along the Swan Coastal Plain (BGPA, 2011, 2014). Perth is the fourth most populated state capital of Australia, with an estimated population of 2.09 million people in 2019, and with density of up to 3400 people/km<sup>2</sup> (Regional Population Growth, Australia, 2018-19, 2020). The area experiences a Mediterranean-type climate, with hot summers and wet, mild winters. Temperatures can reach upwards of 40°C during the peak of summer, with maximum and minimum annual temperatures averaging 23.3°C and 13.3°C, respectively (BoM, 2017). The mean annual rainfall for Perth is 868.3mm, which is received over a period of 91 days (BoM, 2017).

The reserves in this study cover a combined area of 8.37km<sup>2</sup> and consist of bushland, parkland and the Botanic Gardens located at Kings Park (Jackson *et al.*, 2007). Reabold Hill is a major land formation within Bold Park, with an elevation of 84.9m (Australian Height Datum). Soil types range from calcareous soils to various sand formations caused by different dune systems (Kordes, 2004; Jackson *et al.*, 2007). There are a myriad of different land uses surrounding the parks, including commercial and residential infrastructure, green ways and open spaces, wetlands and lakes. The Swan River runs along the south-eastern side of Kings Park, with Mounts Bay Road separating the two landmarks. Coastal dune systems occur within and around the western side of Bold Park. The eastern border of Bold Park adjoins Perry Lakes Reserve, while the Wembley and Cottesloe Golf Courses are located at the northern and southern

ends of the park, respectively. There are several closed bodies of water occurring within a few kilometres of either reserve, including Herdsman Lake, Lake Monger and Lake Claremont.

Both parks support a high floral diversity, including up to 325 native and 232 naturalised plant species (Kordes, 2004; BGPA, 2011, 2014). There are two distinct landform types at Kings Park, mixed-closed heath along the Mount Eliza Escarpment (limestone) on the southeast side of the park and *Eucalyptus*, *Allocasuarina* and *Banksia* forest throughout the rest of the area (BGPA, 2014). Bold Park contains a mosaic of native vegetation communities and sub-communities, with the major vegetation formations being Tuart (*Eucalyptus gomphocephala*) and banksia woodlands and limestone heath (BGPA, 2011).

Faunal species richness is also high, with over 300 invertebrate and approximately 127 vertebrate species occurring across the reserves (BGPA, 2011, 2014). Of the vertebrates, there are approximately 91 bird (84 native and seven introduced), 27 herpetofauna and 9 mammal (four native and five introduced) species (How & Dell, 2000; Kordes, 2004).

#### GPS schedule details and testing

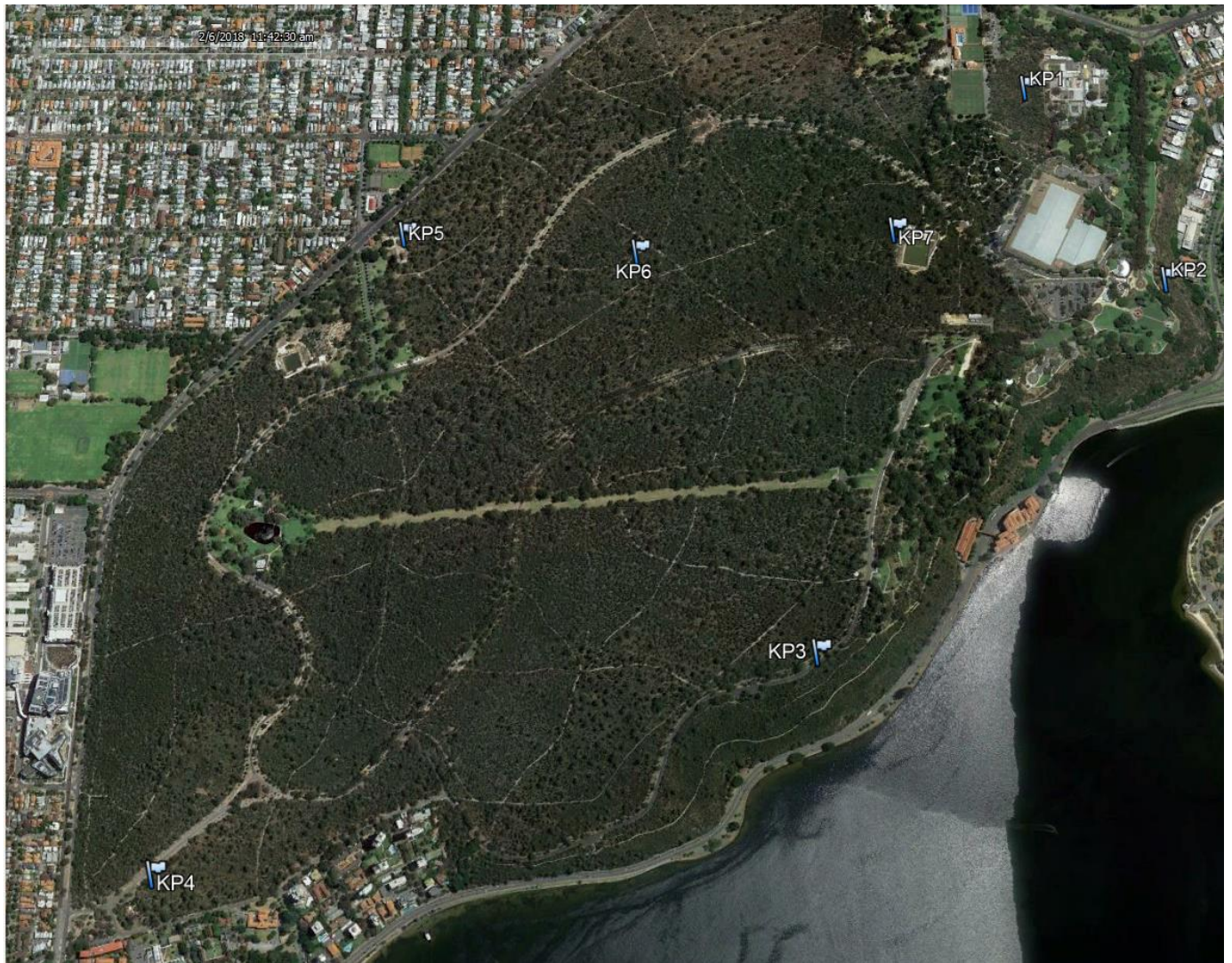
I used Sirtrack LiteTrack 140 GPS-radio collar (135-140g) for the purposes of this telemetry study. Each collar was equipped with a VHF beacon that transmitted between 148.01 to 148.15 MHz, with a difference of 0.02MHz set between each collar. Collars were programmed to record at least one location every hour, with recordings being taken at intervals of 15 minutes between 0500 to 0700 and 1700 to 1900 (AWST) to coincide with the crepuscular activity of foxes. This meant that collars could potentially record 36 fixes per day, which allowed detailed movements to be observed in the sample group. Collars were programmed to record telemetry data for 90 days, to coincide with the release times of the Micro-TRDs (timed release devices). Location fixes were stored onto the collars, requiring collars to be collected at the end tracking period. To determine the degree of positional error of the GPS collars, the horizontal precision ( $\sigma_{H\_precision}$ ) and accuracy ( $\sigma_{H\_accuracy}$ ) was previously calculated using the methods described by Yoshimura and Hasegawa (2003) (See Appendix 3). Root mean squares (RMS) was used to calculate and compare the horizontal precision, where the variance of the positional error along the x and y axes are combined and then square rooted. The horizontal accuracy was calculated by square-rooting the combined squared values for the sample means of x and y axes positional error subtracted by the true location of the x and y coordinates. To ensure that the true position of the x and y coordinates was known, the Geodetic standard survey marker (SSM) located at Reabold Hill (long:

115°46'33.381"E; lat: 31°56'25.798"S) was used as the test site. The test was conducted for two hours, with each collar programmed to record its location every 15 minutes.

#### Trapping program and transmitter attachment

A previous trapping program using cage traps failed to capture any foxes at Kings Park and Bold Park (See Appendix 7). For this reason, a second trapping program was conducted in both study areas using Victor Soft-Catch leghold traps. A total of 96 trap nights (KP= 56; BP= 40) were conducted within the study areas between 11<sup>th</sup> to the 21<sup>st</sup> of December 2018. To prevent the risk of injury to people and domestic pets, traps were deployed near sand tracks closed to the public and appropriate warning signage was displayed at both ends of the tracks. Foxes that had been captured were restrained using a pole snare and anaesthetised using Zoletil 100 solution administered via an intramuscular injection. The weight, sex, age (determined by tooth wear) and body condition of each animal was recorded (Table 3.1). Collars were only attached if the weight of the collar was less than 5% of the fox's total body weight. Foxes were then placed in a sheltered location at the site of capture and were monitored to ensure that they recovered from the effects of the anesthetic.

Over the trapping period, four (4) foxes were successfully trapped and collared before being released at their capture site (Figure 3.1). Attempts to relocate the collars were performed by different personnel over the months of March and April. VHF signals were scanned using a hand-held receiver and Yagi antenna along transects throughout the study area to narrow down the search radius for each collar. Only one collar (Miranda) was found to have released successfully; signals of two other collars (Beth and Rob) were detected erratically over the study area, indicating that the release mechanisms had likely failed. This was confirmed by camera photos showing one or more foxes with affixed collars. The signal from John's collar was not detected within the study area.



**Figure 3.1. Trap locations within Kings Park.** Foxes were caught at sites KP2, KP3 and KP5.

### Interpreting fox movement and utilization of roads

Location fixes were downloaded and exported as csv files using the PinPoint Host software provided by Sirtrack. Using the adehabitatLT package in R (Calenge, 2006), the minimum daily movements (MDM) that the fox traversed was determined by summing the distance between successive fixes recorded within a 24-hour period (0800-0700). The influence of diurnal cycle on movement rates was assessed by organising fixes into three time periods. These periods were: day (0800-1600); crepuscular (0500-0700; 1700-1900) and night (2000-0400). Both day and night movements were taken from fixes recorded at 1-hour intervals and crepuscular movements were recorded at 15-minute intervals. A *t*-test was conducted to determine if there was a significant difference of hourly movement rates between day and

night periods. Distances that fixes occurred from roads, foot paths and sand tracks were measured using the 'near' function in ArcMap (v10.2.2).

### Estimating home range sizes

Home range size and shape was determined using the adehabitatHR package (Calenge, 2006) available in R. This package stores coordinates of points into space, as well as stores relevant attribute data (i.e. animal ID; age; sex; date/time of recording etc.) allowing home ranges of multiple animals to be estimated simultaneously (Calenge, 2006). Two methods were used to estimate HRS of foxes, minimum convex polygon (MCP) and kernel density estimate (KDE). The MCP estimation (Mohr, 1947) calculates home range by determining the distance of the furthest location fixes from the centre of the home range. This is the simplest form of interpreting HRS in animals and can be directly compared to findings of other investigations (Harris *et al.*, 1990). However, this method often leads to overestimations of HRS, as it does not exclude fixes taken during forays beyond the boundary of the home range (Powell, 2000). Also, MCPs cannot differentiate between areas of different usage by an animal, which makes them insufficient for studies determining habitat use (Mitchell & Powell, 2008). The kernel density estimator (KDE) is regarded as the most accurate method for estimating an animal's home range (Worton, 1989; Powell, 2000; Börger *et al.*, 2006), however see Row and Blouin-Demers (2006) for implications of smoothing parameter selection. Like other probabilistic methods, kernel estimates allow the utilisation distribution (UD), which predicts the likelihood that an individual will be found in a certain location at any given time, of an animal occurring in its home range to be calculated (Worton, 1989; Powell & Mitchell, 2012). Though it has been argued that small sample sizes result in an overestimation of home range size (Seaman *et al.*, 1999), the robustness of the kernel method has produced accurate home range estimates from as few as 10 fixes (Börger *et al.*, 2006). The most important component of the kernel method is the selection of an appropriate smoothing parameter, which can either be set at a constant (fixed) or variable (active) value (Worton, 1989).

For this study, fox home ranges were estimated using both 95% MCP and 95% KDE; core areas of fox home ranges were also determined using 50% KDE. We used the reference bandwidth ('href' function in adehabitatHR) to produce a fixed selection parameter for both the 95% and 50% KDE.

### Analysing habitat selection

After estimating home range sizes, the selection of different habitat types by foxes was investigated. It was not possible to determine habitat availability for the fox population in the study area, as location data from only one fox was retrieved. Instead, selection was determined by identifying the use of different habitats within the home range (95% KDE) and core area (50% KDE) for the individual. Habitat classes were identified by overlaying home range boundaries with shapefiles containing information on vegetation assemblages. There were six habitats identified: mixed open woodland, banksia woodland, mixed heath, Parrot Bush shrubland, disturbed spaces, and open space. Areas of native woodlands had a canopy height >10m with a sparse understory between reaching 0.5m to 2m in height. Mixed open woodland was characterized by the presence of *Corymbia calophylla*, *Allocasuarina fraseriana* and *Banksia attenuata* understory, while banksia woodland had higher abundancies of *B. attenuata* and *Banksia menziesii*. Mixed heath and Parrot Bush shrubland (mixed *Banksia sessilis* and *Acacia cochlearis*) occurred in dense thickets along the south eastern corner of the study area, along the limestone scarp. Areas were classified as disturbed if they contained abundant assemblages of exotic species or were currently undergoing revegetation. Ornamental lawns, parking lots and vacant lots were classified as open spaces. Water bodies, including ponds, dams, lakes and rivers, within the home range of the fox were excluded from the analysis as they were considered unavailable forms of habitat for the fox. Habitat use was then determined by using the methods described by Neu *et al.* (1974), which determines whether observed patterns of use coincide with availability through the use Chi-square ( $\chi^2$ ) goodness-of-fit statistic. After identifying a significant difference between the use and availability of one or more habitats, Bonferroni confidence intervals (Miller, 1981) were calculated at  $P < 0.05$  to determine whether individual habitats were used more frequently (preferred) or less frequently (avoided) than expected. To determine if habitat selection was influenced by temporal factors, the use of different habitats was assessed for four different time periods: dawn (0500-0700), day (0800-1600), dusk (1700-1900) and night (2000-0400).

