

Behaviour, temporal activity, and control of the red fox in the city



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Statement of Originality

This work has not previously been submitted for a degree in any university. This thesis does not contain previously published material, with the exception of the cited references.



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MSc. Margarita Gil Fernández

Note to the examiners

This thesis is written in the form of a journal article as an original paper and a short note for the journal **Biological Invasions**, except for the format requirements from the Department of Biological Sciences, Macquarie University. As this thesis has two chapters, a general abstract and general conclusions are presented.

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General abstract

Foxes (*Vulpes vulpes*) are an invasive predator implicated in the decline and extinction of many Australian native species, and are thought to thrive better in urban than in natural areas. We investigated the behaviour of foxes towards a novel object (a control device – canid pest ejector), temporal activity, and interactions with potential prey and domestic predators, by comparing behaviour among site types and to several environmental variables. We assessed the risk of using this device via visitation by domestic dogs, and in relation to distance from human habitations. We used camera-traps in 16 sites around Sydney to record temporal activity, visitation, and behaviour of our study species. Our major finding was that foxes behaved more confidently in urban areas and under high vegetation cover than in sites within peri-urban areas and low vegetation cover. Foxes appeared slightly more nocturnal in urban areas, where they have a higher temporal activity overlap with introduced mammals, than in peri-urban areas. Only two non-canid species were recorded pulling-up the ejector, confirming its high target-specificity. The ejectors could be effective in urban areas as a method of control. They could be safely deployed in sites with effective dog restrictions, regardless of the distance from human habitation.

CHAPTER 1: Behavioural and temporal activity adaptations of the urban foxes (*Vulpes vulpes*) in Sydney, Australia

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Abstract. With urban areas spreading constantly, it is essential to understand how wildlife adapts to anthropogenic change. We aimed to contrast the behaviour of foxes toward a novel object (canid pest ejector), as well as interactions with potential prey and domestic predators. We allocated five stations (each consisting of a camera trap and an ejector), in eight urban and eight peri-urban sites around Sydney. Through Generalized Linear Mixed Models, we tested the influence of environmental variables on fox visitation and behaviour, as well as the time spent around the ejector by site type. We contrasted activity overlap between foxes, prey species, and domestic predators through kernel density estimates. Foxes showed more confident behaviours (e.g. pulling the ejector) in urban areas ($p < 0.01$), and under high vegetation cover ($p < 0.001$). Foxes in urban areas also spent more time around the ejector than foxes in peri-urban areas ($\chi^2 = 8.25$, $p < 0.01$). Urban foxes were also more nocturnal than foxes in peri-urban areas. There was a higher activity overlap in urban areas with introduced mammalian prey (Dhat4=0.92 vs 0.85 peri-urban). The temporal overlap between foxes and cats was 7%, whereas for dog it was 16%. We conclude that foxes are more confident and more nocturnal in urban than in peri-urban areas.

Keywords: urban predator, invasive species, Canidae, urban ecology, novel object.

Introduction

Cities are highly modified landscapes but can still sustain significant biodiversity (van Heezik and Seddon 2018). In Australia, urban areas can harbor substantially more threatened species per unit of area than non-urban sites (Ives et al. 2016). In the context of the rapid spread of urban areas, there is an increasing need to understand the response of wildlife to these urban conditions (Šálek et al. 2015). Some species can maintain varying levels of closeness to humans, residing within cities, despite the artificial nature of the environment and the severe conditions (Bateman and Fleming 2012; Saito and Koike 2015). In urban areas, some species show behavioural or life-history modifications related to movement, diet, reproduction, density, disease, and survival (Ditchkoff et al. 2006).

The urban landscape is not homogenous, it contains mixed densities of buildings, small to large green spaces, rivers, roads and railways (Soulsbury and White 2015). Nevertheless, most urban areas have a greater availability of food than agricultural or natural environments, due to the availability of human rubbish and food waste. These food resources can also be unpredictable and may be rapidly depleted at a local level (Hulme-Beaman et al. 2016). Therefore, a wide variety of responses from wildlife to these resources and habitat characteristics is to be expected. Species can be classified into three groups regarding their response to urbanization. These groups include urban dwellers, urban utilizers, and urban avoiders. Urban dwellers include species that do not need any population input from natural areas to persist in cities (Fischer et al. 2015). Urban utilizers occur in urban environments as non-breeders and disperse from natural to urban areas. Finally, urban avoiders rarely occur in urban areas and persist only in sites with natural habitat (Fischer et al. 2015).

Urbanization is more likely to facilitate the spread of highly opportunistic and resilient species (Bateman and Fleming 2012). Many nonindigenous organisms are often restricted to human-altered environments within the region of introduction, because they are advantaged by anthropogenic alterations (Sol et al. 2017). Interactions with species that live in close proximity to humans can vary from “true commensalism” which describe species that live within houses, to “occasional commensalism”, that refers to species that spend time within houses and outdoors (Hulme-Beaman et al. 2016). Within human commensal species, there are exotic species that live largely off the resources associated with human activity (Banks and Smith 2015). There is a wide variety of well-known urban commensals, such as black rats (*Rattus rattus*), pigeons (*Columba livia*), bed bugs (*Cimex* spp.), and cockroaches (order Blattodea) (Johnson and Munshi-South 2017).

Of all the species that thrive in urban areas, predators can be especially influential community members (McNeill et al. 2016). Generally, the most successful urban predators tend to have generalist diets (i.e. not hypercarnivores), medium body size (average 4.60 kg) and show highly adaptable behaviour (Bateman and Fleming 2012). For example, in Japan, mid-sized mammal species, such as the masked palm civet (*Paguma larvata*), the raccoon dog (*Nyctereutes procyonoides*), and the domestic cat (*Felis catus*), share traits like high annual reproductive capacities and flexible diets, and are some of the most successful mammals in urban environments (Saito and Koike 2015). Similarly, coyotes (*Canis latrans*) in North America are successful urban-dwellers due to their behavioural and dietary plasticity (Bateman and Fleming 2012). When introduced into new ecosystems, predators can have great negative impacts on native biodiversity, including on native species that otherwise persist in cities (Doherty et al. 2016).

The fox (*Vulpes vulpes*) (hereafter “fox”) is the most widespread carnivore in the world. Their native range stretches from the Arctic Circle to southern North America, Europe, North Africa, the Asiatic steppes, India, and Japan (Hoffmann and Sillero-Zubiri 2016). In their native range, foxes were first recorded in 1930 in large cities of Great Britain such as London (Teagle 1967 in Bateman and Fleming 2012). Foxes are now widely observed in cities around the world, they can be considered as urban dwellers and occasional commensalists, they are one of the most scientifically well-observed urban predator species (Plumer et al. 2014; Scott et al. 2014; Vuorisalo et al. 2014; Soysal et al. 2016). After being introduced to Australia in the 1860s, for the sport of fox hunting, foxes were first recorded in an Australian city, Sydney, between 1907-1910 (Short 1998; Abbott et al. 2014). The presence of foxes in cities is thought to be due to the availability of anthropogenic food sources, which may have increased with urbanization (Gortázar et al. 2000; Yom-Tov and Geffen 2011; Oro et al. 2013).

Foxes in urban areas rely mainly on anthropogenic sources, which allows them to exist in greater population densities than in peri-urban or more rural areas, and this results in decreases in home range sizes and territoriality (Contesse et al. 2004; Bino et al. 2010; Bateman and Fleming 2012). To be able to exploit these new sources of food and resources in general, foxes (and other urban species) may have higher exploratory tendencies and the willingness and ability to gather new information from the environment (Thompson et al. 2018). The exploitation of anthropogenic resources in urban areas can result in increased body mass and body morphometrics in foxes (Stepkovitch 2017).

In Australia, the red fox has been catalogued as a pest and an invasive species, and is strongly implicated in declines and extinctions of Australian terrestrial fauna (Woinarski et al. 2015). Other

possible impacts of foxes include changes to ecosystem services, changes to ecosystem processes, and negative effects on local economies and livelihoods (Novoa et al. 2018). These negative effects exacerbate the need for controls and immediate action. Fox control within cities is currently very limited, due to concerns about impacts on humans and their pets (Southwell et al. 2013; Mallick et al. 2016). However, we need further understanding of the biology of urban and peri-urban individuals of this species to effectively mitigate their effects (Ditchkoff et al. 2006).

Variables related to fox visitation

Many anthropogenic and environmental factors are likely to influence the activity of foxes (Towerton et al. 2011). Dense vegetation cover may moderate the impacts of foxes (Abbott et al. 2014) and lower fox activity has been reported for forested areas compared to cleared land on the central western slopes of New South Wales (Towerton et al. 2011). On the other hand, vegetation cover represents safety across different systems and species (Lone et al. 2014). Even large predators avoid human activity, looking for shelter under high cover (Ordiz et al. 2011). Similarly, habitat structure variables are important predictors of fox activity (Díaz-Ruiz et al. 2016). When foxes are looking for shelter, they show a clear preference for dense vegetation while denning and resting (Janko et al. 2012).

Moon cycles can cause activity changes in several nocturnal species (Penteriani et al. 2013). For prey species, this variation can be related to increased predator wariness, weighed against the potential for increased foraging success (Pratas-Santiago et al. 2016). The response of a predator to the moon phase is defined by multiple variables, such as antipredator strategy of its main prey, home range habitat structure, and intrinsic traits like age, and health (Penteriani et al. 2011). Additionally, mesopredators reduce potential dangerous encounters with intraguild predators based on the moonlight (Penteriani et al. 2013). Therefore, any study of urban fox ecology must consider the influence of moon phase and vegetation cover on activity and behaviour. Understanding these relationships could also have direct implications for the planning of control programs, to potentially increase the efficacy of lethal baiting programs.

Behavioural responses to novelty in urban areas

Behaviour can be a major factor driving animals' responses to disturbance, because it determines how animals interact with the environment (Lapiedra et al. 2017). Urban areas are full of novel environments and objects, dealing with novelty is a key component of adapting to city life. How animals decide to interact with a novel object depends on a balance of their fear (neophobia) and their interest in exploring new objects (neophilia) (Greenberg and Mettke-Hofmann 2001).

Reactions to novelty can range from fear to indifference, to intense interest (Greggor et al. 2015). There are mixed outcomes from being more or less neophobic. Individuals could reduce exposure to danger by being neophobic, but this could also limit exploratory behaviour resulting in a diminished access to resources such as new foods (Moretti et al. 2015). Thus, the tendency of individuals to be neophobic *versus* neophilic is crucial for determining their success under human-induced rapid environmental change (Greggor et al. 2016; Lapiedra et al. 2017). In this study we classified the behaviour of the foxes as confident (neophilic, or bold) or timid (i.e. neophobic) responses.

Within most vertebrates, individuals from urban areas tend to be bolder than their rural counterparts. For example, when comparing the behaviour of lizards from urban areas to individuals from natural areas, urban inhabitants tend to be bolder and more explorative (Lapiedra et al. 2017). In the case of prey species (e.g. fox squirrels, *Sciurus niger*), species in urban habitats show a reduction in anti-predator responses and vigilance behaviours, which could also be seen as bolder behaviour (Mccleery 2009). For birds, this response was very similar, where birds in urban areas approached objects made from human litter faster in comparison to rural birds (Greggor et al. 2016).

Responses to novel objects are also important when developing or implementing attractants or control devices (Heffernan et al. 2007). The efficiency of predator control and selectivity may be increased by considering the animal's natural behaviour and how such behaviours affect the vulnerability of the species in different contexts (Travaini et al. 2013). In this study, we used the canid pest ejector as a novel object to foxes, with applied importance through its potential to be used in future urban control programs. The canid pest ejector is a baited, spring-activated device that propels the content of a poison capsule into a predator's mouth (Connolly and Simmons 1984) (for more details about the ejector, see chapter 2).

Activity overlap between foxes and potential prey

Urban dwellers generally have flexible activity patterns that allow them to thrive within cities (Bateman and Fleming 2012). For example, within urban areas, individuals might become more nocturnal in order to avoid encounters with humans (Ditchkoff et al. 2006). For foxes, this change in activity could influence the potential for interactions with prey, and hence potential impacts on other, smaller urban wildlife (Faeth et al. 2005).

The best predictors of the ecological impact of an alien species are the character and strength of their interactions with native species (Carthey and Banks 2014). Both response and vulnerability to fox predation depend on the species, and even individual species may vary in their responses to individual threat factors at different sites or times (Woinarski et al. 2015). For native species, those that weigh between 35 g and 5,500 g, defined as the *critical weight range*, are known to be particularly at risk from red fox predation (Burbidge and McKenzie 1989). However, for urban foxes, there are also non-native potential prey species such as mice (*Mus musculus*), rats (*Rattus rattus* and *Rattus norvegicus*), rabbits (*Oryctolagus cuniculus*), birds and invertebrates (Davis et al. 2015).

Understanding the overlap in fox and potential prey temporal activity patterns would indicate the degree to which both species are active at the same time, indicating the potential for predation. In some cases, predators adjust their activity to match that of their main prey, so as to reduce foraging energy expenditure (Foster et al. 2013). The fox has been shown to exhibit behavioural plasticity in activity patterns in its native range, which allows it to adapt to environmental changes and prey activity (Díaz-Ruiz et al. 2016). In natural pine-wood Mediterranean forests, a seasonal fluctuation in the diet of foxes has been shown, where the activity of foxes was highly dependent on the activity of prey during the warm season (Lovari et al. 1994). Given that both native and non-native prey are potentially available to foxes in cities, it would be useful to understand the degree to which each prey type is potentially vulnerable to fox predation. Such interactions between foxes and potential prey are still understudied in urban areas (Jokimäki and Huhta 2000).

Activity overlap between foxes and domestic predators

Interspecific interactions between mammalian wild predators have been fairly well studied, nevertheless, little is known about wild predator interactions with domestic predators (Krauze-Gryz

et al. 2012). The interactions between domestic and wild carnivores can be agonistic, to the extent that one predator may eat the other (Harrison et al. 2011; Plumer et al. 2014). For example, foxes have been recorded killing domestic cats in urban areas (Plumer et al. 2014).

More so than domestic cats, domestic dogs (*Canis lupus familiaris*) may have important effects on foxes (Harris 1981). All types of domestic dogs, from feral to fully domestic, can interact with wildlife and severely impact biodiversity (Doherty et al. 2017). The presence of domestic dogs can incur temporal displacements in the activity of mammalian carnivores, such as bobcats and coyotes (George and Crooks 2006). In their native range, the distribution of urban foxes is negatively correlated to the distribution of stray dogs, especially where the latter have high abundance (Harris 1981). Dogs impact the behavior of carnivores directly by chasing, barking and attacking, and indirectly through fear effects, mediated by scent marking via urine and scats (George and Crooks 2006). Within an urban setting, domestic dog presence may therefore be expected to represent danger to foxes, and so be avoided.

In this study, we used canid pest ejectors (hereafter: ejectors) as novel objects to assess changes in exploratory behaviour in foxes in urban and in peri-urban areas of Sydney. The ecological aims were to investigate how foxes respond to cover, moonlight, distance to human habitation, and the presence of dogs, in both site types. Finally, we compared the temporal activity changes of foxes in urban and peri-urban areas, as well as the activity overlap with prey groups (mammals and birds), as an indicator of the potential for foxes to predate upon these species.

Our key hypotheses were:

1. *Variables related to fox visitation.* Due to previous observations of higher densities of foxes in urban areas (Bino et al. 2010; Šálek et al. 2015), we expected to find a higher visitation rate in urban than in peri-urban sites with ejectors. We also hypothesized that variables such as vegetation cover and moon phase would affect fox visitation rates, with foxes more active under cover and in darker phases of the moon.
2. *Behavioural responses to novelty.* We hypothesised that foxes in urban areas would display more confident behaviour than foxes in peri-urban areas, and explored how this behaviour relates to environmental variables such as cover, moon phase, and distance from human habitation.

3. *Variation in fox temporal activity.* The activity of animals in urban areas is generally more nocturnal (Ditchkoff et al. 2006), therefore, we expected urban foxes to be more nocturnal than foxes in peri-urban areas.
4. *Activity overlap between foxes and potential prey.* We expected a higher overlap with mammalian prey, because of their nocturnal activity, than with bird prey, which are mainly diurnal. The overlap with mammalian prey could be stronger in cities if the activity of foxes is more nocturnal. Thus, the activity overlap with birds could increase in peri-urban areas if foxes are more active during the day.
5. *Activity overlap between foxes and domestic predators.* We hypothesized that the overlap with domestic cats would be higher than the overlap with domestic dogs, because of the nocturnal activity of this first species. While both cats and foxes may naturally be nocturnal, dogs in cities are generally kept in yards or indoors at night, whereas this is less true for cats.
6. *Fox behaviour in relation to the presence of domestic dogs.* Foxes may be more confident in sites with dog restrictions due to the absence of this potential agonistic competitor (Harris 1981).

Methods

Study area. The Greater Sydney Region is highly diverse, extending from densely urbanised cities and coastal waterways through to rural lands and extensive World Heritage wilderness areas (Local Land Services of Greater Sydney, 2018). This region has a total population of 5.1 million, and a total of 1,855,734 private dwellings (Australian Bureau of Statistics, 2018). We selected 16 sites across the Greater Sydney Region. Eight of our sites were within urban areas and eight sites were within in peri-urban areas. All sites were at least 5 km apart from each other to ensure site independence, based on recent fox home range calculations for Sydney (Martin, J. 2018 - *Unpublished data*).

Sampling design. At each site, we installed five sampling stations, at intervals of 50 m from a single human habitation. However, these distances were not always constant and varied depending on the terrain (± 20 m). In some urban sites, cameras were hidden from humans, to avoid vandalism or theft, and this added variability to the spacing of the stations. The stations were located strategically to maximize the probability of detecting foxes (i.e. in close proximity to trails, dens or sandy soil). Eight of the sites had domestic dog restrictions and the other eight did not have dog restrictions (dog restriction sites - Figure 1, 2). See data analyses for further explanation about site types and dog restrictions.

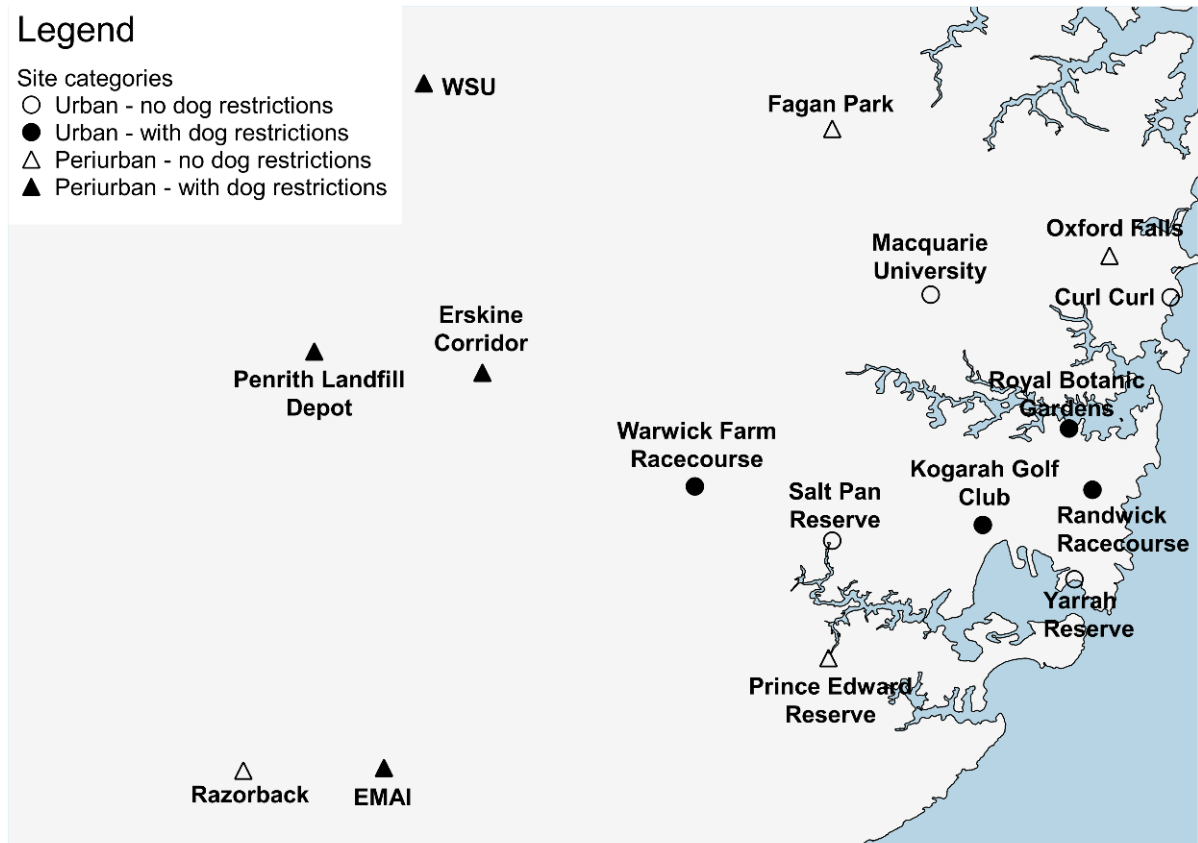


Fig. 1. Study sites for the assessment of the behaviour and ecology of the red fox in urban and peri-urban areas in Sydney, NSW, Australia

Each sampling station consisted of one ejector and one camera trap. In total, we had 80 sampling stations. The sites were surveyed over two separate periods: April 3 to April 27, 2018, and May 1 to May 25, 2018. We divided the site types among sampling periods evenly, thus each period had the same combination of site types (i.e. number of urban, peri-urban and with or without dog restrictions). The ejectors deployed in this study were not activated (i.e. their springs were not depressed) and did not contain any toxic component (they did not have any poison capsule inside the bait head). The bait heads of the ejectors were made from dried beef liver treats (Black dog®) blended and mixed with PVA glue. The bait heads were replaced on each weekly visit to the sites. After ejector installation, we spreaded 50 ml of fish oil (Wilson Fish Attractant®) within a radius of 30 cm around the ejector. From the second period of sampling onwards, we also staked the ejectors with fishing line to prevent them from being removed by either dogs or foxes.

We used HC600 Reconyx remote-sensing trail cameras (<http://www.reconyx.com.au>) to monitor each ejector. At each sampling station, the camera was placed facing the ejector at a distance of 2m. We tied the cameras to trees or posts approximately 60 cm above the ground (some camera heights

varied slightly due to sloping terrain). The cameras were programmed to take 10 consecutive photos in the hyperfire mode, without delay between activations.



Fig. 2. Sampling stations design to assess the behaviour and ecology of red foxes in Sydney, Australia. At each site, we located five sampling stations (a). Each station was composed of: b) Reconyx HC600, one camera was allocated per station, c) canid pest ejector installed into the ground, with only the bait head on the surface, d) tuna oil spread around the canid pest ejector

Data analyses

Variables related to fox visitation. Pictures from the camera traps were tagged with the software DigiKam (<https://www.digikam.org>) and were processed with the CamtrapR package from R (Niedballa et al. 2016). We conservatively defined visits as independent if they were separated by at least 24 h. Data on fox visitations to stations were analysed using a Generalized Linear Mixed model fit by maximum likelihood, with the Laplace Approximation in the package lme4 (Bates et al. 2015). We used the binomial family with the logit link function. The response variable was the count of presence *versus* absence of foxes in intervals of 24 h, i.e. the total number of nights when a fox was recorded – treated as a “success”, *versus* the nights where there was no record of foxes – treated as “failures”. The explanatory variables were:

- a) Vegetation cover. Measured immediately above the ejector location, using wide-angle photographs taken with a GoPro Hero4 Silver® camera. The pictures were processed with the Gap Light Analyzer software (<https://www.caryinstitute.org/science-program/our->

[scientists/dr-charles-d-canham/gap-light-analyzer-gla](#)), which determines the percentage of vegetation openness by dividing pixel intensities into sky and non-sky classes.

- b) Moon phase. The data of moon phases was recorded by the camera traps on each capture. The data from the camera traps considers eight moon phases: full moon (which also includes gibbous phases), quarters, and new moon (that also comprises the crescent phases).
- c) Distance from habitation. As the sampling stations were located at intervals of 50 m from a single human habitation, we had a range of distance from 50 to 250 m from human habitation. We divided the distance in two categories <150 m and >150 m, as the Pesticide Control (1080 Bait Products) Order 2017 limits baiting within 150m of human habitation. This in relation to further analyses in Chapter 2.
- d) Site type. Sites were classified as urban or peri-urban based on human habitation density. Sites with house densities exceeding 900 habitations/km² were considered urban, and those with < 900 habitations/km² were considered peri-urban.
- e) Dog restrictions. In half of the sites, dogs were not allowed. Most of these sites were completely fenced, with only one exemption (Kogarah Golf Club). The fences were present to avoid human access, not specifically dog access, however, this would decrease the probability of dogs entering with human assistance. Moreover, the presence of the restrictions was confirmed by asking the managers and by the presence of signs. However, in one of our sites with dog restrictions there were three known resident dogs.

All the possible combinations of variables into models were analysed and compared with the MuMIn package in R (Barton 2018). The best models were chosen based on the Akaike Information Criteria for small samples (AICc), because the number of observations was less than 40 times the number of explanatory variables in the models (Anderson et al. 2001).

Behavioural responses to novelty. We used two different measures to assess fox behaviour. First, we identified individual foxes by conspicuous marks and report the number of foxes that displayed confident or timid behaviour toward a novel object (see Appendix 1 for ethogram). For this analysis, we discarded all unidentifiable foxes. Second, we considered all independent records (i.e. records separated by at least 24 hours at each station) obtained while the ejector was present in the area (in some stations ejectors were removed before the end of the sampling period by foxes, dogs or humans).

We divided the behaviours displayed into two categories, either *timid* or *confident* behaviours. The *timid* behaviour included: a camera-shy response: a slow and cautious approach to the camera,

usually in a crouching position, or a cautious posture towards the ejector (Figure 3). *Confident* behaviours included: pulling the ejector, digging and removing the ejector, marking the ejector area, either by spraying or rolling (Figure 4). In a single visit, a fox could display one or more of these behaviours. We only recorded each behavioural category once per visit. Thus, the same individual in the same visit could display confident followed by timid behaviours, or *vice versa*, and both categories of behaviour were recorded. However, when an individual displayed different behaviours, but all were in the same category, this was only taken as one display.

The behaviour data were analysed with Generalized Mixed Linear Models with a binomial distribution with the R package lme4 (Bates et al. 2015). The response variable was timid *versus* confident behaviour. The explanatory variables for the global model were vegetation cover, moon phase, site type, distance from habitations, and presence or absence of dog restrictions, with stations and site identities included in the models as random factors. All possible combinations of explanatory variables were compared using the Akaike Information Criteria for small samples (AICc) within the MuMIn package from R (Barton 2018). The best models were considered to be those with the lowest AICc and a ΔAIC of less than two (Bozdogan 1987).