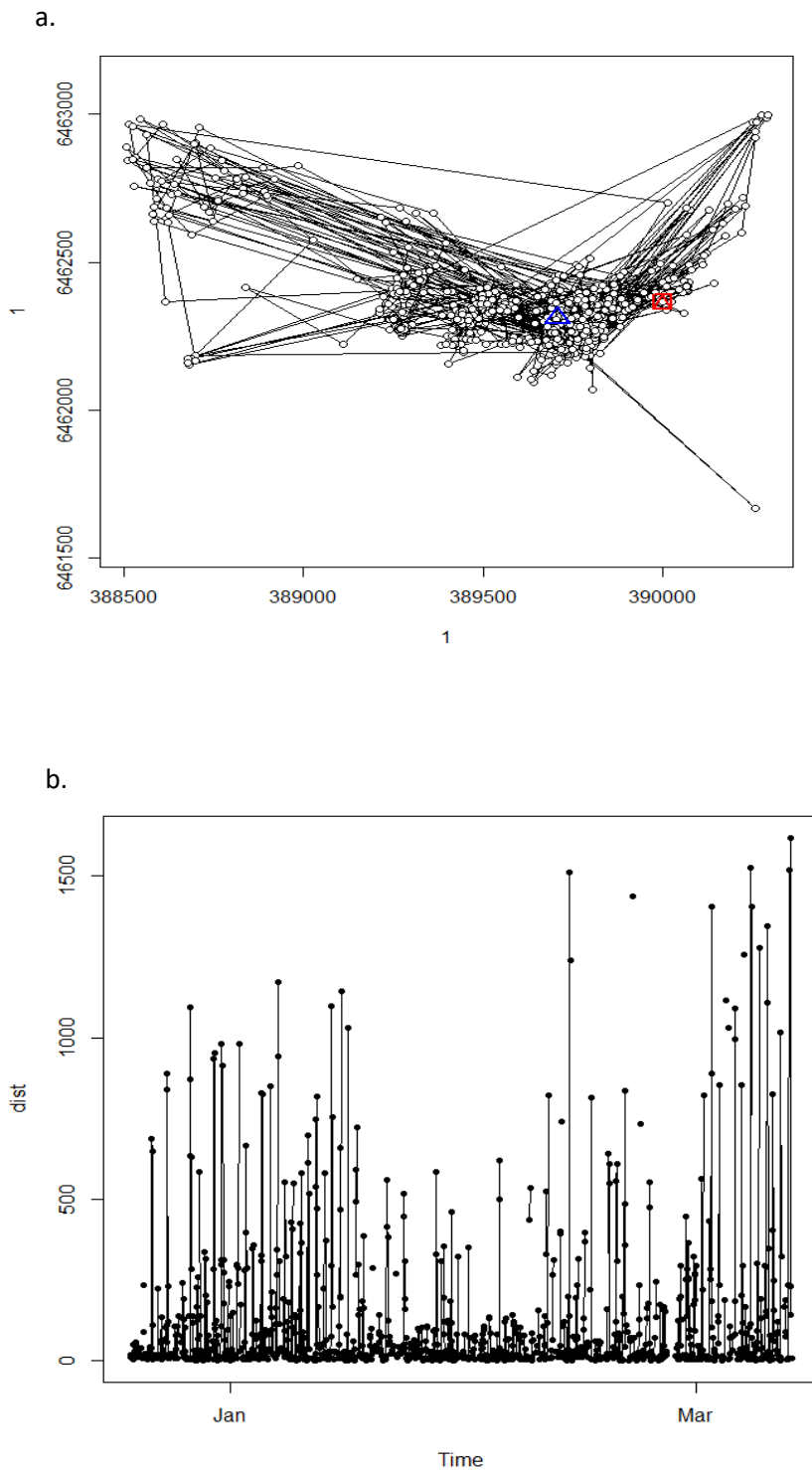
**Table 3.1. Results of fox trapping at Kings Park from the 11<sup>th</sup> to the 21<sup>st</sup> of December 2018.** The below table shows the date foxes were captured and sex, age, weight and condition of each animal. Collar IDs are also shown, as well as the date collars were retrieved.

Name	Date of Capture	Sex	Age Group	Weight (kg)	Body Condition	Collar ID	Retrieved
John	11/12/2018	Male	Adult	6.07	Average	148.130	N/A
Rob	11/12/2018	Male	Sub-adult	3.70	Good	148.070	N/A
Joan	18/12/2018	Female	Adult	4.90	Average	148.050	N/A
Miranda	18/12/2018	Female	Sub-adult	2.85	Good	148.110	25/03/2019

### 3.3 Results

#### Positional error of GPS collars

After testing the collars, the horizontal precision and accuracy was calculated to be 36.29 and 6.25m, respectively. A review of the dataset showed an outlier that occurred several hundred meters from the true location. Removing this outlier from the samples yielded horizontal position and accuracy values of 9.20 and 2.03m, respectively. This confirmed that the positional error for the GPS recordings obtained from the collars was less than 10m, which is satisfactory for the purposes of this study.



**Figure 3.2. a#:** 15-minute location fixes, for the period 19/12/2018 to 13/03/2019, recorded for the fox (Miranda) within the study area. **b#:** distance traveled (in metres) between consecutive hourly location fixes\* for the period 19/12/2018 to 13/03/2019. \*Lines between points represent consecutive hourly fixes that were successfully recorded.

### Movement

From the one collar that was successfully retrieved from a female sub-adult fox, A total of 2231 active fixes were recorded over 83 days. After excluding all non-successive fixes, there were 1752 consecutive fixes in the dataset. The average MDM for the fox was 2.22 km (Table 3.2), while the longest single movement recorded was 1.62km. The average movement of the fox during the three time periods was calculated and compared (Table 3.2). The average hourly movements for the fox during and night periods were 20.87 m and 258.44 m, respectively. The results of the *t*-test revealed that the fox moved significantly further at night than during the day. The average distance travelled during 15-minute traverse was 27.61 meters (Table 3.2). At any given time, the average distance that the fox was from the edge of a road, foot path or sand track was 35.36 meters (+S.E. 0.56), with a similar value seen for the median (31.07 metres). Almost 97% of the fixes occurred less than 100m from a road.

**Table 3.2. Mean movement rates of the fox (standard deviation shown).** Day and night movements were calculated from consecutive 1-hour fixes over 10-hour periods; crepuscular movements were calculated from consecutive fixes recorded at 15-minute intervals over two 2-hour periods. Minimum daily movement (MDM) was estimated from all consecutive fixes recorded over 24-hours. All values for movement are shown in m.

	No. of fixes	X	s.d.	Range
MDM	1752	2215.2	1095.5	407-4399
Day	371	20.9	30.8	0.2-222
Night	374	258.4	323.0	2-1525
Crepuscular	1007	27.6	62.9	0.3-1000



**Figure 3.3. Estimates of home range size, shape and position.** The above figure is an aerial image taken of King's Park. The 95% MCP(solid-bold line;  $0.302\text{km}^2$ ), 95% KDE (dashed line;  $0.331\text{km}^2$ ) and 50% KDE (solid-thin line;  $0.025\text{km}^2$ ) home range estimates for the fox (Miranda) are shown.

### Home Range and Habitat Selection

The ranging behavior for the individual fox was determined using the available telemetry data. Estimated home ranges for the individual were small, with less than a 10% difference in size between 95% MCP (0.302 km<sup>2</sup>) and KDE (0.331 km<sup>2</sup>) estimates (Figure 3.3). The core area of the individual's home range (KDE 50%) was 0.025 km<sup>2</sup> (Figure 3.3), less than one-tenth the size of the 95% KDE. All of six habitat types were present in the 95% KDE home range. However, mixed open woodland, Parrot Bush shrubland and disturbed areas were the only habitats found in the core area (50% KDE). Results of the chi-squared test revealed that habitat use was disproportionate to the availability of habitats for both the 95% KDE ( $\chi^2 = 4429$ ,  $df = 5$ ,  $P < 0.001$ ) and 50% KDE ( $\chi^2 = 28$ ,  $df = 2$ ,  $P < 0.001$ ) estimates (Table 3.3). Both parrot bush shrubland and disturbed areas were preferred habitats use by the fox for the 95% KDE home range, while only Parrot Bush shrubland was preferred in the 50% KDE core area. Habitats were used disproportionately for all the time periods ( $P < 0.001$ ) (See Appendix 4). Parrot bush shrubland and disturbed areas were preferred for all time periods; though more fixes were recorded for Parrot bush than disturbed areas during the day, and vice versa for night. Mixed open woodland was used proportionately to its availability within the animal's home range during dawn and night periods, and open space were used proportionately at night (Table 3.4).

**Table 3.3. Habitat selection within the 95% KDE home range and 50% KDE core area of the fox.**

Habitat Class	Total area (km <sup>2</sup> )	Proportion of total area	Observed use	Expected use	Proportion observed in each area	Bonferroni Confidence Interval (95%)	Result
Within 95% KDE Home Range							
Mixed open woodland	0.049	0.153	232	327	0.108	0.090 - 0.127	Avoided
Banksia woodland	0.183	0.566	492	1211	0.230	0.204 - 0.255	Avoided
Disturbed	0.014	0.044	426	94	0.199	0.175 - 0.223	Preferred
Mixed heath	0.034	0.106	21	227	0.010	0.004 - 0.016	Avoided
Parrot Bush shrubland	0.032	0.098	944	209	0.441	0.411 - 0.471	Preferred
Open space	0.011	0.034	25	72	0.012	0.005 - 0.018	Avoided
Within 50% KDE Home Range							
Mixed open woodland	0.002	0.089	26	45	0.052	0.028 - 0.075	Avoided
Disturbed	0.011	0.452	189	227	0.376	0.325 - 0.426	Avoided
Parrot Bush shrubland	0.011	0.459	288	231	0.573	0.521 - 0.624	Preferred

**Table 3.4. Habitat selection during different time periods (within 95% KDE home range).** Habitat types that were preferred (+), avoided (-) or proportional (P) are indicated in the below table.

Time	MW	BW	D	MH	PB	O
<b>Dawn</b>	P	-	+	-	+	-
<b>Day</b>	-	-	+	-	+	-
<b>Dusk</b>	-	-	+	-	+	-
<b>Night</b>	P	-	+	-	+	P

### 3.4 Discussion

Minimum displacement distances differed between time periods that the fox was tracked with significantly greater movements seen during the night (258.4m) compared to daytime movements (20.9m). This confirms the prediction that movement is influenced by the diurnal rhythm of foxes, with increases in activity during nocturnal periods. Though direct comparisons were not made, the fox travelled, on average, a greater distance within a shorter timeframe during crepuscular periods than daytime periods (27.61m/15-minute interval > 20.87m/1-hour interval). The results of this study are consistent with those of comparable studies, which report foxes are predominantly active during crepuscular and nocturnal timeframes (Moseby *et al.*, 2009; Diaz-Ruiz *et al.*, 2016).

The movement rates of the fox observed in this study were considerably less than those occurring within remote areas of Australia (Carter *et al.*, 2012; Towerton *et al.*, 2016). In their study, Towerton *et al.* (2016) reported that minimum daily movements of post-dispersal foxes averaged over 9km and travelled significantly further during nocturnal time periods than diurnal time periods. Similarly, the minimum daily movements of foxes inhabiting an arid region of northern South Australia were 4.55km, with significantly further distances travelled between night and crepuscular fixes than day fixes (Moseby *et al.*, 2009). Mammals demonstrate reduced movement in areas with high human footprints, with some species showing a three-fold decrease in movement rates in urban areas when compared to less disturbed areas (Tucker *et al.*, 2018). For instance, Diaz-Ruiz *et al.* (2016) found a negative correlation between diurnal activity of foxes and degree of human disturbances. In their study of foxes inhabiting central Spain, Diaz-Ruiz *et al.* (2016) report that diurnal activity patterns decreased when transitioning from areas of dense cover to areas closer to human settlements. As Kings Park is located within Perth's metropolitan area, it is likely foxes are less active during the day to avoid interactions with people.

Most of the locations recorded for the fox occurred within 100 m of a road or other track, indicating that they were regularly used for movement within the reserve. Several studies have indicated the importance of roads and other man-made features (i.e. railways) in facilitating the movement of foxes and other predators through their immediate surroundings (Kolb, 1984; Trehwella & Harris, 1990; May & Norton, 1996; Towerton *et al.*, 2016). For instance, Towerton *et al.* (2016) found that foxes were often within 200 m of a road and crossed them more than expected. However, roads are often associated with vehicle collisions with animals. Foxes inhabiting Bristol (UK) were found to cross roads less than expected, with fewer crossings seen in juveniles than adults (Baker *et al.*, 2007). Road crossings by foxes increased after midnight when there was less vehicle traffic, indicating foxes altered their activity

patterns to reduce the mortality risk from vehicle collisions (Baker, Dowding, Molony, White & Harris, 2007).