Time spent around the novel object. We compared the time that the foxes spent in sight of the camera-trap on each independent visit to each of the study variables (i.e. site type, vegetation cover, moon phase, dog restrictions, and distance from habitation) univariately, using a non-parametric Kruskal-Wallis rank sum test due to the lack of normality of the data (Kruskal and Wallis 1952).



Fig. 3. Examples of fox behaviours that were classified as timid. a) Camera shyness: the fox ran away as it heard the camera triggering, b) Cautious behaviour: the fox approached the canid pest ejector, but its posture was tense, it kept its hind legs away and kept its body close to the ground. Pictures from the station at Erskine Biological Corridor, Sydney, NSW, Australia. See Appendix 1 for a detailed description of each behaviour

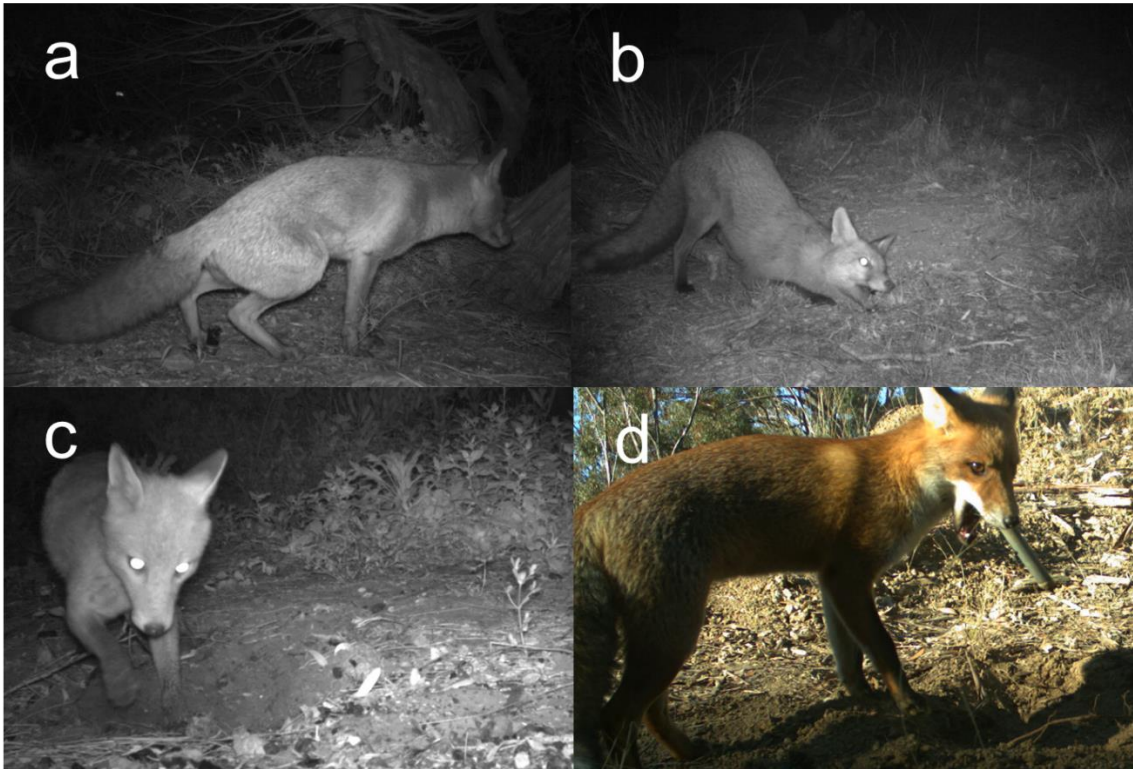


Fig. 4. Examples of fox behaviours that were classified as confident. a) marking of the ejector area, b) pulling the ejector, c) digging around the ejector, d) removing the ejector from the ground. Pictures from stations at Curl Curl Beach, Elizabeth Macarthur Agricultural Institute, Yarrah Reserve, and Razorback, Sydney, NSW, Australia. See Appendix 1 for a detailed description of each behaviour

Activity overlap between foxes and potential prey. To compare temporal activity overlap among foxes and different prey species, we used the package *overlap* in R, which determines the overlap between two activity densities based on kernel density estimates (Ridout and Linkie 2009). We used the estimate *Dhat4*, which is the most suitable for samples with more than 50 observations per species (Ridout and Linkie 2009). We first compared the temporal activity overlap of foxes between urban and peri-urban areas. Next, we compared fox activity during different moon phases. We then compared fox activity overlap with potential bird and mammalian prey (introduced and native) between urban and peri-urban sites (See Appendix 2 for the list of species in each group).

Activity overlap between foxes and domestic predators. As done for potential prey, we compared the temporal activity of foxes with cats and domestic dogs, across all sites and compared by site type. Due to the low number of captures of domestic cats per site type, we used the density estimate *Dhat1*, which is used when the records of activity are less than 50 (Ridout and Linkie 2009). For dogs we continued to use the *Dhat4*. We assessed the response of foxes to the presence of dogs by comparing the visitation rate of foxes in sites with and without dog restrictions through a generalized mixed effects models that includes sites and stations as random factors.

Results

We achieved a sampling effort of 1,659 camera trap nights. However, at some of the stations, the ejector was removed before the end of the sampling period by foxes, dogs or humans. For all the visitation and behaviour analyses, we only considered sampling effort when the ejector was present, which left 1,472 camera trap nights across all sites. On average, each sampling station was active for 19.2 camera trap nights ($SD = 4.10$). We had a total of 409 independent fox visits (defined by 24 h difference in time) to 72 of 80 sampling stations. There was a large variability in the visitation rate of foxes among study sites (Figure 5). The site with the highest number of independent visits was Warwick Farm Racecourse, with a total of 49 independent visits in a total of 75 trap nights at this site, and an average visit rate per night of 0.68 across all five stations ($SD = 0.25$).

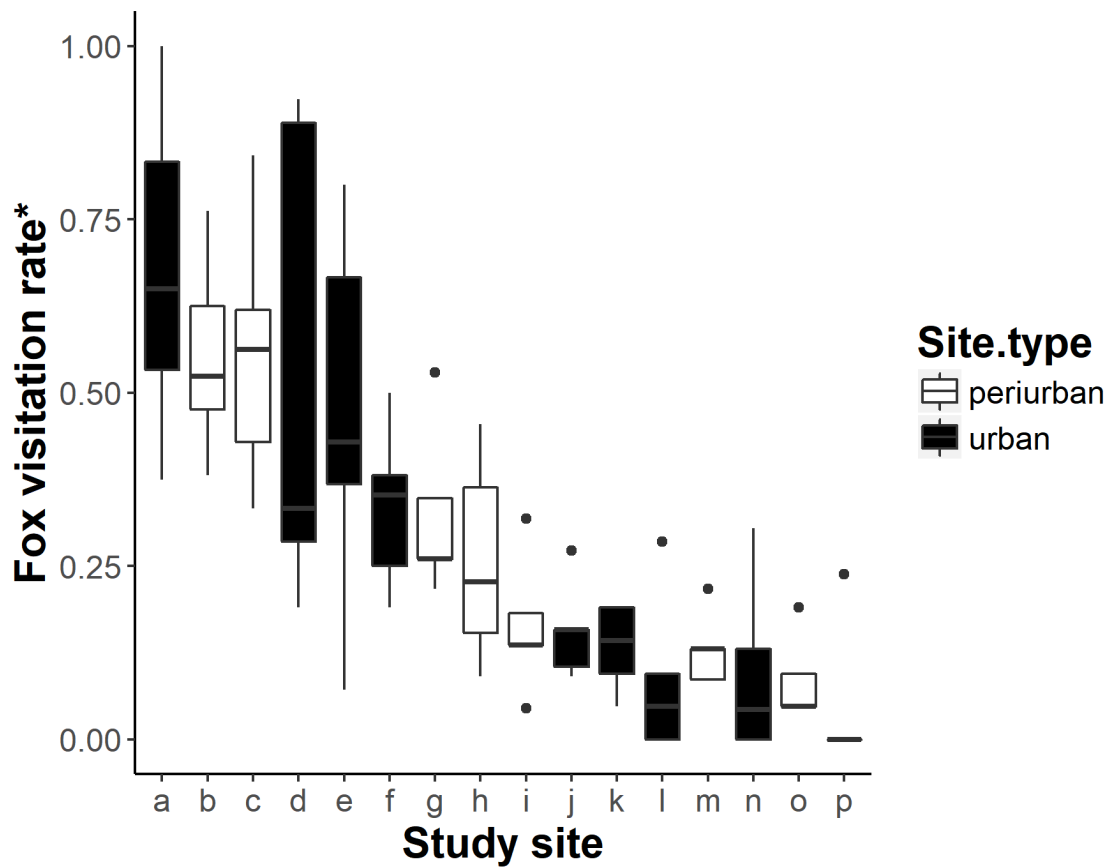


Fig. 5. Fox visitation to the canid pest ejector at each study site in Sydney, NSW, Australia. Total nights of presence in relation to the total sampling effort. Sites: a = Warwick Farm Racecourse, b = Erskine Biodiversity Corridor, c = Fagan Park, d = Yarrah Reserve, e = Kogarah Golf Club, f = Royal Botanic Gardens, g = Prince Edward Reserve, h = Razorback, i = Elizabeth Macarthur Agricultural Institute, j = Salt Pan Reserve, k = Randwick Racecourse, l = Curl Curl Beach, m = Oxford Falls, n = Macquarie University, o = Western Sydney University (Hawkesbury campus), p = Penrith Landfill Depot. *The fox visitation rate is defined by the proportion of nights with presence of foxes divided by the total nights of sampling on each station

Variables related to fox visitation

Among all possible combinations of explanatory variables, there were five models with good support, as reported by the ΔAICc (Table 1). The supported models had different combinations of vegetation cover, distance from habitation, presence or absence of dog restrictions and moon phase as explanatory variables. However, the only variable with a significant effect was vegetation cover ($p < 0.05$). Considering this variable only, high vegetation cover stations had 24% probability of visitation (CI 95% = 8% - 43%), whereas stations with low cover had 14% probability of visitation (CI 95% = 8% - 21%). These values did not change with the inclusion of other variables.

Table 1. Best models to explain fox visitation to the canid pest ejectors in Sydney, NSW, Australia. In all models, the site and stations were fitted as random factors. Lower AICc values indicate better support for the model. Models with differences in AICc (ΔAICc) < 2 are considered well supported

Model	AICc	d.f.	ΔAICc
Fox visitation ~ cover + moon phase	642.1	6	0
Fox visitation ~ cover + distance + moon phase	642.8	7	0.7
Fox visitation ~ moon phase	643.6	5	1.5
Fox visitation ~ cover + dog restrictions + moon phase	643.7	7	1.6
Fox visitation ~ distance + moon phase	643.7	6	1.6

Fox visitation = number of nights with presence of fox vs nights without fox records. Cover = percentage of vegetation cover categorized in high (>50%) and low (<50%). Moon phase = Three categories related to the quantity of moonlight: full moon, quarters and new moon

Variation in fox temporal activity patterns between moon phases was not significant (Figure 6). However, during full moon and gibbous phases, fox activity tended to increase from sunset, with a peak of activity before 24 h, and a subsequent decrease at dawn (Figure 6, dashed line). The highest overlap in activity was between the new moon and crescents, and the quarters (Dhat4 = 0.92, Figure 6, black and grey lines respectively). The overlap estimate between the full moon and the other phases was 0.82 (Dhat4).

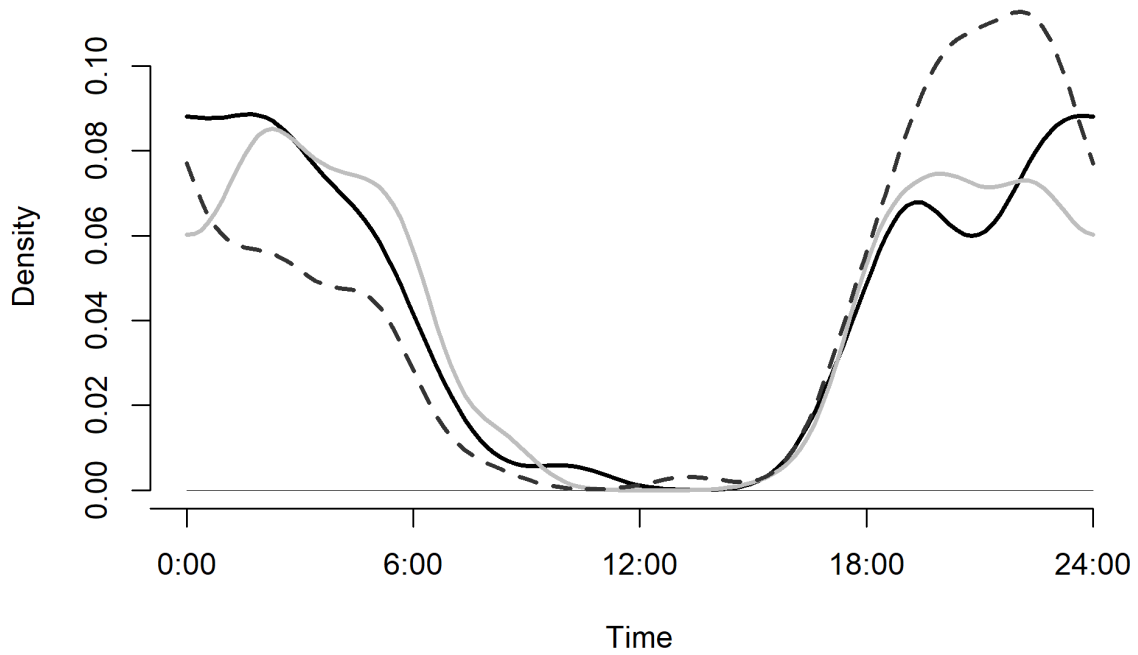


Fig. 6. Temporal activity of the red fox (*Vulpes vulpes*) compared by moon phases: A) new moon and crescents (black line), B) first and last quarters (grey line), and C) full moon and gibbous (dashed line). Sydney, NSW, Australia

Behavioural responses to novelty

Across all sites, we classified 178 fox interactions with the novel object as confident and 174 as timid using the behavioural categories in Appendix 1. We did not consider the identity of the individuals in this analysis in order to include the unidentified individuals, instead we used the independent visits as those separated by 24 h on each station as response variable. The model with the lowest AICc to explain confident behaviour had vegetation cover and site type as fixed effects, and site as a random factor, however, there were three acceptable models ($\Delta\text{AICc} < 2$) among the combinations (Table 2). The probability of foxes displaying confident behaviours was significantly different among site type ($p < 0.01$) and increased in sites with high vegetation cover ($p < 0.001$). With regards to the other variables that were also present in the supported models, foxes were less confident at sites with dog restrictions. Similarly, foxes were more confident when closer to human habitation.

Table 2. Best models to explain red fox confident behaviour in the canid pest ejector area in Sydney, NSW, Australia. In all models, site was used as a random factor. Lower AICc values indicate better support for the model. Models with differences in AICc (ΔAICc) < 2 are considered well supported

Models	AICc	d.f.	ΔAICc
Fox behaviour ~ cover + site type	246.7	4	0
Fox behaviour ~ cover + dog restrictions + site type	247.5	5	0.0
Fox behaviour ~ cover + distance + site type	248.4	5	1.7

Confident behaviour increased with increasing vegetation cover in peri-urban sites (black line, Figure 7), but this relationship was even stronger in urban sites (grey line, Figure 7). Overall, in urban sites the probability of foxes displaying confident behaviour was 62% (95% CI = 9% - 80%), whereas in peri-urban areas this probability was 50% (95% CI = 41% - 60%).

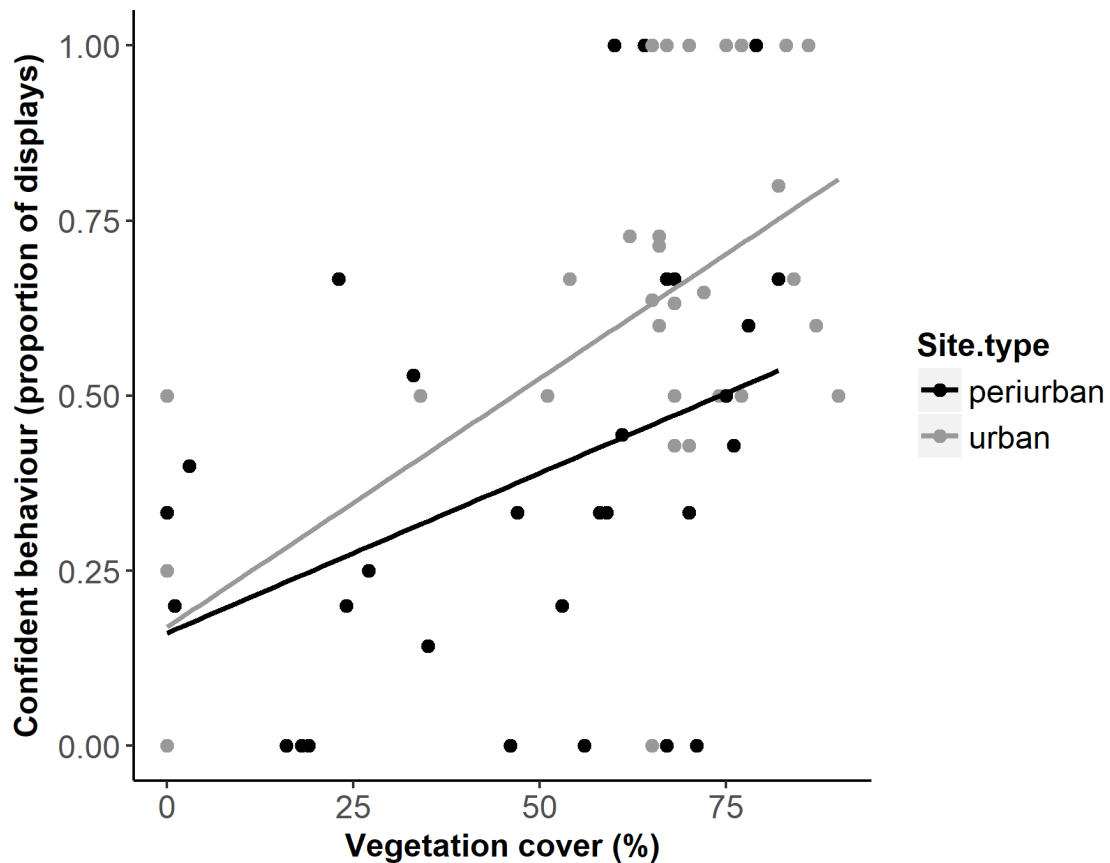


Fig. 7. Proportion of confident displays (proportion of confident behaviours scored per camera station, across the total sampling period) in relation to the percentage of vegetation cover and site type. Sydney, NSW, Australia. Each dot on the graph represents a sampling station. The lines represent linear regressions, but these are not related to our statistical analyses, these are only to show the tendency in the data

Time spent around the novel object

Foxes in urban areas spent significantly more time in the ejector area than individuals from peri-urban areas ($\chi^2 = 8.25$, $p < 0.01$). On average, foxes in urban areas spent 19 seconds in the ejector area, whereas foxes in peri-urban areas spent 14 seconds in the area. Also, when compared by vegetation cover category (high $> 50\%$, low $\leq 50\%$), foxes spent significantly more time in sites with high vegetation cover (average 18 s), than in sites with low cover (average 13 s) ($\chi^2 = 7.40$, $p < 0.01$). The moon phase had a significant effect over the time spent in the ejector area ($\chi^2 = 6.13$, d.f. = 2, $p = 0.04$). During the full moon, the foxes spent on average 23 s exploring the ejector (SD = 192 s), while in new moon (15.5 s, SD = 126 s) and in quarters (14 s, SD = 127 s) foxes spent less time in the area. Regarding the distance from habitation categories (<150 m, ≥ 150 m), there was no significant difference in the time the foxes spent on the ejector area ($\chi^2 = 0.17$, $p = 0.68$). Similarly, there was no significant difference in the amount of time foxes spent in the ejector area between sites with or without dog restrictions ($\chi^2 = 2.16$, $p = 0.14$).

Activity overlap between foxes and potential prey

The temporal activity of foxes was slightly different between urban and peri-urban areas, with a temporal overlap of 0.89, on a scale from 0 to 1. Foxes in peri-urban areas tended towards greater activity in the mornings (Figure 8, grey line), whereas foxes in urban areas tended towards greater activity at night (Figure 8, black line).

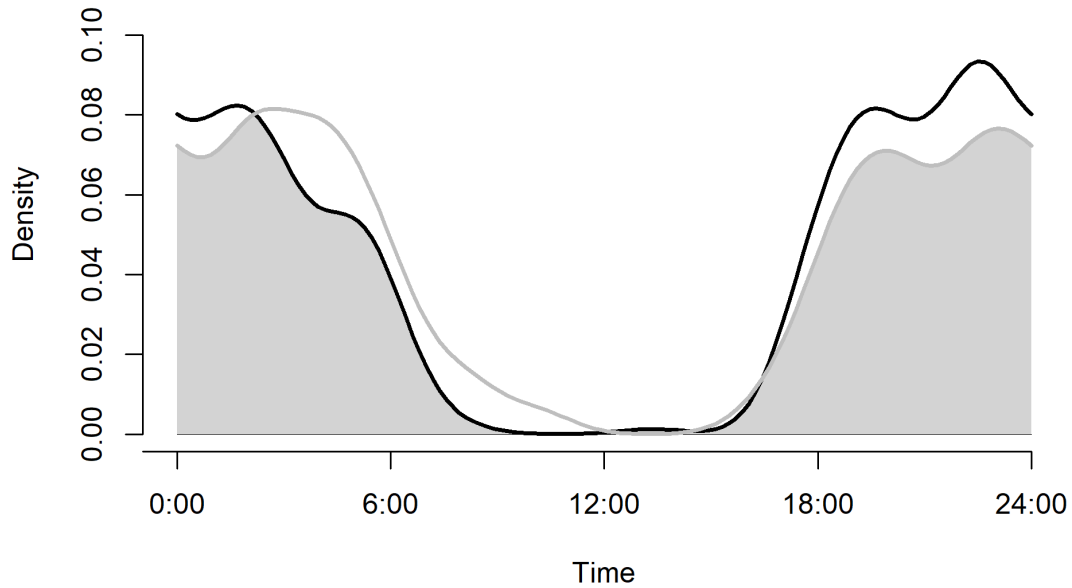


Fig. 8. Activity overlap of the red fox (*Vulpes vulpes*) between individuals in urban (black line) and peri-urban areas (grey line), shaded area represents the overlap. Sydney, NSW, Australia

The prey group with the highest overlap with foxes were the introduced mammals, *Oryctolagus cuniculus*, *Lepus europeaus*, and *Rattus rattus*, with a coefficient of 0.94. However, the overlap with native mammals was equally high (0.9) (Figure 9). In general, for mammals, the overlap coefficient was 0.95. This contrasts with both groups of bird species, which are mainly active during the day. The overlap for birds and foxes was 0.09 (Figure 10).

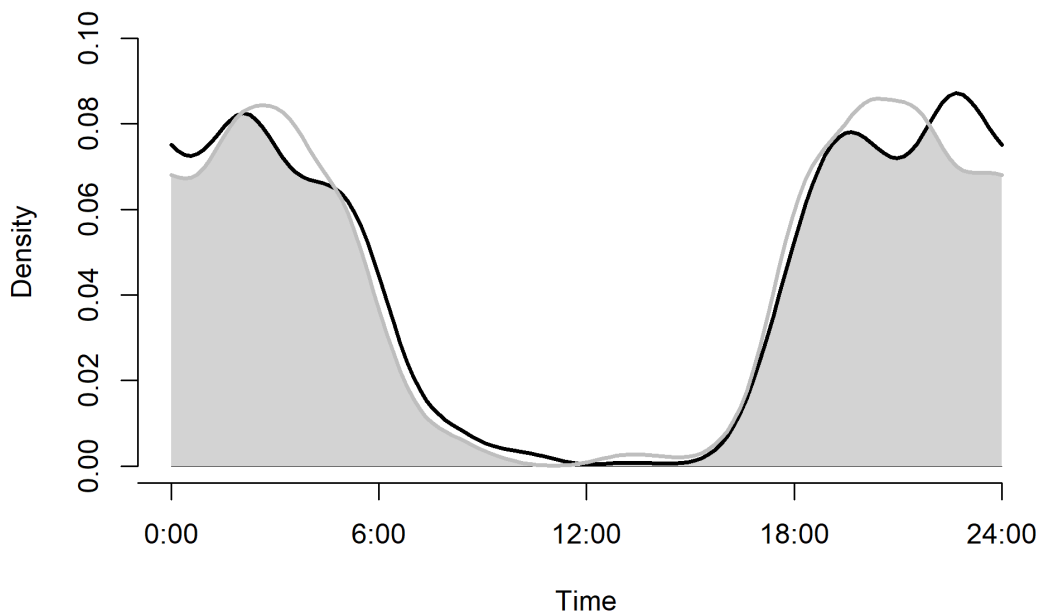


Fig. 9. Activity overlap of the red fox (*Vulpes vulpes*, black line) and mammal prey species (grey line), shaded area represents the overlap. Sydney, NSW, Australia

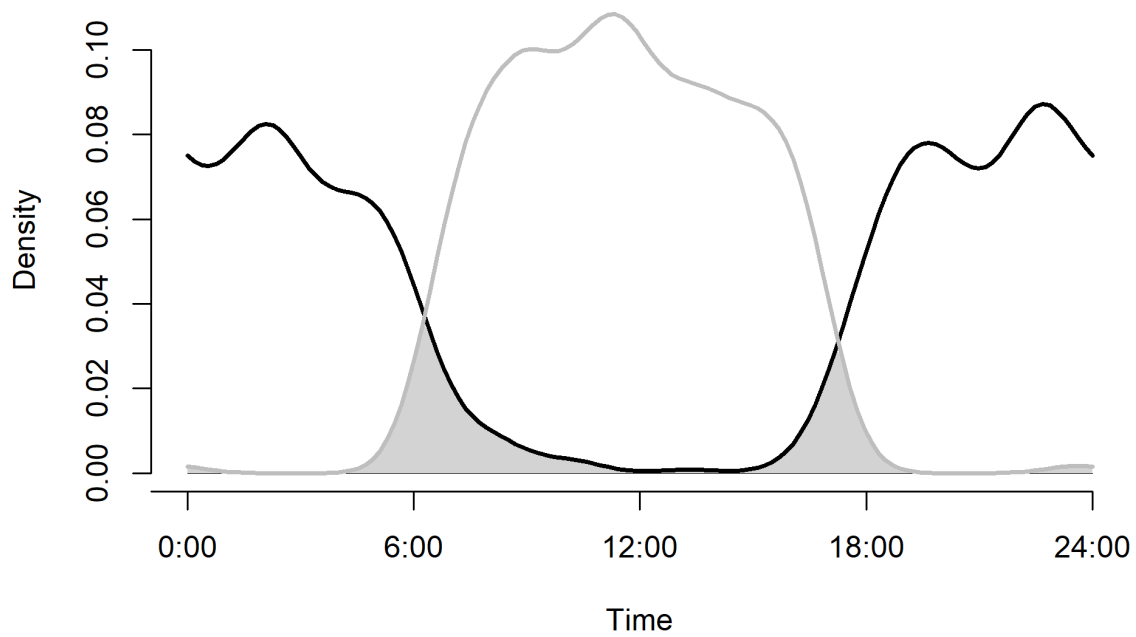


Fig. 10. Activity overlap of the red fox (*Vulpes vulpes*, black line) and bird prey species (grey line), shaded area represents the overlap. Sydney, NSW, Australia

When compared by site type, we found little variation among the overlap of foxes with potential prey species group (Figure 11). However, the overlap with introduced mammalian prey was smaller in peri-urban areas than in urban areas ($D_{\text{hat4}} = 0.85$ and 0.92 respectively). Contrarily, the overlap with native mammalian prey was slightly higher in peri-urban than in urban areas ($D_{\text{hat4}} = 0.87$ and 0.85). Finally, the overlap with birds was higher in peri-urban areas than in urban areas ($D_{\text{hat4}} = 0.13$ and 0.07 , Figure 11). We were not able to split birds into introduced and native due to a very low number of records of introduced birds in peri-urban areas (only three records).