The size of the fox's home range was consistent with home ranges sizes reported in similar studies carried-out in urban areas of Australia (Coman *et al.*, 1991; Marks & Bloomfield, 2006; White *et al.*, 2006). For instance, foxes inhabiting Melbourne's urban and peri-urban areas maintained average home range sizes of 0.296km<sup>2</sup> (Marks & Bloomfield, 2006) and 0.446km<sup>2</sup> (White *et al.*, 2006), respectively. Home range sizes of foxes inhabiting Australia's urban areas are similar to those reported in international cities, including Oxford, UK at 0.388km<sup>2</sup> (Doncaster and Macdonald, 1991), Bristol, UK at 0.205km<sup>2</sup> (Saunders *et al.*, 1993) and Toronto, Canada at 0.52km<sup>2</sup> (Adkins and Stott, 1998). Home range size decreases with increasing urbanisation and anthropogenic changes to a landscape for several meso-carnivore species, including foxes (Šálek *et al.*, 2015). As was seen in Chapter 2, the intensity of the human footprint index (HFI) was negatively correlated with home range sizes in foxes, with increasing human disturbances resulting in decreasing range sizes. Reduced home range sizes seen in carnivores inhabiting urban environments is likely attributed to an increase of food resources from anthropogenic sources (Fleming & Bateman, 2018). Changes in the size of fox home ranges has been linked to the availability of anthropogenic food, with reports identifying a two-fold increase in size following removal of these food resources (Bino *et al.*, 2010). Several studies also indicate a high exploitation of anthropogenic food sources by foxes in urban areas (Doncaster *et al.*, 1990; Saunders *et al.*, 1993; Gortázar *et al.*, 2000; Contesse *et al.*, 2004). However, a dietary analysis of fox scats taken from BGPA reserves indicated that anthropogenic food was consumed infrequently (see Chapter 5). Lack of anthropogenic food found in fox diet may be due to a reliance on prey species, as several medium-sized mammals and other prey occur at high densities within the reserves.

Habitats within Kings Park were used disproportionately to their availability, confirming the hypothesis that the fox demonstrated a preference and avoidance of certain habitat categories. Observations of the fox in our study revealed a preference for areas of dense vegetation while avoiding woodlands with sparse understory and open spaces. This is consistent with other studies reporting vegetation cover as the key driver of habitat selection by foxes inhabiting urban areas (Saunders *et al.*, 1997; Robertson, Baker & Harris, 2000). Dense vegetation is often used for diurnal shelter and den sites, due to increased cover protecting foxes from people and predators. For instance, White *et al.* (2006) found that foxes inhabiting outer suburban Melbourne utilised thickets of introduced blackberry *Rubus fruticosus* and gorse *Ulex europaeus*, occurring in their home range, for diurnal shelter. Similarly, Marks and Bloomfield

(2006) reported that foxes inhabiting Melbourne's interior were more likely to select areas containing densely-growing invasive weeds over areas containing ornamental and native vegetation. However, there was no clear indication that the diurnal rhythm of the fox influenced habitat selection in this study. Although we did see some changes in the number of fixes taken between day and night periods for Parrot Bush and disturbed areas, and other habitat types were used in proportion to their availability at different times. Density of people has been reported to influence habitat selection of foxes inhabiting suburban areas of Toronto (Adkins & Stott, 1998) and London (Harris, 1977). Areas with dense vegetation are less accessible by people, thereby limiting the fox's exposure to human disturbances. The lack of suitable, undisturbed areas within the urban landscape, may influence foxes to utilise these small patches of dense vegetation for shelter and den sites (Marks & Bloomfield, 2006). Furthermore, changes seen in the selection of habitats by the fox at different time periods could be explained by the degree of human activity. Open spaces were avoided throughout the day, when the reserve was busiest, and used more at night, when there are fewer people in the area.

It is difficult to identify the factors influencing habitat selection based on the observational of a single individual. Any analysis of habitat preference is limited by the classification of habitats available to the animal and what is the true availability of these habitats (Johnson, 1980; McClean, Rumble, King & Baker, 1998). Habitat categories identified in this study were based on broad classification of the dominant vegetation types occurring within the home range of the fox, and more specific habitat classes may have existed within these categories. Habitat availability may also be restricted due to competition with other foxes in the reserve. For this study, it is unclear whether territorial borders between fox home ranges were strong, or if a high degree of overlap existed between neighbouring home ranges. For instance, fox groups inhabiting a residential area of Toronto were found to have non-overlapping home ranges (Adkins & Stott, 1998). In an agricultural landscape in northern Victoria, Carter *et al.* (2012) reported that adult foxes predominantly held exclusive core home ranges, however, a high degree of overlap occurred between the core areas of neighboring sub-adults.

### 3.5 Limitation of the study

Only one GPS collar was successfully retrieved from the field. It is suspected that a mechanical failure occurred in the timed-release devices (TRDs), which prevented the remaining collars from releasing. This is supported by the erratic signal detection seen from some of the collars, as well as images taken of collared foxes after the 90 days period (Figure 4). Mechanical or programming errors are common issues that arise in telemetry studies, with several Australian studies reporting TRDs releasing early, late or not at all (Matthews *et al.*, 2013). Failure to retrieve the collars was particularly problematic for this study, as the initial sample size was small (i.e. 4 foxes). It is difficult to make accurate inferences of the ranging and selection behaviour for foxes in the study area, based on data retrieved from one individual. However, by comparing the results of this investigation to similar studies, it was possible to make inferences regarding the factors influencing urban fox ecology.



Figure 3.4. Images taken of a collared fox after the 90-day tracking period had ended.

### *3.6 Conclusion*

Due to failure in retrieving GPS collars, detailed analyses of movement patterns and home range sizes for foxes could not be made. Based on the available data from the one successfully retrieved collar and observation made in similar investigations, it is plausible that foxes inhabiting Perth's urban reserves maintain small home range sizes. However, it is difficult to discern the space use of a population based on a single observation. Comparisons acquired from multiple subjects would be necessary to make accurate prediction of home range size for foxes inhabiting this urban reserve. The observed fox was found to be more active during nocturnal hours, travelling greater distances at night than during the day. Roads and man-made tracks were regularly used by the fox, with 97% of all recorded fixes occurring within 100m of these features. Disturbed vegetation and Parrot Bush shrubland were the only habitat types that were preferred by the fox, although mixed woodland and open spaces were used proportionally to their availability at different time periods. Selection of habitat was most likely influenced by vegetation cover, which provide suitable areas for diurnal shelter and den sites. Density of people may have also influenced habitat selection.

## **Chapter 4: Applications of non-intrusive techniques to monitor invasive species: What can camera traps and dietary analysis tell us about fox occupancy and predation in urban reserves?**

### *4.1 Introduction*

Predation by invasive predators is one of the leading causes of biodiversity decline in Australia (Woinarski *et al.*, 2015), and red foxes are presumed to have contributed to the extinction of several species and threaten a further 51 species (Reaveley *et al.*, 2009). Foxes may also indirectly impact the health of both animals and people by transmitting various zoonoses, including sarcoptic mange and rabies (Saunders *et al.*, 1997). For these reasons, implementing control measures to mitigate the impacts presented by foxes is a top priority for wildlife managers. There are several methods that can be used to control fox numbers within an area, including poisoned baiting, trapping and den fumigation (Fleming *et al.*, 2014; Saunders *et al.*, 1995; Saunders *et al.*, 2010). However, the initial outcome of any coordinated control programs is compromised if they are not preceded by appropriate monitoring measures. Without the ability to determine the relative or total abundance of foxes, wildlife managers and decision-makers are unable to gauge the effectiveness of control programs or if further intervention is required (Robley *et al.*, 2012).

Effective monitoring programs must be designed to ensure that estimates of abundance or predicted impacts are reliable, as well as repeatable in order to identify changes (Mitchell & Balogh, 2007). There are numerous methods that can be used to infer fox densities or abundances (see Mitchell and Balogh (2007) for a detailed review of these methods). The most commonly used methods for detecting foxes include spotlight counts, identifying tracks, scats or dens and visits to bait stations (Vine *et al.*, 2009). However, each of these methods can be subjected to biases, resulting in data that does not accurately represent the actual abundance of the target species. Visual identification of foxes can also be impeded by dense vegetation and weather conditions (i.e. rain; fog etc.), while interference from non-target species and inexperienced field workers can weaken the reliability of indirect measures (i.e. incorrect/inability to identify tracks, scats e.g. Wilson & Delahay, 2001). Camera traps are an alternative means of surveying species, enabling long term monitoring of an area with and minimising effort from personnel (Robley *et al.*, 2012). Camera traps are generally non-invasive to the animals being monitored, which makes them a popular choice for studies into vertebrate ecology and estimates of species abundance and occupancy (Kucera & Barrett, 2011; Swann & Perkins, 2014). Several studies have shown the effectiveness of remote cameras in monitoring the activity, spatial distribution and occupancy of foxes in Australia (Robley *et al.*, 2012; Towerton *et al.*, 2011; Urlus, McCutcheon, Gilmore & McMahon,

2014; Vine et al, 2009). For instance, Towerton et al. (2011) examined activity and occupancy of foxes and potential prey species prior to and following a baiting program in central New South Wales. Images require minimal experience to be accurately analysed and reduce observer bias (Vine et al., 2009); however, see Dundas, Ruthrof, Hardy & Fleming (2019) for drawbacks of camera monitoring in determining species richness and community composition of small reptiles (<10cm). In their comparative investigation, Vine et al. (2009) found that camera traps were the most effective method of detecting foxes at low to medium densities compared to spotlighting, sand plots and hair traps.

Data collected from camera trapping is particularly useful for creating estimates of occupancy. Occupancy is an estimation of the proportion of sampled areas where the presence, or absence, of a species has been confirmed and is a viable alternative to traditional abundance indices (MacKenzie & Kendall, 2002; MacKenzie et al., 2002). Detection of a species at a sample site is an unambiguous measure of presence, however, non-detection of the same species is not indicative of its absence. Failure to detect the species at a site where it is present can produce biased estimates of occupancy (MacKenzie, Nichols, Royle, Pollock, & Bailey, 2005). To reduce bias to occupancy estimates, it is recommended that an appropriate number of repeated surveys are conducted, and the timing of each survey corresponds to the aims of the study (i.e. changes in occupancy observed between seasons/years). It is also important to consider whether the conditions of the sample locations (i.e. habitat structure) are accurate representations of the entirety of the study area (MacKenzie et al., 2002).

Dietary analyses of invasive carnivores can benefit management programs that are aimed at conserving environmental and economical assets by determining the impacts predators have on prey populations and potential competition with native species (Klare, Kamler & Macdonald, 2011). For instance, Saunders et al. (2004) used stomach contents of red foxes to identify potential increases in native fauna and livestock predations following the release of Rabbit Haemorrhagic Disease (RHD) to control rabbits (*Oryctolagus cuniculus*), an important prey item for foxes. In Australia, dietary analyses have also been used to determine the influence invasive predators have on native ecosystems, including predation of native fauna, seasonal changes in diet (Risbey *et al.*, 1999; White *et al.*, 2006) and dietary-overlap with sympatric carnivores (Brunner, Moro, Wallis, & Andrusek, 1991; Doherty, 2015; Glen, Fay, & Dickman, 2006; Glen, Pennay, Dickman, Wintle, & Firestone, 2011).

In this study, we examined how dietary analysis and camera trapping can be used to monitor predation and occupancy of foxes in urban reserves. The presence of foxes in these reserves presents a serious

threat to conservation efforts, through direct predation, competition for resources and the spread of pathogens. Previous efforts to control fox numbers within the park have been restricted to coordinated trapping (Butcher, 2015, 2016), although there is limited information on occupancy prior to and immediately after, resident foxes were culled. Without this knowledge, it is difficult for wildlife managers to evaluate the success of control efforts or effectively plan future management programs. Fortunately, Kings Park's personnel have been conducting a long-term fauna monitoring program within the boundary of the reserve since 2016, making it possible to identify trends in fox occupancy since these cameras have been active. Assessing diet through scat analysis is the most common method used to identify prey items consumed by terrestrial carnivores, as it is a non-invasive and cost-effective strategy. By collecting fox scats within the reserves, it was possible to determine the diversity and quantity of prey items occurring in the predator's diet. The aims of this study were to i) determine the potential impacts predation is having on native species by performing a dietary analysis on collected scats, and ii) determine the influence of seasonality and habitat on fox occupancy and detection probabilities within Kings Park using data taken from camera traps.

## 4.2 Methods

### Scat collection and identification

From November 27<sup>th</sup> 2017 to June 18<sup>th</sup> 2018, scats were collected opportunistically from both Kings Park and Bold Park. Scats were identified on-site based on the descriptions provided by Triggs (2004). Fox scats are generally no greater than 20 mm in diameter and are cylindrical-shaped, often with hair or whiskers present at the pointed end (Triggs, 2004). The odor and presence of animal remains (i.e. fur, bone fragments, feathers etc.) and plant material (i.e. seeds and berries) was also used to identify scats belonging to foxes (Triggs, 2004). A majority of samples were collected along the edges of footpaths, walking trails and sand tracks frequently used by people, as they were easier to locate and foxes often used and returned to these areas. Each sample was placed into a paper bag that was labelled with a sample number, date of collection, and name of the collector. The GPS coordinates (in decimal degrees) and habitat type where the scat was found were also recorded. The length of time that fox scats had been deposited was not determined, though based on their appearance were no more than 30 days old from the time of collection. Accurately identifying the species that the scat came from was, at times, difficult, as fox scats can be similar to those of small dogs and cats. Scats that could not be identified on-site as fox were labeled as unknown until they underwent further analysis.

### Scat preparation and content analysis

All samples were sent to an analytical facility (Scatsabout; [www.scatsabout.com.au](http://www.scatsabout.com.au)) for a content analysis. Scats samples were placed into ovens and heat treated at 100°C for 24 hours to eliminate bacteria and pathogens. Samples were then be placed into fine-woven nylon bags and washed to separate any indigestible items for identification. Items belonging to animals were identified to the lowest possible taxonomic level. Mammal remains found in the samples were grouped based on species weight (Menkhorst & Knight, 2011; Van Dyck, Gynther, & Baker, 2013), using group sizes described by Glen and Dickman (2006) (i.e. small: 1-499g; medium: 500-6999g; large: 7kg≤). All other animal remains were grouped as either bird, herpetofauna and insect. Other food items identified included fruits, other vegetation and rubbish (i.e. plastic; anthropogenic materials).