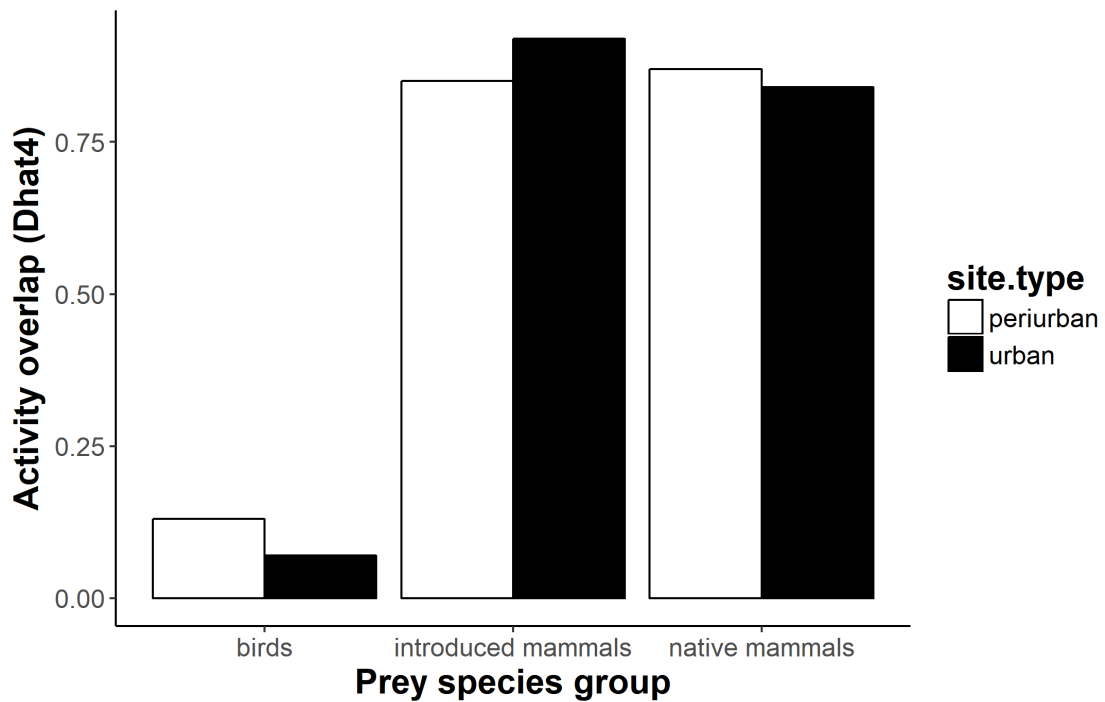


Fig. 11. Temporal activity overlaps between foxes (*Vulpes vulpes*) and potential prey groups compared among urban and peri-urban areas of Sydney, NSW, Australia

Activity overlap between foxes and domestic predators

Across both site types, there is a higher activity overlap between foxes and cats ($D_{hat4} = 0.76$, Figure 12) than between foxes and dogs ($D_{hat4} = 0.16$, Figure 13). When comparing by site type, the overlap with cats increases from 0.70 in peri-urban areas (D_{hat1}), to 0.77 in urban areas (Figure 14). In the case of dogs, the overlap estimate remains almost constant, going from 0.16 in peri-urban areas (D_{hat4}), to 0.17 in urban areas.

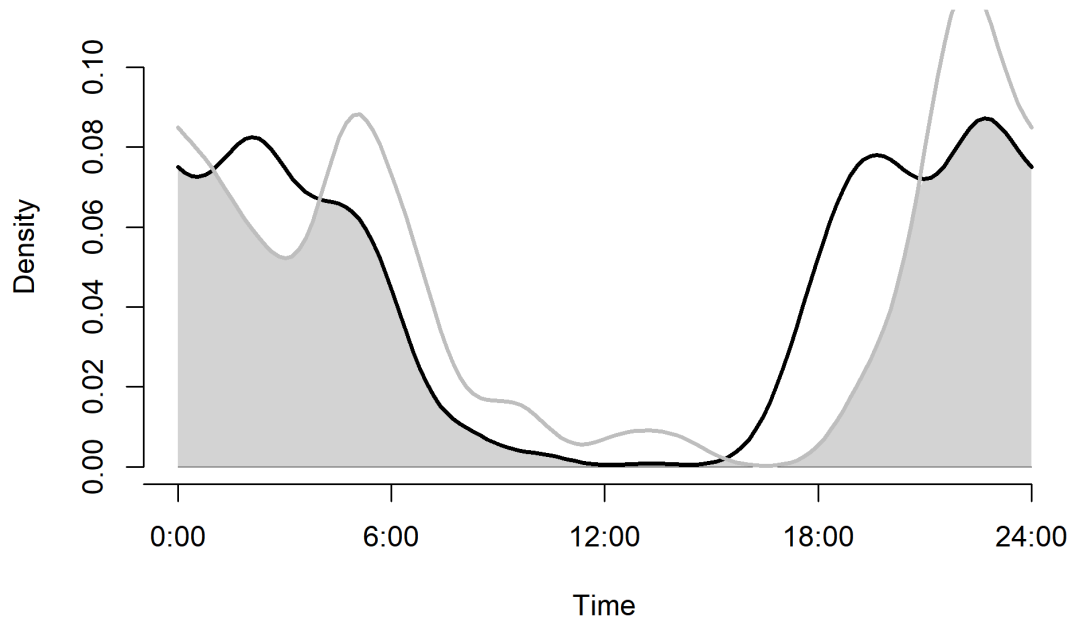


Fig. 12. Activity overlap of the red fox (*Vulpes vulpes*, black line) and domestic cat (*Felis catus*, grey line), shaded area represents the overlap. Sydney, NSW, Australia

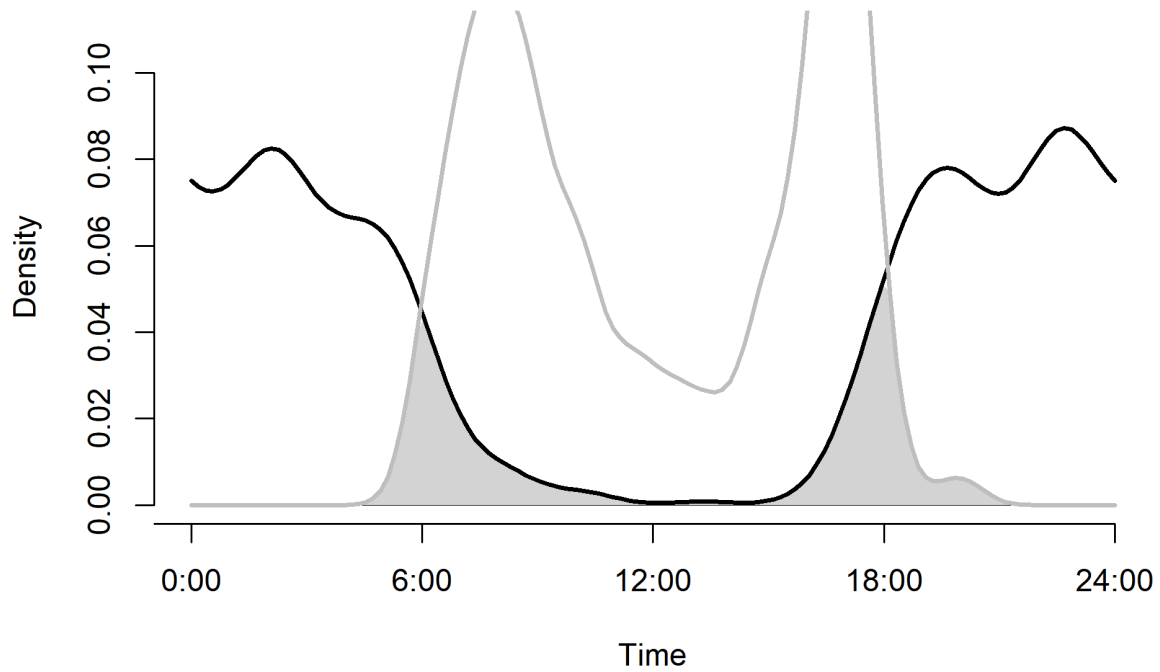


Fig. 13. Activity overlap of the red fox (*Vulpes vulpes*, black line) and domestic dog (*Canis lupus familiaris*, grey line), shaded area represents the overlap. Sydney, NSW, Australia

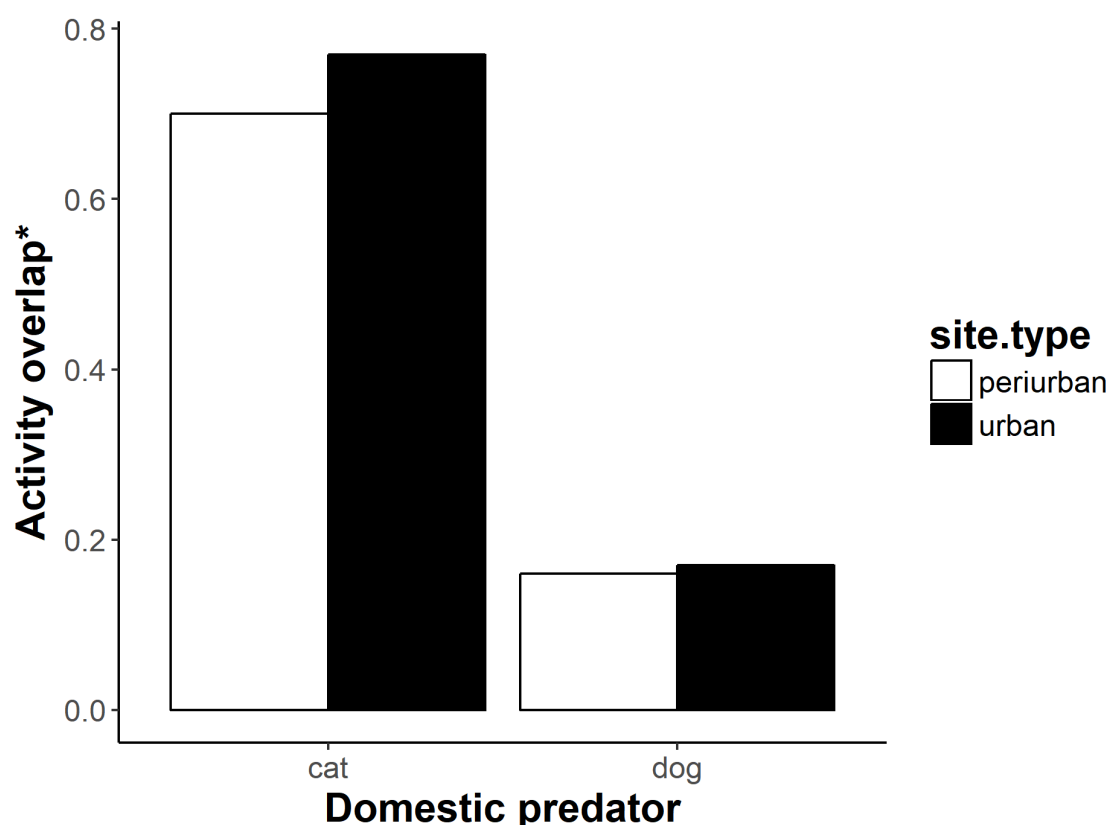


Fig. 14. Temporal activity overlaps between foxes (*Vulpes vulpes*) and domestic predators compared by urban and peri-urban areas of Sydney, NSW, Australia. *Due to the number of records, the estimate used for cats is Dhat1, while for dogs is Dhat4

Dog restrictions at sites did not have a significant effect on fox visitation ($p = 0.88$). In the univariate model (i.e. with only restrictions as explanatory variable), stations at sites with dog restrictions had 24% of probability of visit by foxes (95% CI = 3% - 71%), whereas without dog restrictions this probability was 22% (95% CI = 10% - 40%).