### Statistical analysis

There are numerous analytical methods that can be used to interpret data from carnivore scats, although it is important to realise that the results obtained from each type of analysis can vary substantially and need to be interpreted with the method of analysis in mind (Klare et al., 2011). Frequency of occurrence is perhaps the simplest and most commonly used method to interpret the contents of scats (Klare et al., 2011). However, this method can over-estimate the importance of items occurring frequently in scats but that only contribute to a small amount of the total content volume (Corbett, 1989; Glen & Dickman, 2006). For this reason, it is more appropriate to use the relative composition, as a percentage of mass or volume, of different food groups to determine their significance in the animal's diet (Klare et al., 2011). This method, however, is not without limitations. Volumes in which food items occur in scats do not accurately represent the volumes in which they are consumed, particularly for soft materials that are mostly digested before excretion (Glen & Dickman, 2006). Easily digested items will be under-represented when analysing the volume of food groups in scats (Macdonald, 1987). For these reasons, both the frequency of occurrence and volume (%) of food groups were recorded for all scat samples, as these methods allow comparisons between studies and to reduce bias generated by each method individually (Glen & Dickman, 2006; Klare et al., 2011).

### Camera monitoring design

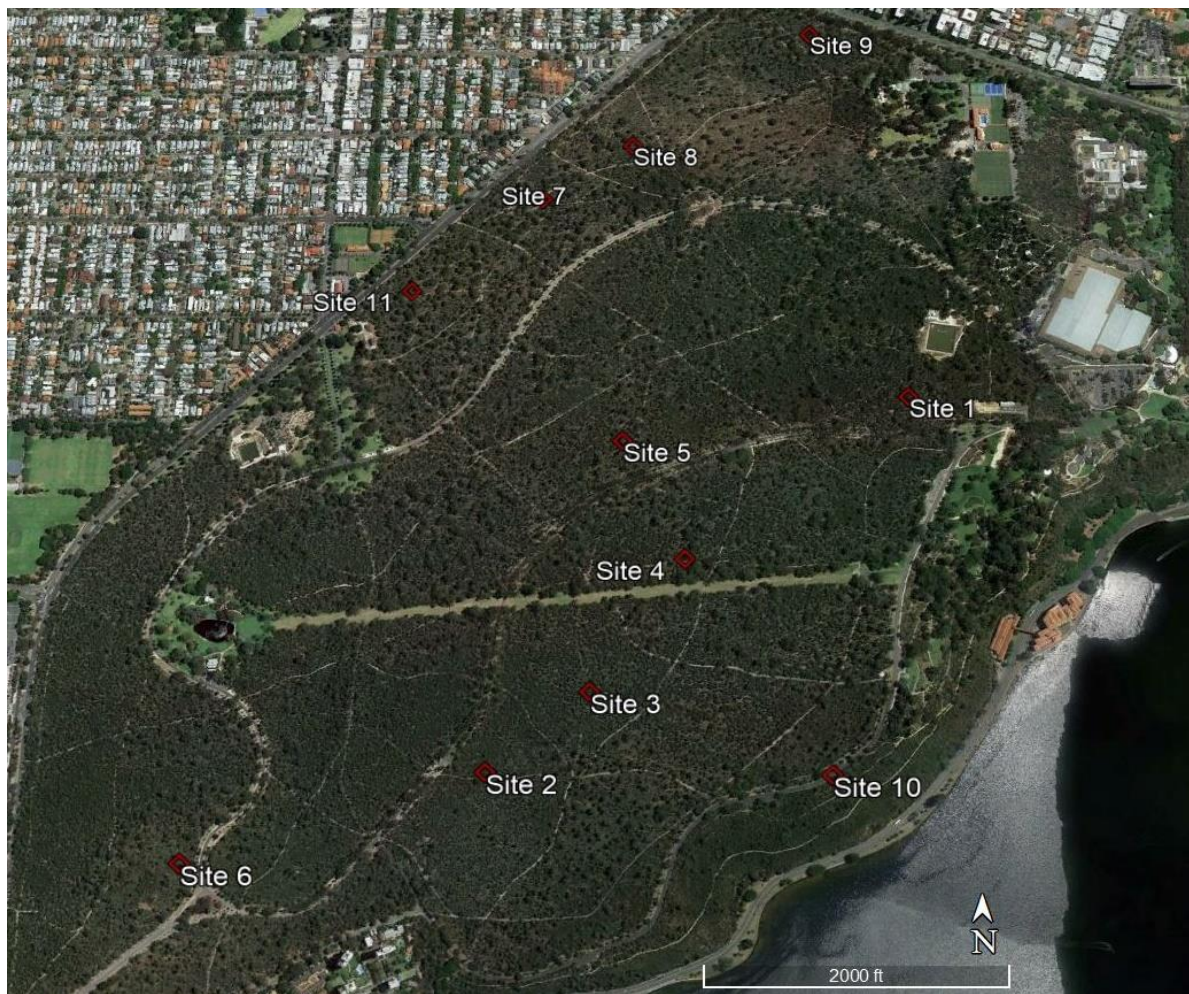
From August 2016 to April 2018, the Department of Biodiversity, Conservation and Attractions – Botanic Gardens and Parks Authority (BGPA) had installed Reconyx HC600 HyperFire cameras to monitor 11 sites within Kings Park (Table 4.1; Figure 4.1). Cameras remained in the field indefinitely throughout the

monitoring period, with SD cards replaced regularly to ensure continuous monitoring at the sites. Habitat type, based on dominant vegetation structure at each site, was identified using readily-accessible spatial layers in ArcMap (v10.2.2). An additional 10 cameras of the same make and model were deployed at the pre-existing monitoring sites within Kings Park during December 2017. These cameras remained in place throughout the 21 month duration of the study, however, were only active for three separate occasions: 1 month over summer (December 1<sup>st</sup> to January 2<sup>nd</sup>, 2018); two weeks over autumn (April 26<sup>th</sup> to May 11<sup>th</sup>, 2018); and 2.5 weeks over winter (July 22<sup>nd</sup> to August 11<sup>th</sup>, 2018). A meat bait, encased inside a container anchored to the ground, was placed approximately 2m from each of the 10 additional cameras deployed in the study area. A 100m buffer zone was maintained between the passive and baited cameras.

The design of the camera trap survey was set-up based on recommendations provided by Meek, Ballard, and Fleming (2012) for sampling introduced carnivores. Cameras were placed 1-2m from the edge of an accessible walking trail at a height of 30cm off the ground. The cameras were able to record images in infrared, ensuring nocturnal activities of foxes could be monitored. Cameras were set to take three consecutive images when the motion sensor was triggered, with no time delay between triggers. Cameras were positioned to face open areas or tracks to ensure that images were free from obstructions, such as understory vegetation. Cameras were visited regularly to replace SD cards and batteries and inspect the condition of the camera, as well as to clear any vegetation and objects that impeded the camera's view.

**Table 4.1. Coordinates for monitoring sites at Kings Park and their respective habitats.**

Site	Long	Lat	Habitat Type
1	115.837500	-31.960595	Mixed banksia/acacia
2	115.828129	-31.968236	Banksia woodland
3	115.830354	-31.966676	Banksia woodland
4	115.832418	-31.964009	Banksia woodland
5	115.830979	-31.961520	Mixed eucalypt/banksia
6	115.821702	-31.969967	Parrot bush shrubland
7	115.828983	-31.956101	Mixed eucalypt/banksia
8	115.831099	-31.954868	Mixed eucalypt/banksia
9	115.835368	-31.952102	Mixed eucalypt/banksia
10	115.835618	-31.968305	Banksia woodland
11	115.825982	-31.958192	Mixed eucalypt/banksia



**Figure 4.1. Locations of monitoring sites in Kings Park.**

#### Modelling Occupancy and Detection of Foxes

The occupancy ( $\psi$ ) of foxes within the study area was calculated using the method described by MacKenzie et al. (2003) for a multi-seasonal analysis. This method is an extension of MacKenzie et al. (2002) single-season analysis, combining the results of multiple monitoring periods to determine changes in the occupancy state of a species over time. This is achieved by incorporating local colonisation and extinction probabilities for the population being monitored (MacKenzie et al., 2003; Mackenzie et al., 2017). This method has the advantage of being highly robust, with little bias caused by missing data values and unequal sample sizes. There are two possible outcomes for each site during the monitoring periods: detection (1) or non-detection (0) of the target species. Instances where monitoring of the site failed (i.e. mechanical failures) were denoted as missing observations (-) and were included in

the analysis. To ensure that detection of foxes was possible throughout the monitoring periods, the dataset was reduced by removing dates that occurred before and after the first and last detection, respectively (MacKenzie et al., 2002).

Models were ranked using Akaike's information criterion (AIC) (Burnham & Anderson, 2002). This method accounts for the uncertainty surrounding parameter estimations of models by estimating the expected variance between fitted models and the factor responsible for generating the observed conditions (Burnham & Anderson, 2002). A difference (referred to as the delta AIC;  $\Delta AIC$ ) of  $\leq 2$  between the AIC values ( $\Delta$ ) can be used to gauge the acceptability of a model, with the best model having a  $\Delta i - \Delta min = 0$  (Burnham & Anderson, 2002). Occupancy models were produced using PRESENCE software (v. 12.34), which calculate the  $\Delta AIC$  and Akaike weights ( $\omega_i$ ) for each model.

### Covariates

Occupancy and detection of foxes within the study area and between sites was suspected to change due to differences in seasonality, habitat and detection method. Each of these factors were included in the analysis as covariates.

As sites were monitored continuously for this study, the beginning and end of each month was considered a single season period.

Different habitats were identified within the study area using preexisting GIS databases for vegetation communities. Five habitat categories were identified: mixed banksia/acacia, banksia woodland, mixed eucalypt/banksia and parrot bush shrubland.

Detection method was tested by comparing sites with lures to those that were monitored passively. To ensure quality of the results, only days that coincided with the duration of the baited sites were used from passive cameras.

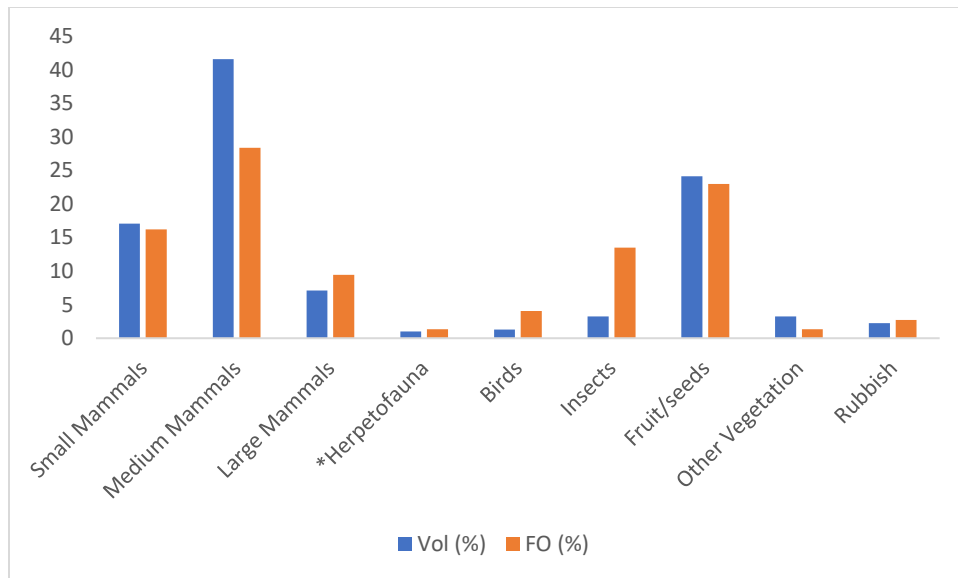
### 4.3 Results

#### Dietary analysis

A total of 55 scats were collected and analysed during this project; of these samples, only 31 were identified as fox scats. The remaining scats were identified as domestic dog, as these samples were composed entirely of commercial dog food (seen as vegetable products when screened in the analysis). There were 16 food items identified from scats analysis (Table 4.2). Mammalian prey composed a majority of the diet of foxes (Figure 4.2), particularly mammals that occurred in the medium weight group. Common brushtail possum (*Trichosurus vulpecula*), quenda (*Isodon fusciventer*), European rabbit (*Oryctolagus cuniculus*), black rat (*Rattus rattus*) and house mouse (*Mus domesticus*) were present. Fox hairs were present at small volumes in scats containing them, indicating that they were most likely from excess grooming and not predation. Fruits from the Moreton Bay fig (*Ficus macrophylla*), which were identified from seeds, were the second most consumed food item by foxes, occurring regularly in scat samples and at high volumes. Both herpetofauna, birds, other vegetation and rubbish occurred infrequently in scat samples and contributed to only a small percentage of the total volume of fox diet.

**Table 4.2. Results from a dietary analysis of 31 fox scats collected from Kings Park and Bold Park, Western Australia.** The frequency of occurrence (FO) and volume (Vol) of different food items found in the scat samples are shown as percentages. Values in BOLD are the total values for each food group.