Discussion

In this study, foxes were somewhat more nocturnal and significantly more confident in urban than in peri-urban areas. Foxes were also more confident when protected by dense vegetation cover, with this effect being stronger in urban than peri-urban areas. These findings suggest that this highly generalist species alters its activity levels and behaviour in response to habitat heterogeneity in cities (Trehwella and Harris 1988). Interestingly, foxes did not appear to respond to domestic dogs as a threat – showing more confident behaviour in sites without dog restrictions, where dog activity is much higher. However, urban dog activity is almost exclusively diurnal, whereas fox activity is mostly nocturnal. Foxes also spent longer around ejectors on brightly moonlit nights. Together, these results suggest that the biology and ecology of foxes can differ substantially between urban

and rural populations, as has been shown for other species of wildlife (Ditchkoff et al. 2006; Magle et al. 2016).

We found that fox visitation was higher at stations with high vegetation cover, which was slightly more noticeable in urban sites. Studies from Europe have shown that when foxes are active, they may move in areas with or without vegetation cover, but they show a clear preference for dense vegetation for denning and resting (Janko et al. 2012; Drygala and Zoller 2013). However, foxes can have individual preferences for different habitats, especially at night (Towerton et al. 2016). Humans (and potentially domestic dogs) are likely a fox's greatest threat in urban areas. Thus, it makes sense that in more densely populated areas (urban versus peri-urban areas), foxes should value cover particularly highly, as found here. Understanding these differences in biology and behaviour among urban and peri-urban populations can help to control and manage our study species more adequately in urban areas (Bateman and Fleming 2012).

In our study, the moon phases with the highest visitation rates were the first and last quarters, although this difference was not significant. A decrease in activity during new and full moons has been reported for another canid species, the Mexican wolf (*Canis lupus baileyi*) (Sánchez-Ferrer et al. 2016). However, we also recorded that foxes spent significantly more time on each independent visit to the ejector area during full moon nights. It has been reported that foxes and other canids tend to be more active on the darkest nights, especially where there is a risk of intraguild predation (Penteriani et al. 2013; Welch et al. 2017).

Therefore, foxes may have little interaction with, or fear of, domestic dogs in cities. This could be because domestic dogs in cities are generally kept in yards or indoors at night and are only out during the day (as evidenced through our activity overlap analyses). Therefore, foxes may have little to fear from domestic dogs in cities. In contrast, foxes are generally wary of wild dogs and dingoes in more rural or natural bush settings (Newsome et al. 2017), and the difference may be that these dogs are free-ranging and active at night.

Predators can also be more active on the brightest hours of the night and during a full moon, because they search intensively for prey, which are generally less active on bright nights. Foxes may even benefit from the high visibility in locating scarce prey on bright nights (Penteriani et al. 2011). We could relate the more exploratory behaviour of the foxes with the brightest nights of full moon because they have better vision and are able to distinguish the novel object and feel more confident while exploring.

Urban foxes in our study were more likely to display confident behaviours than their peri-urban counterparts. This has also been reported for hyenas, where juvenile spotted hyenas (*Crocuta crocuta*) living in low-disturbance areas were significantly more neophobic and less exploratory than individuals living in high-disturbance areas (Greenberg and Holekamp 2017). The novel object presented in this study, the ejector, is designed to be attractive to foxes, which makes it a non-neutral object and influences positively the way the animal interacts with it (Greggor et al. 2015), increasing the probability of confident behaviour.

We found that the display of confident behaviour towards a novel object (the ejector) was more likely in places with high cover. In previous studies, higher bait uptake has been reported for sites with more vegetation in comparison to open paddocks (Carter and Luck 2013). Moreover, in urban sites bold behaviour (here: confident behaviour), potentially facilitates adaptation to new environments and the exploitation of novel resources (Bateman and Fleming 2012; Plumer et al. 2014). It appears that Sydney's urban foxes are more confident than peri-urban foxes. This may be due to plasticity or rapid adaptation to urban environments and novel objects. Our findings about the more confident behaviour of foxes around the ejector in urban areas and under high vegetation cover in Australia could potentially be used to improve success rates for control programs, for example by targeting such areas for the placement of baits or ejectors.

We found a small difference in the temporal activity between foxes in peri-urban areas and foxes in urban areas. Foxes in urban areas were more active during the night, whereas foxes in peri-urban areas were relatively more active after sunrise and showed some activity up until about midday. The variation in temporal activity is most likely related to human activity in urban areas, which is mostly concentrated in daylight hours and forces some urban species to switch their activity to crepuscular periods, or in some cases to become strictly nocturnal (Ditchkoff et al. 2006). This tendency towards nocturnality has been previously reported for foxes, but on the other hand, in rural areas, foxes can be active during the day where encountering people is unlikely (Plumer et al. 2014). Nocturnality in urban areas has been reported for species such as hedgehogs (*Erinaceus europaeus*), coyotes (*Canis latrans*), dingoes (*Canis lupus dingo*) and bobcats (*Lynx rufus*) (Grinder and Krausman 2001; George and Crooks 2006; Dowding et al. 2010; McNeill et al. 2016), and may explain the slight shift towards nocturnality in urban foxes that we observe here.

Overall, overlaps that we observed between foxes and potential prey had a markedly higher value than those reported in other studies. We found an overlap of 0.90 between foxes and potential mammalian prey, however, other studies have reported as high overlaps of 0.60 between mammalian prey and predators (Foster et al. 2013). For foxes and rabbits, a previously reported

overlap was 0.4 (Díaz-Ruiz et al. 2016), whereas we found an overlap of 0.95 with introduced prey, including rabbits. This points out a high overlap and potential for predatory interactions with introduced mammals in urban and peri-urban areas. Moreover, this could be explained by increasingly nocturnal activity of prey species in urban areas, if they perceive humans as a bigger threat than animal predators (Parsons et al. 2016).

For introduced mammalian prey, we found a higher overlap with foxes in urban areas, whereas for native mammalian prey, the overlap was slightly higher in peri-urban areas. This suggests that native mammalian prey may be more at risk from fox predation in peri-urban areas, but practical differences are likely to be small. Being generalists, foxes prey on a wide variety of native and introduced Australian species (Glen et al. 2011; Davis et al. 2015). As expected, we also found a higher potential for predatory interactions between foxes and their mammal prey than for bird prey, which are largely diurnal (Figures 9 and 10). Similar findings have been reported in fox diet studies (Goszczynski 1974; Goldyn et al. 2003).

The sympatry of a potential prey species and a predator does not ensure that the predator is playing a role as a controller. For example, city rats can persist in high densities, just by altering their movements, even in the presence of domestic cats (Parsons et al. 2018). Furthermore, shifts in food web dynamics are likely to be common in urban ecosystems (Faeth et al. 2005). Urbanization can alter trophic dynamics by reducing top-down control through multiple mechanisms and by increasing bottom-up forcing through the greater availability of anthropogenic food (Fischer et al. 2012). In urban areas, anthropogenic resources, when available, have been reported to be the main component of the diet of foxes (Contesse et al. 2004; Panek and Budny 2017). If foxes are largely satiated by anthropogenic food resources, it may reduce the role of the fox as a pest controller as well as a threat to native species.

We recorded a high activity overlap between cats and foxes, while the overlap was much lower for domestic dogs. The main drivers of interactions between domestic and wild predators in natural areas are the antagonistic interactions and differences in foraging ecology (Krauze-Gryz et al. 2012). Thus, the higher overlap with cats is likely simply due to their nocturnal activity patterns, as cats are more likely to be allowed to roam at night in cities than are domestic dogs. Dogs in cities are generally kept in yards or indoors at night, and their diurnal activity is related to that of humans – e.g. through dog-walking. In our records, some of the dogs were clearly accompanied by humans, but most of them were not. However, we cannot discard the presence of the owners given that most of the individuals presented collars as signs of being domestic dogs. Given that foxes avoid human activity, they are also avoiding dog activity (George and Crooks 2006). Regarding the spatial

overlap (measured by the presence or absence of dogs and the response of foxes), the visitation by foxes did not differ between sites with or without dog restrictions. Which means that, more than a spatial avoidance, we have a temporal avoidance of dogs, which has also been reported for other carnivores in the United States of America (Parsons et al. 2016)

To summarize, our results suggest that foxes in urban areas are more confident toward novel objects, which is likely related to the range of novel habitats and anthropogenic resources to which foxes are exposed in cities. The higher nocturnal activity of foxes in urban areas could be due to an avoidance of human activity, which is mainly diurnal. The interactions with potential prey varied from urban to peri-urban sites, with the slightly higher overlap in urban sites with invasive mammalian prey suggesting a potential for more interactions, however, practical differences are likely to be small. Human activity is also closely tied to dog activity, which foxes in turn also avoid.

Foxes and their prey show modified activity and behaviour in cities. For foxes, they also shape their behaviour by becoming bolder, which may enable them to profit from anthropogenic resources. This shows how flexible our study species can be, learning times or places to avoid and resources to exploit, in order to thrive within the growing cities. The flexibility of foxes is clearly leading to burgeoning populations, which does not bode well for urban native wildlife.

Conclusions

Foxes in urban areas were significantly more confident around a novel object than individuals from peri-urban areas, which was reflected in both displays of confident behaviour and time spent around the novel object. These results are evidence of the plasticity of foxes with highly contextual behaviour across different areas, even within the same city. Given these differences in activity and behaviour, the use of ejectors in cities, particularly in covered areas on moonlit nights, might be more effective than in peri-urban areas. The confident behaviour of foxes under high vegetation cover shows how even in cities, foxes benefit from the presence of vegetation remnants as safe havens. However, confident behaviours may also be due to the current lack of consistent and effective control efforts using ejectors or other types of baiting in cities – such behaviours may decrease once ejectors were used regularly due to the selection against more confident animals. Given that ejectors protect the lethal dose of toxicant in a plastic capsule, and eject that dose directly into the throat of the animal, the kill rate is high and an animal pulling an ejector is unlikely to get the opportunity to learn to avoid them. However, if animals witnessed conspecific deaths, they may also learn indirectly to be wary of ejectors.

Although the temporal activity difference was small, foxes appeared to be more nocturnal in urban areas, and this may be related to human activities. This, in turn, can modify the way that foxes interact with other species. We found very high overlap with mammals, whether introduced or native, suggesting the potential for high levels of interaction between foxes and other nocturnal mammals. More importantly, we found a stronger activity overlap between foxes and introduced mammals in the cities. This is consistent with previous findings and it is worthy to evaluate more carefully the impacts of foxes in the city. For this we should further investigate fox predation in cities, in order to evaluate the impacts on native *versus* exotic prey, and likely flow-on effects to lower trophic levels, if fox numbers were to be significantly reduced in urban areas.

CHAPTER 2: The canid pest ejector challenge: controlling urban foxes while keeping domestic dogs safe

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Abstract. It is widely recognized that foxes (*Vulpes vulpes*) are more abundant within urban areas, however, it is difficult to apply the current control of lethal measures in cities, due to concerns about domestic dog safety. We tested canid pest ejectors as a potential method of fox control for cities by measuring visitation and pulling-up behaviour of foxes and other wildlife and assessing risks to domestic dogs. We compared eight urban and eight peri-urban sites in Sydney, with half of the sites having domestic dog restrictions. We allocated five camera traps and ejectors per site. Through Generalized Linear Mixed Models, we compared the probability of a potential ejector activation between foxes and dogs. We also assessed the relationship between dog visitation and distance to habitation and dog restrictions as measures of dog safety. Both species of canid were equally likely to pull the ejector ($p = 0.26$). As expected, dog visitation was significantly lower in sites with dog restrictions ($p < 0.001$). However, it was not related to distance from habitation. Only two non-canid species were recorded pulling the ejector, suggesting high target-specificity for canids. In sites with dog restrictions the risk of dog casualties is minimal. However, distance from habitation does not increase dog safety, at least within 250 m. We conclude by providing specific recommendations for the design of a potential fox control program using ejectors in urban and peri-urban areas.

Keywords: pest control, invasive predator, urban carnivore.

Introduction

Red foxes (*Vulpes vulpes*) were introduced to Australia in the late 1860s. This species was first recorded in Sydney between 1907-1910, and had colonized the entire state by 1915 (Short 1998; Abbott et al. 2014). Foxes were declared a pest species within a few years of its establishment in Australia, and was declared as a noxious animal in New South Wales in 1893 (Saunders et al. 2010). The high density of foxes is strongly related to a local decrease in local native fauna populations (Saunders et al. 2010). Foxes have been implicated in the decline and extinction of a vast array of Australian native fauna, with a failure to recognize fox predatory cues often blamed (Glen and Dickman 2005; Abbott et al. 2014). Given the extent of their impact on biodiversity, predation by the red fox is listed as a key threatening process under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

At the national level, the annual impacts of foxes on Australian agricultural production were conservatively estimated to be \$21.15 million, which includes both production losses and the costs of control. The most affected industry is wool production, with \$16.42 million in losses (Gong et al. 2009). The economic losses for 2013-14 in New South Wales were of \$11.7 million dollars, only considering production loss, and excluding pest management costs of private and public landholders (NSW Natural Resources Commission 2016). Regarding the Government investment, the Office of Environment and Heritage (including National Parks and Wildlife Services) spends around \$5.1 million on the management of foxes, which represents 34% of the pest management budget (NSW Natural Resources Commission 2016).