Group	Species Name	FO (%)	Vol (%)
<b>Small Mammals</b>		<b>16.22</b>	<b>17.10</b>
	<i>Rattus rattus</i>	13.51	15.48
	<i>Mus domesticus</i>	2.70	1.62
<b>Medium Mammals</b>		<b>28.38</b>	<b>41.58</b>
	<i>Isoodon fusciventer</i>	10.81	13.87
	<i>Trichosurus vulpecula</i>	10.81	18.68
	<i>Oryctolagus cuniculus</i>	6.76	9.03
<b>Large Mammals</b>		<b>9.46</b>	<b>7.10</b>
	<i>Canis lupus familiaris</i>	2.70	5.81
	<i>Vulpes vulpes</i>	6.76	1.29
<b>Herpetofauna</b>			
	Scincidae spp.	<b>1.35</b>	<b>0.03</b>
<b>Aves</b>		<b>4.05</b>	<b>1.29</b>
<b>Insects</b>		<b>13.51</b>	<b>3.26</b>
	Beetle	8.11	1.52
	Grasshopper/cricket	5.41	1.74
<b>Fruit</b>		<b>22.97</b>	<b>24.16</b>
<b>Other Vegetation</b>		<b>1.35</b>	<b>3.23</b>
<b>Rubbish</b>		<b>2.70</b>	<b>2.26</b>



**Figure 4.2. The frequency of occurrence (orange) and volume (blue) (as percentages) of different food groups found in the diet of fox occurring in Kings Park and Bold Park. (\*Volume of herpetofauna occurred in <1 % of all fox scats).**

#### Camera monitoring

The combined efforts of all 21 cameras captured over 195,000 photos, although many of these were of non-target species or resulted from false triggers. While the number of images that recorded foxes were estimated to be less than 1%, there was still a sufficient number of recordings between sites to calculate probabilities for occupancy and detection. There were several occasions where missing observations occurred. The camera from site 11 was stolen sometime after April 3<sup>rd</sup> 2017 and was replaced on May 4<sup>th</sup> 2017; the new camera was placed near enough (~25m) to the stolen camera's position to still represent the same conditions of site 11. A fire within the northwest section of Kings Park destroyed the baited camera at site 2, meaning data was not collected from this site during the second and third survey. A malfunction in the baited camera at site 3 meant that no data was collected during the time it was deployed, as was the case with the baited camera at site 7 during the second and third survey. The image files from site 9 were also corrupted, resulting in missing data from March 15<sup>th</sup> to April 23<sup>rd</sup> 2018. In total, there were 76 missing observations from the seasonal dataset and 158 missing observations from the detection method dataset. Given the robustness of the analysis method, the missing values did not compromise the results of this investigation.

### Seasonal and habitat influence on fox occupancy

The results of the multi-seasonal models for foxes occurring in Kings Park are shown in Table 4.3. From this, the month of the survey and the combination of habitat type and survey month influenced probabilities for occupancy and detection of foxes. The predicted occupancy of foxes remained relatively constant between years 2016 and 2017 (Table 4.4). However, foxes were detected at all monitoring site during 2018, resulting in a 'perfect' detection probability ( $p=1$ ). An interactive effect was observed between the timing of the survey and the detection of foxes, as shown in Figure 4.3. The probability of detecting a fox at any given location increased substantially during the summer months (December-February), with a fall in detection rates leading into autumn and winter (March-August) before steadily rising during the spring (September-November). The highest detection rate occurred in February 2017 ( $0.245 \pm 0.031$ ) and the lowest rate was recorded in November 2016 ( $0.024 \pm 0.011$ ), though detection increased during the November of the following year ( $0.079 \pm 0.018$ ).

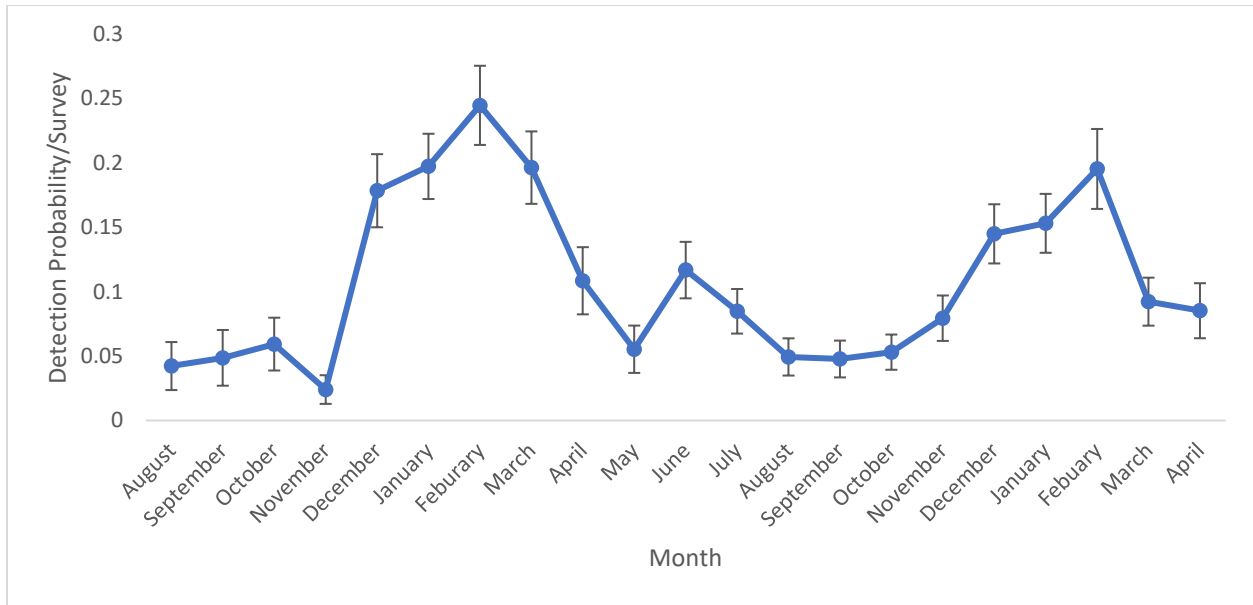
Changes in occupancy probabilities observed across different habitat types were calculated for 2017 only, as occupancy values of 1 were observed in 2018. The habitat types with the highest and lowest occupancy probabilities were banksia woodland ( $.900 \pm .071$ ) and parrot bush shrubland ( $0.470 \pm 0.131$ ), respectively. Occupancy values and confidence intervals for all habitat types are shown in Figure 4.4. Although model selection indicated that habitat type affected model likelihood, there did not appear to be a significant difference between habitats.

**Table 4.3. Results of multi-seasonal model selection for long-term seasonal monitoring of red foxes occurring in Kings Park, Western Australia.** The monitoring year, model, AIC , delta AIC ( $\Delta AIC$ ), Akaike weights ( $\omega_i$ ), likelihood of the model and number of parameters (K) are represented in each column. Only models with a  $\Delta AIC$  of  $\leq 2$  are shown. For the model design: psi=species occupancy at sites; gamma=colonisation probabilities; eps=extinction probabilities; and, p=species detection during the survey. For the covariates: 'Mon' represents the month of the monitoring period; 'Hab' represent the habitat type of each site; '.' represents constant value (i.e. no change to the parameters).

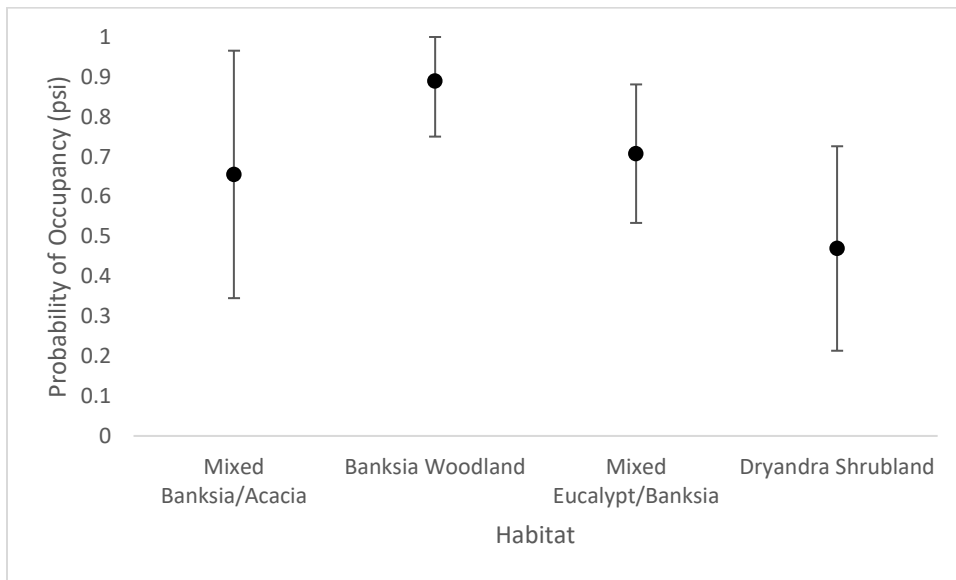
YEA R	MODEL	AIC	$\Delta AIC$	$\omega_i$	LIKELIHOOD	K
2016	psi(.),gamma(.),p(Mon)	455.73	0	0.3046	1	7
	psi(.),gamma(Mon),p(Mon)	456.81	1.08	0.1775	0.5827	10
	psi(.),gamma(.),eps(.),p(Mon)	457.22	1.49	0.1446	0.4747	8
	psi(.),gam(.),eps=1-gam,p(Mon)	457.34	1.61	0.1362	0.4471	7
	psi(.),gamma(.),eps(Mon),p(Mon)	457.43	1.7	0.1302	0.4274	11
2017	psi(Hab),gamma(.),p(Mon)	1987.72	0	0.4093	1	17
	psi(.),gamma(.),p(Mon)	1988.13	0.41	0.3334	0.8146	14
2018	psi(Hab),gamma(Mon),eps(.),p(Mon) )	707.18	0	0.2164	1	12
	psi(.),gamma(Mon),eps(.),p(Mon)	707.34	0.16	0.1997	0.9231	9
	psi(.),eps(.),p(Mon)	708.38	1.2	0.1188	0.5488	6
	psi(.),gamma(.),p(Mon)	708.38	1.2	0.1188	0.5488	6

**Table 4.4. Probability of occupancy for foxes in Kings Park.**

YEAR	PSI (+-S.E.)
2016	0.67591 (0.11195)
2017	0.6555 (0.1582)
2018	$\geq 1$ (0)



**Figure 4.3. Detection probability of foxes in Kings Park from August 2016 to April 2018 (with S.E values).**



**Figure 4.4. Probability of occupancy (psi) for foxes between different habitat categories from January to December 2017 (95% confidence error bars have been included).**

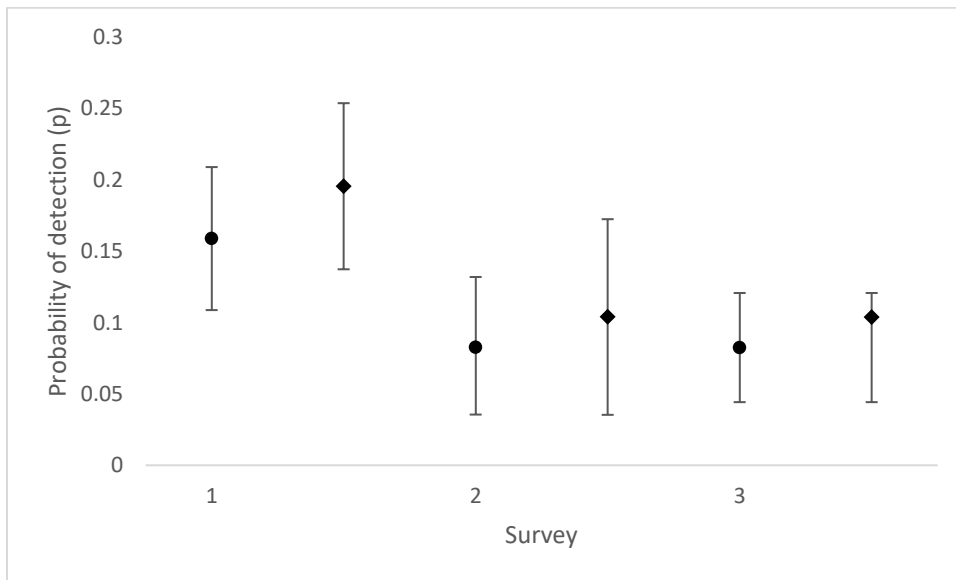
#### Detection method

Table 4.5 shows the model selection for the different methods of detecting foxes within the study area. The presence of a lure influenced the probability of detecting foxes at the sites, when compared between surveys. When surveys were examined separately from each other, however, there was no significant difference between detection probabilities of foxes for passive and baited cameras (Figure 4.5). The likelihood of detecting foxes was significantly higher during the first survey when compared to the following survey, suggesting that the timing of the survey has the greatest influence on detection probabilities. This is consistent with the previous findings of this study.

**Table 4.5. Results of model selection for different detection methods used to monitor foxes in Kings Park, Western Australia.**

Only models with a  $\Delta i$  of  $\leq 2$  are shown. For the model design: psi=species occupancy at sites; gamma=colonization probabilities; eps=extinction probabilities; and, p=species detection during the survey. For the covariates: 'Survey' represents detection probabilities between surveys, 'Baited' incorporates lures used at sites as a covariate for detection probabilities, '.' represents constant value (i.e. no change to the parameters).