The opportunistic and flexible foraging behaviour of the fox is one of the features that make it so successful in Australia. Fox diet was recently widely reviewed for the state of Victoria, Australia (Davis et al. 2015). In this study 62 mammal species (48 native species and 14 introduced species), five bird species and two reptile families were recorded as diet items for the red fox. Furthermore, foxes have been recorded to consume arthropods and carrion more frequently than other predators in New South Wales (Glen et al. 2011). Wild regional and seasonal variations on the diet have also been recorded (Davis et al. 2015).

The diet of foxes in urban areas can rely mainly on anthropogenic food sources, and this trend is stronger in the center of cities than in peri-urban areas (Contesse et al. 2004). Anthropogenic sources of food include rubbish, compost, cultivated fruit and crops, domestic pets and their food (Harris 1981; Doncaster *et al.* 1990; Contesse *et al.* 2004). These food resources allows foxes to

achieve greater population densities in urban than in rural areas (Bateman and Fleming 2012). For example, fox densities range from 0.025 foxes/km² in rural Scotland, compared to as high as 37 foxes/km² in some Scottish urban areas (Harris and Smith 1987; Bino *et al.* 2010; Šálek *et al.* 2015, Hoffmann and Sillero-Zubiri 2016). Similarly, in rural Australia, densities in non-urban areas range from 0.46 adult foxes/km² in rangelands of Western Australia (Marlow *et al.* 2000), to a maximum summer density of 3 foxes/km² in rural areas of Victoria (Coman *et al.* 1991). In rural areas of New South Wales, there are estimates of 4.55 foxes/km² (Thompson and Fleming 1994). By contrast in urban areas of Australia, recorded densities range from 3 to 16 foxes/km², in Melbourne, Australia (Marks and Bloomfield 1999).

Red fox control

Despite evidence that the red fox is more abundant in urban areas (Bateman and Fleming 2012), most control efforts have focused on agricultural and conservation lands (Gentle *et al.* 2007). In these areas, a wide variety methods such as lethal baiting, shooting, trapping, den fumigation, den destruction and exclusion fencing have been used (Saunders *et al.* 2010). However, only cage trapping, den fumigation and shooting are considered safe in urban areas, due to the potential risk of lethally baiting activities on humans and/or domestic animals, which includes domestic dogs.

In rural areas and national parks of Australia lethal baiting is the most common fox control technique, it accounts for 74% of control effort, and it may well be the most effective method when coordinated properly (West and Saunders 2003; Newsome *et al.* 2014). One potential method to improve the safety of lethal baiting is the canid pest ejector or M-44 ejector (ejector), which is a baited, spring-activated device that propels the content of a poison capsule into a predator's mouth (Connolly and Simmons 1984) (Figure 15). The use of ejectors with the 1080 toxin capsules was recently approved for the control of wild dogs and foxes in Australia (Kreplings *et al.* 2018). If effective, the ejector could permit carefully managed fox control in areas where the movement and caching of poison baits would otherwise endanger neighboring native and domestic animals (Van Polanen Petel *et al.* 2004).

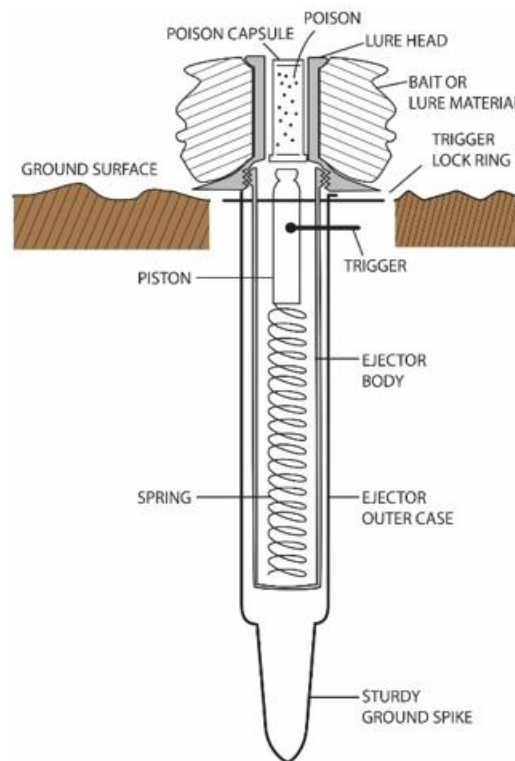


Fig. 15. Schematic of the canid pest ejector. Spring activated device used to specifically target members of the Canidae family. The bait head must be pulled up with enough strength so that the trigger hits the poison capsule and it releases the content inside the mouth of the canid. Source: Smith and George, 2016

Restrictions of the PCO and dog safety

Currently, lethal baiting is not allowed in urban areas of New South Wales by decree of Pesticide Control (1080 Bait Products) Order 2017 (PCO from now on), due to potential risks to domestic dogs. As a result, foxes are not well controlled in cities and further research is required to develop effective and safe urban control techniques (Kirkwood et al. 2014). The delivery of toxicants via a mechanical ejector could reduce non-target casualties (Mallick et al. 2016), however, in the case of the ejector, there is an intrinsic risk of non-target uptake for any other member of the Canidae family, which includes domestic dogs (*Canis lupus familiaris*).

Very few studies have assessed the probability of activation of the ejector by domestic dogs. Moreover, ejector activation by dogs can be very context-specific and highly related to human activity. Under the common frameworks of lethal baiting, bait uptake by domestic dogs is not a common issue. For example, Matheny (1976) reported only one ejector activation by domestic dogs, compared to 604 activations by foxes, and 3443 activations by coyotes in a period of 13 months of baiting in Texas, USA. An adequate selection of the baiting site and adequately trained

deployers could have an important impact on the effectiveness of fox control and also, on the safety of the non-target species (Matheny 1976; Carter and Luck 2013).

The Pesticide ACT 1999 (Schedule 2) specifies that 1080 capsules for fox control must not be laid within 150 m of a habitation (i.e. accommodation occupied by people), this would include the ejectors, which contain a capsule of poison that currently could only be 1080. There can be exceptions to this distance restriction, such as when the landholder uses the capsules on their own property or where an Authorised Control Officer plans a baiting program (Pesticide Control Order 2017).

Non-canid activations of the ejector

In Texas, USA, 12% non-target activation of an earlier model of the ejector was reported, where the main species activating were skunks and opossums (Matheny 1976). In Australia, only red foxes, wild dogs and feral cats have been recovered dead from field trials of ejectors, indicating a high level of target specificity (Busana et al. 1998; Marks et al. 2003). This specificity is due to the strength needed to pull up the bait-head and release the poisonous content. In a field trial, the estimated trigger force of an ejector was 26.46 N, which only allowed foxes weighing >3 kg to trigger the device, and it eliminates exposure for a wide range of native carnivores and omnivores (Marks and Wilson 2005). The ejector induces a bite-and-pull response specifically from canids (Shivik et al. 2014). Even though bigger Australian carnivores such as the spotted-tailed quoll (*Dasyurus maculatus*) and the Tasmanian devil (*Sarcophilus harrisii*) may have enough strength to activate it, modifications to increase the specificity base on the head morphology have already been suggested (Nicholson and Gigliotti 2005).

The ejector preserves the toxicity of the lethal compound in a capsule protecting it from rainfall and other weather conditions. By ensuring the ingestion of a lethal dose, the development of learned aversion to baits or pesticide resistance can be avoided (Gentle et al. 2007; Allsop et al. 2017). Studies of the efficacy of the ejector have been carried out in natural reserves, on islands, rural and peri-urban areas (Marks et al. 2003; Van Polanen Petel et al. 2004; Marks and Wilson 2005; Moseby and Read 2014; Gentle et al. 2017), however, no studies have been undertaken in urban areas.

The goals of this research were to determine whether ejectors might be safely used in urban areas to control foxes, whilst minimising risks to domestic dogs and other species. We focused on three main aspects: A) comparison of the ejector-pulling behaviour between canids, B) domestic dog

visitation to ejectors in relation to site type (urban/peri-urban), dog restrictions (presence/absence), and distance from human habitations, C) distance restrictions from the current PCO. We evaluated the effectiveness of this restriction by comparing dog visitation rates within and above 150m distance.

We had the following hypotheses:

1. *Ejector-pulling behaviour in canids*. Based on previous finding, we expected that the ejector would be more frequently activated by foxes than any other species, including domestic dogs.
2. *Domestic dog visitation rate*. We expected a higher dog visitation rate in sites without dog restrictions. We hoped to find zero visitation by dogs in sites with dog restrictions.
3. *Baiting distance restrictions of the PCO and dog safety*. Given that 150 m is not a biologically significant distance, we expected no difference in dog visitation rates to ejectors within and beyond the 150 m distance boundary.
4. *Non-canid species visitation rate*. As ejector use specifically aims to minimise risk to non-canid species, we expect to find significantly lower visitation and ejector activation rates for non-canids.

Methods

We selected 16 sites across the Greater Sydney Region. Sites were classified as urban or peri-urban based on human habitation density (less than 900 houses/km² in a 5 km buffer from the site were considered peri-urban). At each site we installed five sampling stations, at intervals of 50 m from a single human habitation. Each station consisted of one ejector and one camera-trap to monitor it. However, these distances were not always constant and varied depending on the terrain (± 20 m). The ejectors were located strategically to maximize the probability of detecting foxes (i.e. near trails, dens or sandy soil). (Detailed methods in Chapter 1).

Eight of the sites prohibited access to domestic dogs. We confirmed the prohibitions through the landowners or managers of the sites and by the signage indicating “no dogs allowed”. We selected sites with fences, which would ensure the absence of dogs within the site. However, one of our sites, Kogarah Golf Club, was not completely fenced. Additionally, in Warwick Farm Racecourse, we were later informed of the presence of three resident dogs inside the fences. Nevertheless, there were no external dogs allowed. We considered the visits of the dogs in the statistical analyses, even when, in a baiting scenario, these dogs could be easily managed to avoid incidental poisoning.

Ejector-pulling behaviour in canids

Pictures from the camera traps were tagged with the software DigiKam and processed with the CamtrapR package from R (Niedballa *et al.* 2017). As we had ten consecutive images per trigger, we were able to observe the behaviour of the canids in the ejector area. We compared the independent visits (defined as visits >24 hours apart) when canids (dogs and foxes) pulled up the ejector vs the times when they did not in a binomial generalized mixed linear model, with site as random factor. Only for this analysis, we excluded the stations with dog restrictions, to make an even contrast between species. Data and analyses on visitation by foxes is given in chapter 1.

Baiting distance restrictions of the PCO and dog safety

Data on dog visitation to the ejector were analysed by a Generalized Linear Mixed model fit by maximum likelihood, with Laplace Approximation in the package lme4 (Bates *et al.* 2015). We used the binomial family with the logit link function. The response variable was the count of presence *versus* absence of dogs in intervals of 24 h, i.e. the total number of nights when dogs were recorded (success), and the nights where there was no record of dogs (failure). We used distance from habitation, site type (urban/peri-urban), and dog restrictions as explanatory variables. The distance was used as categorical variable, where distances below 150 m were considered not allowed given what is stated in the PCO. The cameras placed at 150 m or more, were considered under the category of allowed distance. We used station and site as random factors to explain the visitation of the domestic dogs to the ejector area. All the possible combinations were analysed and compared with the MuMIn package from R (Barton, 2018). The best models were chosen based on the Akaike Information Criteria for small samples (AICc).

Non-canid species visitation to the ejector area

We recorded the identity of the species that visited the ejector area and their interactions with the ejector. As we had only three records of non-canid species pulling-up the ejector we were not able to calculate an activation rate for these species.

Results

We achieved a sampling effort of 1,659 camera trap nights. However, at some stations the ejector was removed before the end of the sampling period. For all the visitation and behaviour analyses we only considered sampling effort with the ejector present, which was 1,472 camera trap nights across all sites. On average, each sampling station was active for 19.2 camera trap nights (SD = 4.10).

Ejector-pulling behaviour in canids

Across all sites, based on the descriptive statistics for individuals, 28.6% of the domestic dogs we recorded by the cameras pulled up the ejector, whereas, in the case of foxes, 39.1% pulled the ejector (see Table 3 for total number of individuals). Dogs were generally confident around the ejector, with only one recorded display of cautious behaviour. By comparison, more than half of the individual foxes displayed cautious behaviour (Figure 16). On 16 occasions, foxes ran away from the camera, while no dogs displayed camera-shy

behaviour (Figure 16). According to the binomial mixed model, which was based on independent visits rather than individual behaviour, dogs had a slightly higher probability of pulling up the ejector (14%, CI 95% = 6% - 24%) than foxes (9%, CI 95% = 2% - 31%), although this was not significantly different ($p = 0.26$).

Table 3. Number of identified individuals and number of independent pulling-up behaviours displayed by each canid species per site type, Sydney, NSW, Australia.