Model	$\Delta$	$\Delta i$	$\omega_i$	Likelihood	K
psi(.),gamma(.),p(Survey)	649.02	0	0.2632	1	5
psi(.),gamma(.),p(Survey+Baited)	649.87	0.85	0.172	0.6538	6
psi(.),gamma(Survey),p(Survey)	650.59	1.57	0.12	0.4561	6
psi(.),gamma(.),eps(.),p(Survey)	651	1.98	0.0978	0.3716	6



**Figure 4.5. Detection probability (p) of foxes for passive (circle) and baited (diamond) cameras (95% confidence error bars have been included).**

#### 4.4 Discussion

##### Diet of urban foxes

The results from the composition analysis of fox scats in this study are comparable to reported fox diets under similar conditions (Brunner *et al.*, 1991; White *et al.*, 2006). Foxes occurring in urban and peri-urban environments are described as being opportunistic predators and scavengers, utilising numerous food resources to satisfy their daily energy expenditure (Saunders *et al.*, 1993). Mammalian fauna was the most common food item present in the diet of foxes, occurring in over half of the samples and contributed to 65% of the total volume. This finding is consistent with many other fox dietary studies conducted in Australia (Brunner *et al.*, 1991; Glen, *et al.*, 2006; Mitchell & Banks, 2005; Risbey *et al.*, 1999; White *et al.*, 2006).

A majority of the mammal remains found in scats belonged to medium sized mammals, which are those that occur within the critical weight range. Mammals that occur within the critical weight range, particularly quenda, are most at risk of continuing population decline and, possibly, extinction due to predation by introduced predators and other environmental pressures, including climate change, changed fire regimes and habitat loss through land clearing and urbanisation (Woinarski *et al.*, 2015). While both small and large mammal groups occurred less frequently than medium sized mammals, black rats were found to be a significant prey species for foxes (FO= 13.5%; VOL= 15.5%). This result is consistent with other dietary studies conducted in urban regions of Australia (White *et al.*, 2006). Birds and herpetofauna were consumed infrequently by foxes and are unlikely to be a key resource for urban foxes. Insects occurred at higher frequency in scat samples, however, contributed to a very small portion of the total volume of prey. Moreton Bay fig (*Ficus macrophylla*) fruits contributed to a large portion of the diet of foxes, indicating that these are important food resources in urban areas. Other studies have found that seasonality influences consumption for both invertebrates and fruits by foxes (Risbey *et al.*, 1999; White *et al.*, 2006).

Food scavenged from refuse occurred at low incidences in fox scats. This finding contradicts the importance of anthropogenic foods for foxes inhabiting highly populated areas outlined in chapter 2, as well as the results of other dietary studies that reported urban foxes frequently scavenged from rubbish and other anthropogenic sources (Contesse *et al.*, 2004; Doncaster *et al.*, 1990; Saunders *et al.*, 1993). It is possible that foxes had greater opportunities to hunt or scavenge prey species in the reserves,

resulting in fewer scavenges from refuse. However, it may be that anthropogenic foods occurring in fox diet is underrepresented by presence of refuse in scats.

#### *Fox occupancy in Kings Park*

The probability of occupancy for foxes in Kings Park remained consistent for a majority of the monitoring period, with little change between subsequent years. There was some variance in model selection between years. Generally, models using habitat types as variables to assess likelihood of occupancy with detection probabilities changing between different months had the most support and best fit the data. This indicates that the ability to assess occupancy and detection rates for foxes is influenced by habitat types and seasonality.

While there was only a minor effect for habitat influencing occupancy, foxes were found to most likely to occur in banksia woodland and least likely to occur in parrot bush shrubland. This contradicts the results of the habitat selection in chapter 2, as parrot bush shrubland was preferred above all other habitat types by the collared fox. Foxes predominantly select habitats consisting of dense vegetation over open and sparsely vegetated areas (Saunders *et al.*, 1997; Robertson *et al.*, 2000). However, it is possible that variances in occupancy between the two habitat types reflects their presence in Kings Park, as parrot bush shrublands cover less area than banksia woodlands. There was no significant difference seen between other habitat types, suggesting that habitat has only a weak influence on occupancy. This study found strong support, however, for detection of foxes to be influenced by seasonality.

The likelihood of detecting foxes was greatest during the summer months, with detection probabilities peaking during February of both 2017 and 2018. Probabilities of detection begin to decline, remaining consistently low throughout the year before rising again during mid-spring. Patterns observed in the detection probabilities of foxes coincided with dispersal of juveniles from natal grounds, with increases in detections observed from late spring to autumn before subsiding at the onset of winter (Coman, 1988; Saunders *et al.*, 1995). Increased activity from dispersing juveniles would explain why detection probabilities peaked during February, and there is also the potential for fox immigrations into the park from surrounding areas during this dispersal period.

There was some support that detection probability for foxes was influenced by the presence of a lure, however, this only occurred when comparing detections between different survey events. The

probability of detecting foxes at monitoring sites with meat lures was only marginally higher than passive camera traps. While there is no substantial proof that the detectability of foxes was affected by the presence of a lure, foxes tended to re-occur more regularly in the photos of baited cameras than passive cameras.

Detection of foxes may have also been influenced by other environmental and mechanical variables that were not incorporated into the models. The proximity of the cameras to footpaths and sand tracks may have increased the probability of detecting foxes within the park. Robley et al. (2012) state that cameras positioned within 5m of a road had higher detection rates than cameras positioned over 100m from roads. Similarly, Robley et al. (2014) found that the distance that cameras were positioned from roads or tracks influenced the rate of detecting foxes. The model of camera used to monitor animals can also influence detection probabilities for different species. Urlus et al. (2014) investigated the likelihood of three different camera traps of detecting different sized mammal species, including foxes, at two locations in Victoria, Australia. In their findings, Urlus et al. (2014) state that the type of camera used did have an influence on detection rates, though the amount of variance between cameras was specific to certain species. Mechanical failures that resulted in the loss of data were corrected for (MacKenzie et al., 2002).

#### *4.5 Limitations and further investigations*

Dietary composition of foxes was determined from a limited sample size and may not accurately represent the importance of different food groups. Increasing the sample size, as well as conducting genetic testing on pooled scat samples, will yield highly accurate results for prey species and other food resources that are consumed by foxes. Densities for open populations can be calculated by using mark-recapture events for a repeated number of times (i.e. Jolly-Seber Estimates). However, the time-constraints for this project and high running costs made this method of estimating densities impractical.

Only one type of lure, chicken meat, was used to test if the probability of detecting foxes changed between baited and passive cameras. Using other types of lures (i.e. different foods, scent-markers etc.) may have more of an influence on the detection rates of foxes, which can be tested in future monitoring programs.

#### *4.6 Conclusion*

Scat analysis and camera monitoring are effective methods for evaluating the presence of foxes at Kings Park and Bold Park, as well as determining the potential impacts predation by foxes is having on native biodiversity. Medium-sized mammals, including brush-tail possums and quenda, were the most frequently occurring prey species in the diet of foxes. Predation pressures exhibited by foxes could be devastating to these native fauna populations that are already experiencing impacts from man-made processes, including fragmentation and habitat loss (How & Dell, 2000). Anthropogenic food sources, in the form of refuse, occurred infrequently in the diet of foxes, contradictory to what has been reported of fox diets in other cities. It is likely that there are fewer chances to scavenge from refuse from the parks, causing foxes to rely on prey populations to meet their metabolic requirements. Fox occupancy showed signs of seasonal fluctuation consistent with the timing of dispersing juveniles. Detection of foxes was highest during summer months, when juvenile foxes disperse from their natal home ranges, before decreasing and remaining low during the following months. With this information, efforts of monitoring fox occupancy and impacts within the reserves can be improved, and appropriate control and follow-up monitoring procedures can be implemented. The benefits and applications of these methods are discussed further in chapter 5.

## Chapter 5: Discussing Management Strategies and Closing Statements

Patches of remnant vegetation are important havens for species inhabiting urban areas, so long as they are managed in a way that promotes connectivity and reduces the impacts of fragmentation and other debilitating processes. However, species occurring in remnant patches are susceptible to predation and competition from invasive species, such as the red fox, which thrive in this new human-made niche. As was seen in chapter 2, home range size decreased exponentially with increasing human disturbances to a landscape, particularly increases in human population densities. Foxes inhabiting urban environments have also been found to occur at higher population densities when compared to their counterparts occurring in natural areas (Šálek *et al.*, 2015). Greater food availability from anthropogenic sources (i.e. refuse; pet food; deliberate feeding etc.) is the most likely explanation contributing to the success of foxes in urban regions. This is supported by manipulation experiments, where fox home ranges doubled in size when the availability of anthropogenic foods was restricted (Bino *et al.*, 2010).

This study attempted to determine the spatial distribution of wild-caught foxes in Kings Park and Bold Park using GPS-collars. From this data, it would be possible to determine fox home range size and overlap for individuals and groups and identify key habitats used by foxes. Unfortunately, telemetry data could only be recovered for a single female sub-adult fox located at Kings Park, making it impossible to draw conclusions on ranging behaviours of foxes inhabiting the reserves. However, based on the results gained from the single collar, as well as incorporating findings from similar studies, it was possible to make presumptions regarding fox home range and habitat selectivity for the study area.

Following 90 days of continuous tracking, the fox in this study maintained a small home range covering just over 0.3 km<sup>2</sup>, and a core area of 0.025 km<sup>2</sup>. This result is consistent with similar studies and the findings of chapter 2, with fox home range size decreasing with increasing human disturbance. The size of the fox's home range suggest food and other resources are abundant in the area and it is likely that competition for space would be low within the reserves. However, as the fox was still a juvenile, the small ranging area and short forays could be attributed to the animal staying near to its natal dens. The fox also showed a clear preference for dense vegetation and disturbed areas over woodlands and open spaces. Several studies (e.g. Marks & Bloomfield, 2006; White *et al.*, 2006; Robertson *et al.*, 2000) identify patches of dense vegetation as important resting sites for foxes, providing refuge from predators and people, while disturbed areas may provide foxes with a greater opportunity to hunt or scavenge for food.

Being an invasive predator in Australia, foxes have wide-ranging impacts on native biodiversity and ecosystem function. Predation by foxes is a leading cause of species loss in Australia, particularly for mammal species within the medium-weight range. The dietary analysis in chapter 4 found native mammals occurring in the medium-weight range to be the most frequently consumed prey species, for both occurrence and volume. Predation risk to native fauna is exacerbated in urban areas due to the combination of other factors, such as land clearing and changed fire regimes, that contribute to biodiversity loss. Evidence from this study of foxes preying on quenda in Kings Park is of particular concern, since this species is only just beginning to re-establish in the park, and their diggings have beneficial impacts on soil and vegetation (Valentine, Ruthrof, Fleming & Hardy, 2018). Therefore, it is paramount that appropriate measures be taken to effectively manage foxes occurring in urban reserves and mitigate their impacts.

As a key threat to Australia's native fauna, it is the responsibility of land managers to enforce appropriate control strategies to mitigate the impacts of foxes and effectively monitor the outcomes of such strategies. However, efforts to control invasive species can result in unanticipated secondary impacts to ecological communities (Zavaleta, Hobbs, & Mooney, 2001). For instance, reductions in fox numbers may lead to population increase for black rats and rabbits and incursions of other invasive predators, such as cats, in the reserves. Improving the effectiveness of conservation strategies through collaborative research is a key outcome of the *Kings Park and Botanic Gardens Management Plan 2014-2019* (BGPA, 2014) and implementing control measures for pest animals is a priority target for both this plan and the *Bold Park Management Plan 2011-2016* (BGPA, 2011).

Given that the fox showed a preference for dense vegetation and disturbed areas, it may be possible to mitigate their occurrence in the reserve by altering or removing these habitats. Managing foxes through habitat modification has been explored in other urban areas of Australia, as it offers a non-lethal approach of removing foxes from areas of high conservation importance. However, there is limited evidence indicating that this is a viable means of managing foxes. Furthermore, the importance of these habitats to native fauna has not been assessed and modifying these habitats may negatively impact biodiversity.

Coordinated trapping is a control strategy that has been used at Kings Park previously to reduce fox populations (Butcher, 2015, 2016). Trapping foxes using cage traps or leg-hold traps is a common

strategy employed when other control techniques present an unsuitable risk to public safety, such as in residential and highly trafficked areas (Saunders *et al.*, 2010; Fleming *et al.*, 2014). However, the effectiveness of trapping as a control method for fox populations in urban areas has not been adequately tested (Fleming *et al.*, 2014). In this study, both cage and leg-hold traps were used to capture foxes within Kings Park and Bold Park, allowing for their effectiveness to be assessed.

Foxes demonstrated an aversion to cage traps, with site visitations per monitoring session declining from 3.7 visits to 0.4 visits following trap installation, and no fox captures occurred over the trapping sessions (see Appendix 7 for a detailed report). Soft jaw leghold traps were moderately more successful than cage traps, capturing four foxes over 96 effective trap nights (one fox/24 trap nights). However, there were several incidences of foxes digging-up traps and taking baits from site without triggering the traps. Furthermore, broad-scale trapping programs are often impractical due to the amount of effort required to install and periodically check traps to satisfy welfare concerns, as well as requiring highly trained and capable personnel to perform the task (Saunders & McLeod, 2007; Saunders *et al.*, 2010).

Baiting programs have been successful at removing foxes from agricultural and natural landscapes, though their applications in urban settings is limited due to the risk of public and non-target exposure. Jackson *et al.* (2007) had previously investigated bait-uptake by foxes and non-target species in Kings Park and Bold Park to determine the likelihood of a baiting program to successfully control foxes. Neither bait type nor presentation method affected bait-uptake by foxes, though tethering baits did reduce uptake by certain non-target species. Also, Jackson *et al.* (2007) highlighted that bait-uptake by dogs can be reduced by encouraging responsible pet ownership, however, the study identified changing public attitudes to be a challenge. Success of baiting programs could be improved by deploying baits at areas most likely to be frequented by foxes, such as along closed tracks or along the edges of dense vegetation, although this would not limit the risk of exposure to pets. Furthermore, recolonisation by foxes from surrounding land uses would negate any positive effect of the short-term removal of resident foxes. To prevent this, fox populations occurring in surrounding areas would need to be controlled simultaneously with foxes inhabiting the reserves.

The results of the fox occupancy and detection probabilities discussed in chapter 4 demonstrate the capacity for remote cameras to be used to determine the effectiveness of future control programs. For instance, Towerton *et al.* (2011) were able to utilise camera traps to assess the effects to foxes and

other prey species following a baiting program in the Goonoo region of central New South Wales, Australia. Based on the findings of this study, as well as the outcomes of similar investigations utilising cameras to determine occupancy probability of red foxes in Australia, the following actions are recommended:

1. Surveys should be conducted annually to monitor trends in occupancy between years. As seasonality was found to affect detection rates for foxes, surveys should be conducted at the same time each year to remain consistent. Surveys should be conducted for at least two weeks, as most of the initial detections of foxes occurred within 14 days of cameras being deployed at sites and few were recorded beyond 28 days of monitoring.
2. In addition to annual surveys, cameras should be deployed immediately before and after any programs aimed at reducing fox occurrences within Kings Park and Bold Park. It is difficult to determine if management actions have had the desired effect without first acquiring a baseline value to compare post-control occupancy probabilities to. Estimating fox occupancy prior to and following control programs will allow wildlife managers to assess the short-term effectiveness of the control programs, as well as determine if fox occurrences reduce in the long-term.
3. Passive monitoring will produce reliable estimates for fox occupancy, as the presence of a meat bait at cameras had no substantial influence on the ability to detect foxes at sites.

In conclusion, the red fox demonstrates the capacity to readily transition from natural to urbanised landscapes, requiring a smaller home range in urban areas to satisfy its metabolic requirements. The fox occurring in Kings Park showed a selection for habitats containing dense vegetation or experiencing some disturbance. Camera monitoring and dietary analyses were effective methods for determining fox occupancy and impacts of predation to prey species. Camera surveys could also be used to assess the effectiveness of programs aimed at controlling foxes within the reserves. However, control of foxes occurring on BGPA tenure alone would not be enough mitigate the impacts of this invasive predator. Instead, an integrated pest control program between land managers and invested stakeholders must be established to reduce, and or eradicate, foxes occurring in metropolitan Perth.

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## **Appendices**

### **Appendix 1 – Data sources used in the global analysis of fox home range sizes**

[ddi13115-sup-0001-AppS1-S2.docx](#)

### **Appendix 2 – Additional results for the global analysis of fox home range sizes**

[ddi13115-sup-0001-AppS1-S2.docx](#)

**Appendix 3 - Analysis of GPS positional error.** Calculation for horizontal precision ( $\sigma$  H\_precision) and accuracy ( $\sigma$  H\_accuracy) of the GPS collars following methods described by Yoshimura and Hasegawa (2003).

Easting	Northing	(X-xtrue) <sup>2</sup>	(Y-ytrue) <sup>2</sup>	(C2+D2)	H_Accuracy	Ox <sup>2</sup>	Oy <sup>2</sup>	Ox <sup>2</sup> +Oy <sup>2</sup>	H_Precision
384303.6	6465504	2.435704	1.702137	4.137841	2.0341683	0.00175	0.009898	0.011648	9.2017862
384301.3	6465506					0.105661	0.016287	0.121948	
384307.1	6465510					0.142399	0.523192	0.665591	
384306.5	6465511					0.094903	0.681374	0.776277	
384313.9	6465496					1.471777	0.958898	2.430675	
384305.8	6465504					0.049979	0.006006	0.055985	
384300.3	6465508					0.201861	0.152323	0.354184	
384303.6	6465506					0.002055	0.044393	0.046449	
384299.3	6465507					0.324933	0.11757	0.442503	
384308.6	6465506					0.314396	0.056558	0.370954	
384307.4	6465506					0.178702	0.033655	0.212357	
384305	6465506					0.014881	0.049909	0.06479	
384309.9	6465508					0.532722	0.15539	0.688112	
384318.2	6465490					3.034447	3.17512	6.209567	
384306.3	6465507					0.080654	0.089051	0.169705	
384297.8	6465501					0.571658	0.132132	0.70379	
384293.9	6465499					1.522082	0.510324	2.032406	
384304.6	6465503					0.005939	0.038274	0.044214	
384305.8	6465508					0.049228	0.143584	0.192811	
384302.2	6465507					0.047528	0.132866	0.180395	
384300.9	6465510					0.136305	0.436616	0.572921	
384302.2	6465507					0.043965	0.11757	0.161535	
384301.4	6465504					0.09509	0.000393	0.095483	
384301.9	6465502					0.063632	0.081054	0.144686	
384298.9	6465511					0.382414	0.706818	1.089232	
384302.3	6465519					0.041371	2.987817	3.029188	
384321.8	6465485					4.754766	5.604795	10.35956	
384311.3	6465498					0.802386	0.629118	1.431503	
384305.3	6465496					0.024853	0.979585	1.004438	
384302.1	6465506					0.049656	0.031973	0.081629	
384307.8	6465494					0.223791	1.705413	1.929204	
384305.7	6465496					0.042917	0.954596	0.997513	
384302.2	6465507					0.047024	0.068392	0.115416	
384302.3	6465514					0.043144	1.418153	1.461297	
384289.6	6465511					3.080838	0.592318	3.673156	
384295.8	6465511					1.006715	0.593071	1.599786	
384300	6465506					0.235449	0.039007	0.274457	
384303.2	6465493					0.007664	1.870691	1.878356	

384297.9	6465509	0.551717	0.253427	0.805144
384300	6465505	0.237219	0.002768	0.239987
384301.8	6465504	0.066966	0.000192	0.067158
384300	6465505	0.240156	0.000142	0.240298
384304.4	6465502	0.002341	0.099328	0.101669
384304.3	6465513	0.00214	1.207497	1.209637
384304.5	6465508	0.004905	0.181448	0.186353
384299.4	6465498	0.310404	0.635882	0.946286
384302.3	6465502	0.042296	0.10201	0.144306
384301.7	6465503	0.07628	0.0443	0.12058
384327.6	6465480	8.326154	9.114915	17.44107
384316	6465506	2.160157	0.016618	2.176774
384303.6	6465509	0.001738	0.364203	0.365941
384307	6465505	0.136867	0.002517	0.139383
384303.3	6465525	0.006828	6.192255	6.199083
384301.3	6465506	0.103724	0.02878	0.132504
384302.3	6465507	0.039339	0.131003	0.170342
384305.4	6465503	0.030671	0.034728	0.065399
384308.3	6465501	0.282907	0.232092	0.515
384294.3	6465504	1.39196	0.004754	1.396714
384315	6465513	1.807649	1.198134	3.005782
384302.5	6465503	0.030235	0.027988	0.058223
384296.2	6465507	0.900691	0.066237	0.966928
384304.9	6465501	0.011959	0.15662	0.168578
384299.2	6465509	0.345701	0.361676	0.707377
384306.2	6465504	0.072358	0.012588	0.084946
384302.7	6465506	0.024879	0.019692	0.044571
384300.7	6465504	0.161808	0.008584	0.170392
384301.1	6465498	0.126588	0.691849	0.818438
384300.1	6465502	0.219052	0.091233	0.310285
<b>384304</b>	<b>6465504</b>			<b>84.67287</b>

**Appendix 4 - Results of the Neu et al test for the different time periods: dawn (a), Day (b), Dusk (c) and Night (d).**

a)

Habitat class	Total Area (km2)	Proportion of total area (Pio)	Observed	Expected	Proportion observed in area	C.I on proportion of occurrence		Outcome
Mixed Open Woodland	0.049346	0.15271	84	91	0.141176	0.101064	0.181289	Proportional
Banksia Woodland	0.182814	0.565745	137	337	0.230252	0.181754	0.27875	Avoided
Disturbed	0.014225	0.044021	96	26	0.161345	0.118969	0.20372	Preferred
Mixed Heath	0.034235	0.105946	8	63	0.013445	0.000178	0.026713	Avoided
Parrot Bush Shrubland	0.031627	0.097874	266	58	0.447059	0.389783	0.504334	Preferred
Open Space	0.010891	0.033704	4	20	0.006723	-0.00269	0.016136	Avoided
Total	0.323138		595	595				

b)

Habitat class	Total Area (km2)	Proportion of total area (Pio)	Observed	Expected	Proportion observed in area	C.I on proportion of occurrence		Outcome
Mixed Open Woodland	0.04934634	0.15271	39	74	0.080247	0.045618	0.114876	Avoided
Banksia Woodland	0.18281409	0.565745	128	275	0.263374	0.207231	0.319518	Avoided
Disturbed	0.01422476	0.044021	82	21	0.168724	0.120988	0.216461	Preferred
Mixed Heath	0.03423523	0.105946	2	52	0.004115	-0.00404	0.012275	Avoided
Parrot Bush Shrubland	0.03162701	0.097874	233	48	0.479424	0.415746	0.543102	Preferred
Open Space	0.01089104	0.033704	2	16	0.004115	-0.00404	0.012275	Avoided
Total	0.32313847		486	486				

c)

Habitat class	Total Area (km2)	Proportion of total area (Pio)	Observed	Expected	Proportion observed in area	C.I on proportion of occurrence		Outcome
Mixed Open Woodland	0.049346	0.15271	37	99	0.057364	0.031636	0.083093	Avoided
Banksia Woodland	0.182814	0.565745	159	365	0.246512	0.198826	0.294197	Avoided
Disturbed	0.014225	0.044021	110	28	0.170543	0.128929	0.212157	Preferred
Mixed Heath	0.034235	0.105946	5	68	0.007752	-0.00195	0.017456	Avoided
Parrot Bush Shrubland	0.031627	0.097874	333	63	0.516279	0.460987	0.571572	Preferred
Open Space	0.010891	0.033704	1	22	0.00155	-0.0028	0.005904	Avoided
Total	0.323138		645	645				

d)

Habitat class	Total Area (km2)	Proportion of total area (Pio)	Observed	Expected	Proportion observed in area	C.I on proportion of occurrence		Outcome
Mixed Open Woodland	0.049346	0.15271	72	63	0.173913	0.121567	0.226259	Proportional
Banksia Woodland	0.182814	0.565745	68	234	0.164251	0.113083	0.215419	Avoided
Disturbed	0.014225	0.044021	138	18	0.333333	0.26823	0.398436	Preferred
Mixed Heath	0.034235	0.105946	6	44	0.014493	-0.00201	0.030998	Avoided
Parrot Bush Shrubland	0.031627	0.097874	112	41	0.270531	0.209181	0.331882	Preferred
Open Space	0.010891	0.033704	18	14	0.043478	0.015315	0.071642	Proportional
Total	0.323138		414	414				

**Appendix 5 - Model selection results for the multi-seasonal and habitat selection analysis for fox occupancy in Kings Park for the years 2016 (a), 2017 (b) and 2018 (c).**

a)

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	-2*LogLike
psi(.),gamma(.),p(Mon)	455.73	0	0.3046	1	7	441.73
psi(.),gamma(Mon),p(Mon)	456.81	1.08	0.1775	0.5827	10	436.81
psi(.),gamma(.),eps(.),p(Mon)	457.22	1.49	0.1446	0.4747	8	441.22
psi(.),gam(.),eps=1-gam,p(Mon)	457.34	1.61	0.1362	0.4471	7	443.34
psi(.),gamma(.),eps(Mon),p(Mon)	457.43	1.7	0.1302	0.4274	11	435.43
psi(Hab),gamma(.),eps(.),p(Mon)	460.18	4.45	0.0329	0.1081	11	438.18
psi(Hab),gamma(Mon),p(Mon)	460.39	4.66	0.0296	0.0973	13	434.39
psi(Hab),gamma(.),eps(Mon),p(Mon)	461.58	5.85	0.0163	0.0537	14	433.58
psi(.),gamma(Mon),eps(.),p(Mon)	462.28	6.55	0.0115	0.0378	11	440.28
psi(.),gamma(Mon),eps(Mon),p(Mon)	463.15	7.42	0.0075	0.0245	14	435.15
psi(Hab),gamma(Mon),eps(.),p(Mon)	464.35	8.62	0.0041	0.0134	14	436.35
psi(Hab),gamma(.),p(Mon)	464.69	8.96	0.0035	0.0113	10	444.69
psi(Hab),gamma(Mon),eps(Mon),p(Mon)	466.38	10.65	0.0015	0.0049	17	432.38
psi(.),gamma(.),p(.)	477.94	22.21	0	0	3	471.94
psi(.),gamma(.),eps(.),p(.)	479.93	24.2	0	0	4	471.93
psi(.),gam(.),eps=1-gam,p(.)	480.94	25.21	0	0	3	474.94
psi(.),gamma(Mon),eps(.),p(.)	484.22	28.49	0	0	7	470.22
psi(.),gamma(Mon),eps(Mon),p(.)	485.16	29.43	0	0	10	465.16
psi(Hab),gamma(Mon),eps(Mon),p(.)	488.7	32.97	0	0	13	462.7
psi(Hab),gamma(.),p(.)	494.73	39	0	0	6	482.73
psi(Hab),gamma(.),eps(.),p(.)	495.93	40.2	0	0	7	481.93
psi(Hab),gamma(Mon),p(.)	501.32	45.59	0	0	9	483.32

b)

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	-2*LogLike
psi(Hab),gamma(.),p(Mon)	1987.72	0	0.4093	1	17	1953.72
psi(.),gamma(.),p(Mon)	1988.13	0.41	0.3334	0.8146	14	1960.13
psi(Hab),gamma(.),eps(.),p(Mon)	1989.96	2.24	0.1335	0.3263	18	1953.96
psi(.),gamma(.),eps(.),p(Mon)	1990.12	2.4	0.1233	0.3012	15	1960.12
psi(.),gamma(Mon),p(Mon)	2002.64	14.92	0.0002	0.0006	24	1954.64
psi(.),gam(.),eps=1-gam,p(Mon)	2003.31	15.59	0.0002	0.0004	14	1975.31
psi(.),gamma(Mon),eps(.),p(Mon)	2005.81	18.09	0	0.0001	25	1955.81
psi(Hab),gamma(Mon),eps(Mon),p(Mon)	2020.84	33.12	0	0	38	1944.84
psi(.),gamma(Mon),eps(Mon),p(Mon)	2020.99	33.27	0	0	35	1950.99
psi(Hab),gamma(Mon),p(Mon)	2028.46	40.74	0	0	27	1974.46
psi(Hab),gamma(.),p(.)	2064.85	77.13	0	0	6	2052.85

psi(.),gamma(.),p(.)	2068.18	80.46	0	0	3	2062.18
psi(.),gamma(.),eps(.),p(.)	2070.08	82.36	0	0	4	2062.08
psi(Hab),gamma(.),eps(.),p(.)	2070.08	82.36	0	0	7	2056.08
psi(.),gam(.),eps=1-gam,p(.)	2078.48	90.76	0	0	3	2072.48
psi(.),gamma(.),eps(Mon),p(.)	2085.81	98.09	0	0	14	2057.81
psi(Hab),gamma(.),eps(Mon),p(.)	2085.82	98.1	0	0	17	2051.82
psi(.),gamma(Mon),p(.)	2085.87	98.15	0	0	13	2059.87
psi(.),gamma(Mon),eps(.),p(.)	2086.2	98.48	0	0	14	2058.2
psi(Hab),gamma(Mon),eps(.),p(.)	2086.22	98.5	0	0	17	2052.22
psi(.),gamma(Mon),eps(Mon),p(.)	2102.3	114.58	0	0	24	2054.3
psi(Hab),gamma(Mon),eps(Mon),p(.)	2102.32	114.6	0	0	27	2048.32
psi(.),gam(.),eps=1-gam,p(Mon+Day)	2112.69	124.97	0	0	33	2046.69
psi(Hab),gamma(Mon),p(.)	2160.13	172.41	0	0	16	2128.13

c)

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	-2*LogLike
psi(Hab),gamma(Mon),eps(.),p(Mon)	707.18	0	0.2164	1	12	683.18
psi(.),gamma(Mon),eps(.),p(Mon)	707.34	0.16	0.1997	0.9231	9	689.34
psi(.),eps(.),p(Mon)	708.38	1.2	0.1188	0.5488	6	696.38
psi(.),gamma(.),p(Mon)	708.38	1.2	0.1188	0.5488	6	696.38
psi(.),gamma(Mon),p(Mon)	709.67	2.49	0.0623	0.2879	8	693.67
psi(Hab),gamma(Mon),eps(Mon),p(Mon)	709.75	2.57	0.0599	0.2767	14	681.75
psi(.),gamma(Mon),eps(Mon),p(Mon)	709.9	2.72	0.0555	0.2567	11	687.9
psi(Hab),gamma(.),eps(.),p(Mon)	710.22	3.04	0.0473	0.2187	10	690.22
psi(.),gamma(.),eps(.),p(Mon)	710.36	3.18	0.0441	0.2039	7	696.36
psi(.),gam(.),eps=1-gam,p(Mon)	711.56	4.38	0.0242	0.1119	6	699.56
psi(Hab),gamma(.),eps(Mon),p(Mon)	712.78	5.6	0.0132	0.0608	12	688.78
psi(.),gamma(.),eps(Mon),p(Mon)	712.91	5.73	0.0123	0.057	9	694.91
psi(Hab),gamma(Mon),eps(.),p(.)	714.28	7.1	0.0062	0.0287	9	696.28
psi(.),gamma(Mon),eps(.),p(.)	714.42	7.24	0.0058	0.0268	6	702.42
psi(Hab),gamma(Mon),p(Mon)	715.02	7.84	0.0043	0.0198	11	693.02
psi(.),eps(.),p(.)	715.3	8.12	0.0037	0.0172	3	709.3
psi(Hab),gamma(.),eps(.),p(.)	717.19	10.01	0.0015	0.0067	7	703.19
psi(.),gamma(.),eps(.),p(.)	717.3	10.12	0.0014	0.0063	4	709.3
psi(Hab),gamma(Mon),eps(Mon),p(.)	717.5	10.32	0.0012	0.0057	11	695.5
psi(.),gamma(Mon),eps(Mon),p(.)	717.63	10.45	0.0012	0.0054	8	701.63
psi(.),gam(.),eps=1-gam,p(.)	718.08	10.9	0.0009	0.0043	3	712.08
psi(.),eps(Mon),p(.)	718.77	11.59	0.0007	0.003	5	708.77
psi(Hab),gamma(.),eps(Mon),p(.)	720.41	13.23	0.0003	0.0013	9	702.41
psi(.),gamma(.),eps(Mon),p(.)	720.51	13.33	0.0003	0.0013	6	708.51
psi(Hab),gamma(.),p(Mon)	723.06	15.88	0.0001	0.0004	9	705.06
psi(.),eps(Mon),p(Mon)	726.27	19.09	0	0.0001	8	710.27
psi(Hab),gamma(.),p(.)	740.13	32.95	0	0	6	728.13

psi(.,gamma(.),p(.))	750.44	43.26	0	0	3	744.44
psi(.,gamma(Mon),p(.))	754.44	47.26	0	0	5	744.44
psi(Hab),eps(.),p(.))	8531.56	7824.38	0	0	6	8519.56
psi(Hab),eps(.),p(Mon)	8537.56	7830.38	0	0	9	8519.56

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## Appendix 6 - Model selection results for the different detection methods used to detect foxes at Kings Park.

Model	AIC	deltaAIC	AIC wgt	Model Likelihood	no.Par.	-2*LogLike
psi(.),gamma(.),p(Survey)	649.02	0	0.2632	1	5	639.02
psi(.),gamma(.),p(Survey+Baited)	649.87	0.85	0.172	0.6538	6	637.87
psi(.),gamma(Survey),p(Survey)	650.59	1.57	0.12	0.4561	6	638.59
psi,gamma(.),eps(.),p(Survey)	651	1.98	0.0978	0.3716	6	639
psi(.),gamma(Survey),p(Survey+Baited)	651.37	2.35	0.0813	0.3088	7	637.37
psi,gamma(.),eps(.),p(Survey+Baited)	651.86	2.84	0.0636	0.2417	7	637.86
psi(.),gamma(Survey),eps(.),p(Survey)	652.79	3.77	0.04	0.1518	7	638.79
psi(.),gamma(.),eps(Survey),p(Survey)	652.82	3.8	0.0394	0.1496	7	638.82
psi(.),gamma(Survey),eps(.),p(Survey+Baited)	653.49	4.47	0.0282	0.107	8	637.49
psi(.),gamma(.),eps(Survey),p(Survey+Baited)	653.78	4.76	0.0244	0.0926	8	637.78
psi(.),gamma(.),eps(.),p(Survey+Lure)	653.86	4.84	0.0234	0.0889	8	637.86
psi(.),gamma(Survey),eps(Survey),p(Survey)	654.53	5.51	0.0167	0.0636	8	638.53
psi(.),gamma(Survey),eps(Survey),p(Survey+Baited)	655.35	6.33	0.0111	0.0422	9	637.35
psi(.),gamma(.),p(.)	655.48	6.46	0.0104	0.0396	3	649.48
psi(.),gamma(.),eps(.),p(.)	657.2	8.18	0.0044	0.0167	4	649.2
psi(.),gamma(.),eps(.),p(Lure)	657.3	8.28	0.0042	0.0159	5	647.3

## **Appendix 7- Results of fox trapping within Kings Park and Bold Park using cage traps**

**Project (short title):** 17589 BLAKE (Urban fox home range and resource selection)

**Investigators:** Michael Main (student), David Blake (principal supervisor), Robert Davis (co-supervisor), Harriet Mills (co-supervisor)

**Contractor:** Mike and Shane Butcher, Animal Pest Management Services

**Aim/reasoning:** Trapping was carried out within Kings Park and Bold Park, in an attempt to successfully capture 8 suitable foxes for GPS-collaring and ear tagging.

**Duration:** 8 weeks (free feeding + trapping)

### **Design and Procedures**

Prior to the trapping of foxes, a 6-week free feeding trial was used to acclimatize foxes to the presence of cage traps and increase the likelihood of foxes entering traps. Lures (meat + scent) were placed at 13 sites within the study area (KP: 7 sites; BP: 6 sites), with a 1x1m sandpad setup at each site to detect fox visitations. Initially, only scent lures were used at sites prior to the installation of cage traps (Figure 1). Cage traps (fixed open) were then placed at each site and a meat bait (rabbit; kangaroo; beef) was placed inside to encourage foxes to enter the trap. Visitations were recorded as evidence of a fox within the area (10 m<sup>2</sup>) of the site.

A 2-week trapping session was then conducted at both Kings Park and Bold Park, with five traps being deployed at both parks. Traps were set in the evening and were checked the following morning, with traps remaining closed during the day.

### **Results**

Fox visitations to sites was high (3.7-3.8 visits/session) at the beginning of the feeding trial; once traps were introduced at the sites, visitations declined dramatically (0.4-0.7 visits/session) (Table 1). No foxes were recorded entering traps during the free-feeding period, and none were caught during the trapping period. There were several captures of non-target species using the cage traps, all were released at the trap site (Table 2). No dog tracks were recorded at feeding and trap sites. A track from a cat was recorded at one trap site in Bold Park, no other cat tracks were observed.

### **Concluding remarks**

Based on the results of the trapping session, cage traps are ineffective at capturing foxes even when a free feeding trial is used prior to trapping. Cage traps frequently captured non-target species, particularly ravens that were attracted to the meat baits. While none of the animals were injured and were released after capture, there is still a high risk of injuring animals that are caught in cage traps. The results of the free feeding trial show that foxes can be lured to a site using scent lures but are deterred from these sites by the presence of the cage traps. Leg hold traps, which are concealed from sight, are believed to be significantly more effective at capturing foxes when scent lures are in place. No dogs and

only one cat were recorded during the feeding and trapping trial, indicating that there is a low likelihood of capturing either animal with leg hold traps. Also, non-target species, including ravens, quenda and possums, were only attracted to cage traps due to the presence of the meat baits, which are not used for leg holds. We conclude that leg hold traps are the only viable option to capture the required number of foxes for this project.

**Table 1. Results of the free-feeding conducted at Kings Park and Bold Park 5/03/2018-13/04/2018.** The table below shows the different species that were detected at the monitoring sites. The total visitations by foxes are shown for before and after cages were installed, with average number of site visits per monitoring sessions shown in (). Site visits by other species are shown as totals only.

Species visitations to sites	Kings Park		Bold Park	
	Pre-cages	With cages	Pre-cages	With cages
<i>Vulpes vulpes</i>	26 (3.7/session)	11 (0.4/session)	26 (3.8/session)	17 (0.7/session)
<b>Other species</b>				
<i>Isoodon fusciventer</i>		3		-
<i>Oryctolagus cuniculus</i>		5		6
<i>Corvus coronoides</i>		30		18
<i>Varanid gouldii</i>		2		5
<i>Pseudonaja affinis</i>		-		1

**Table 2. Results of the cage trapping session conducted at Kings Park and Bold Park 16/04/2018-27/04/2018.** \*Only includes traps that captured an animal.

Date	Time	Park	Location	Trap	Result	Species
17/04/2018	6:15 AM	KP	Scarp-memorial	2	CA	<i>Isoodon fusciventer</i>
17/04/2018	6:58 AM	KP	Scarp- NE Balga CP	3	CA	<i>Isoodon fusciventer</i>
18/04/2018	6:00 AM	KP	Scarp-memorial	2	CA	<i>Corvus coronoides</i>

<b>18/04/2018</b>	6:10 AM	KP	behind water plant	7	CA	<i>Corvus coronoides</i>
<b>19/04/2018</b>	6:29 AM	KP	House	4	CA	<i>Trichosurus vulpecula</i>
<b>19/04/2018</b>	8:59 AM	BP	Zamia Trail	1	CA	<i>Corvus coronoides</i>
<b>20/04/2018</b>	5:57 AM	KP	Scarp-memorial	2	CA	<i>Isoodon fusciventer</i>
<b>20/04/2018</b>	6:32 AM	KP	Scarp- NE Balga CP	3	CA	<i>Isoodon fusciventer</i>
<b>20/04/2018</b>	7:26 AM	BP	Sheoak walk	5	CA	<i>Corvus coronoides</i>
<b>24/04/2018</b>	6:36 AM	KP	behind water plant	7	CA	<i>Corvus coronoides</i>
<b>24/04/2018</b>	7:32 AM	BP	Zamia Trail	1	CA	<i>Corvus coronoides</i>
<b>24/04/2018</b>	7:41 AM	BP	Bridal Trail	3	CA	<i>Corvus coronoides</i>
<b>24/04/2018</b>	7:50 AM	BP	Balga Walk	4	CA	<i>Corvus coronoides</i>
<b>24/04/2018</b>	7:56 AM	BP	Sheoak walk	5	CA	<i>Corvus coronoides</i>
<b>25/04/2018</b>	6:53 AM	BP	Zamia Trail	1	CA	<i>Corvus coronoides</i>
<b>27/04/2018</b>	7:00 AM	BP	Zamia Trail	1	CA	<i>Corvus coronoides</i>
<b>27/04/2018</b>	7:09 AM	BP	Bridal Trail	3	CA	<i>Corvus coronoides</i>
<b>27/04/2018</b>	7:23 AM	BP	Sheoak walk	5	CA	<i>Corvus coronoides</i>

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**Figure 1. Set up of the free feeding site.** Prior to the installation of traps, a 1x1m sand pad was created and scent lures were placed around the site.