	Dog restrictions	Fox		Domestic dog	
		Pull up displays	Total of individuals	Pull up displays	Total of individuals
Curl Curl	Absent	1	*5	6	18
Fagan Park		4	21	4	24
Macquarie University		2	4	1	6
Oxford Falls		1	1	0	5
Prince Edward Reserve		3	6	2	10
Razorback		1	*6	3	5
Salt Pan Reserve		1	*3	2	2
Yarrah Reserve		4	6	4	12
EMAI	Present	2	3	0	0
Erskine Corridor		1	3	0	0
Kogarah Golf Club		5	5	1	2
WSU paddock		1	2	0	0
Penrith Landfill Depot		1	4	0	0
Randwick Racecourse		1	7	0	1
The Royal Botanic Gardens		2	2	0	2
Warwick Farm Racecourse		4	9	3	4

*This number corresponds to independent visits separated by 24 h given that no individual foxes were identified in these sites. The data for the other sites does not include the unidentified individuals

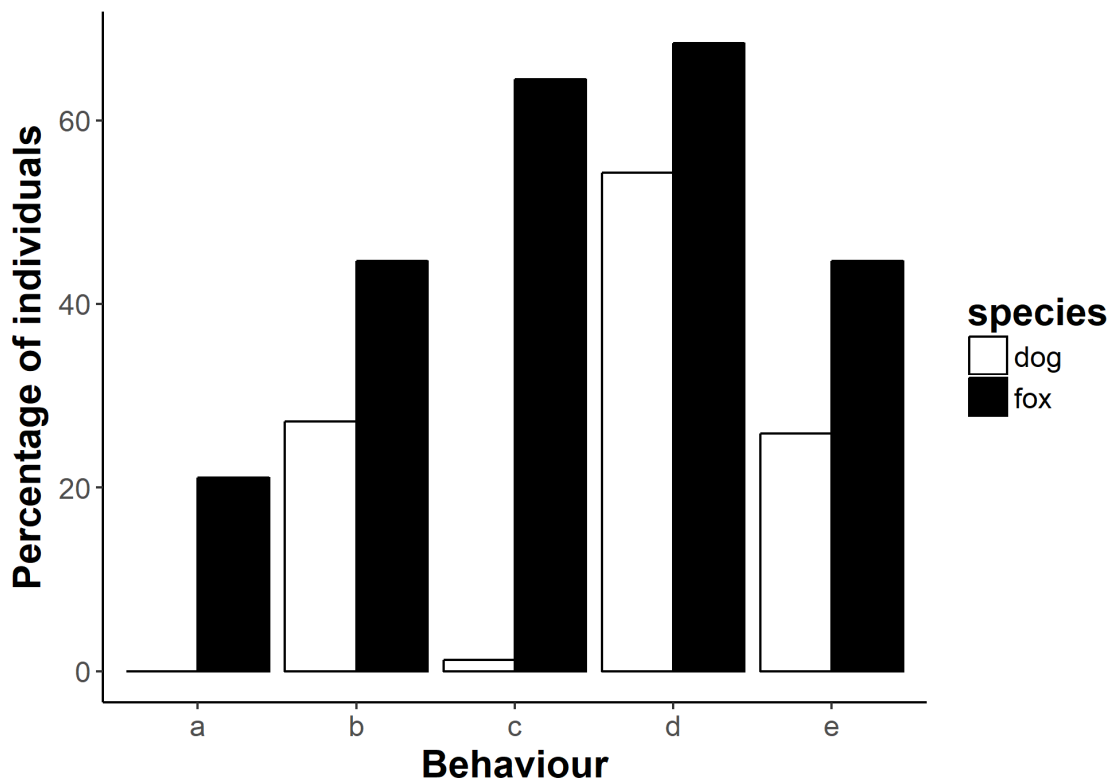


Fig. 16. Percentages of behavioural displays per category of red foxes (*Vulpes vulpes*) and domestic dogs (*Canis lupus familiaris*) around the canid pest ejector in the sampling stations located in Sydney, NSW, Australia. Behaviour categories: a) camera-shy reaction, b) pass by, indifferent response, c) cautious toward the ejector, d) smell the ejector, e) pull up the ejector. *The behaviour categories are explicitly not mutually exclusive; any one individual could display more than one of these behaviours in the same visit. This percentage is related to the total number of identified individuals of domestic dogs (n = 81) and red foxes (n = 76). For a detailed description of the behaviours see Appendix 1

Domestic dog visitation to the ejector area.

Domestic dogs visited 38 out of 80 sampling stations, across 12 sites. We identified 177 independent domestic dog visits (separated by at least 24 hours). The best model (lowest AICc, Table 4) suggested that dog restrictions best explained the visitation rate of dogs at each site.

Table 4. Models to explain domestic dog visitation to the canid pest ejector in Sydney, NSW, Australia. All the models had site and station as random factors

Variables	AICc	df	ΔAICc
Dog presence ~ dog restrictions	246.8	3	0
Dog presence ~ dog restrictions + site type	263.9	4	17
Dog presence ~ distance + dog restrictions	264.5	4	17.6

As expected, very few dogs visited ejectors in sites with dog restrictions ($p < 0.001$, Figure 17). The probability of dog visitation was 12% (CI 95% = 5% - 25%) at ejectors placed in sites without restrictions, whereas, at sites with dog restrictions it decreased to 0.03% (CI 95% = 0.002% – 3%).

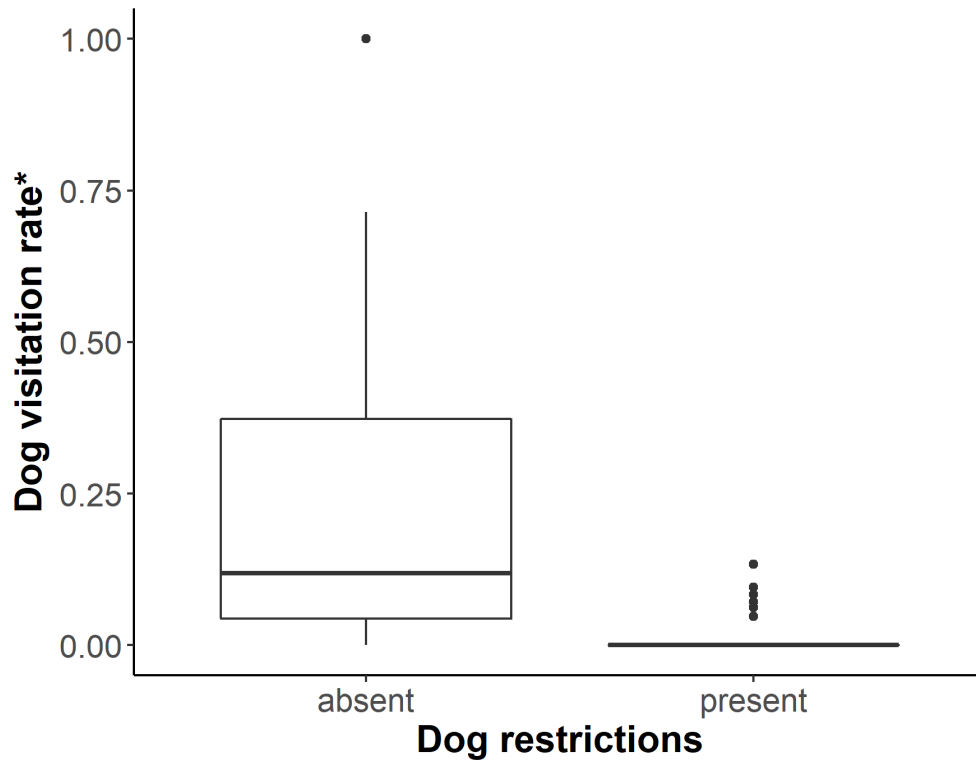


Fig. 17. Boxplot of the visitation rate of domestic dogs (*Canis lupus familiaris*) to canid pest ejectors with regards to the presence of dog restrictions in Sydney, NSW, Australia. *Dog visitation rate is given by the number of nights were dogs were recorded on the total number of sampling nights

The distance from habitation was not included in any of the AICc supported models (Table 3). There was no effect of distance on dog visitation rates to ejectors (Figure 18). The probability of visitation by domestic dogs did not change in relation to the distance from habitation ($p = 0.92$).

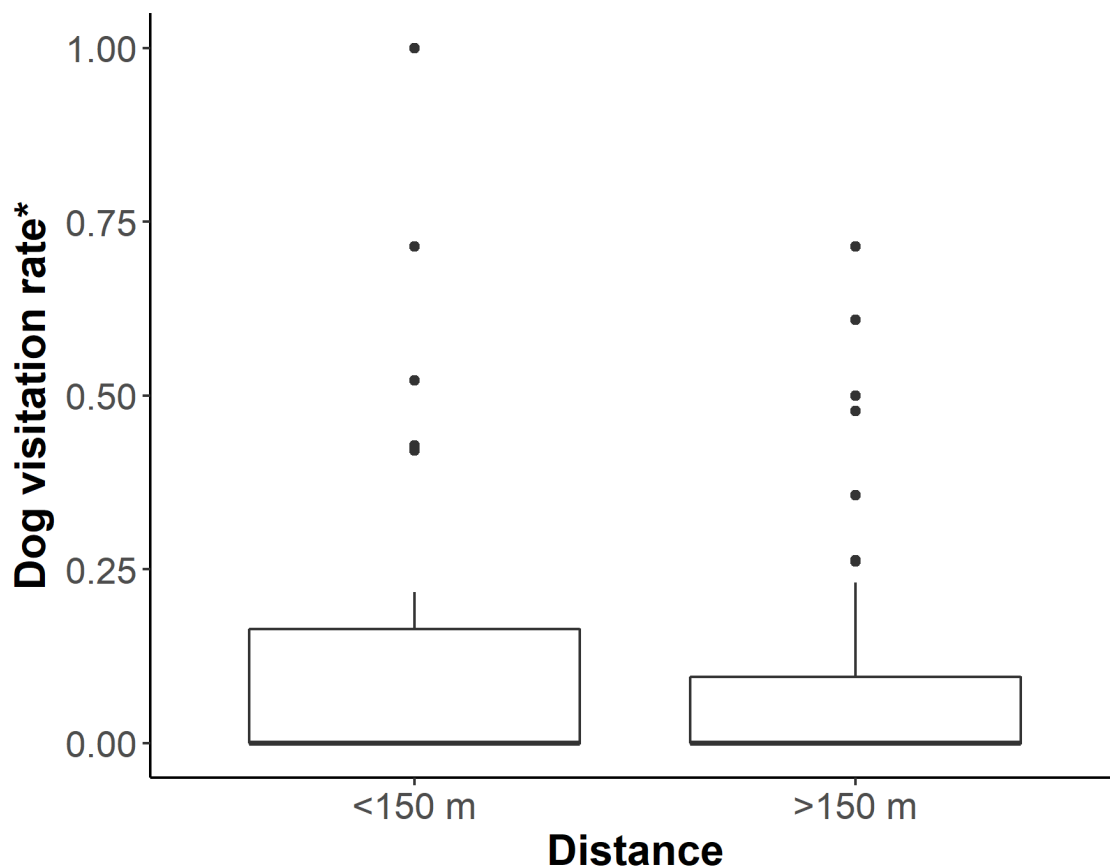


Figure 18. Domestic dog (*Canis lupus familiaris*) visitation rates to canid pest ejectors according to the distance categories (of the sampling station from human habitation) used by NSW Pest Control Order 2017. The >150 m category also includes the stations that were located exactly at 150 m from human habitation. *Dog visitation rate was calculated as the number of nights where dogs were recorded divided by the total number of sampling nights

Non-canid species visitation and ejector-pulling behaviour

As well as dogs and foxes, we detected 51 species of vertebrates; 34 birds, 15 mammals, and two species of reptiles in the ejector area (see Appendix 3 for the full list of species and their interactions with the ejector). From these species, only 18 interacted with the ejector, by biting, eating the bait, marking, or smelling it (Appendix 3). Only two non-canid species were recorded pulling up the ejector, the brush-tail possum (*Trichosurus vulpecula*) and the domestic cat (*Felis catus*), both in only one visit. Only one non-canid species, the raven (*Corvus coronoides*), was recorded removing part of the ejector from the ground, not by pulling up, but by opening the lock ring to take the bait head, which would allow them to remove the entire ejector assembly. Twenty-nine species, including foxes, noticed the camera and stared at it. Of these, only three ran away from the camera; the black rat (*Rattus rattus*), the rabbit (*Oryctolagus cuniculus*), and the fox.

Discussion

Domestic dog safety with ejector use in urban areas remains a major obstacle for fox control in urban areas. In our study, both canids – foxes and domestic dogs – were equally likely to pull up the ejectors in a manner that would activate them. However, only one dog showed any cautious behaviour around the ejector, while more than half of the foxes acted cautiously. This difference in how they approached ejectors confirms concerns for dog safety if ejectors were deployed in urban areas. At the same time, we confirmed that dogs are mostly absent from sites with dog restrictions, with the few observed dog visits at these being these due to resident dogs' presence or incomplete fencing. This finding indicates that effectively restricting dog access to sites and the use of ejectors at such sites would be feasible for future urban control programs, with virtually nil risk for dogs. Additionally, only two non-canid species pulled up the ejector in a manner that would activate it, confirming the low risk of this control tool for non-target species.

Here we recorded 34 different fox individuals pulling the ejector on 1,472 camera trap nights. Previous studies have reported low success rates for ejectors, with only one fox activation out of 24 fox visitations to 18 ejectors set over 2 months in the Eyre Peninsula, South Victoria (Moseby and Read 2014), and no events on 810 camera trap nights in the southern rangelands of Western Australia (Kreplings et al. 2018). The low success rates in earlier work could be explained by the choice of attractants and baits, and/or the settings of the camera trap. We found that the 10 consecutive images taken in rapid fire mode were effective in confirming whether foxes pulled upwards on the ejector.

Our results suggest that the risk of non-target activation could be significantly reduced by targeting fully-fenced sites with dog restrictions. This approach has been previously suggested (Hegglin et al. 2004), although not yet trialed in an urban area, to the best of our knowledge. The current NSW PCO distance prohibition of placing the ejectors within 150 m from human habitation does not appear to bear any relation to domestic dog visitation rates, suggesting that this is not an effective safety measure. Furthermore, the distance restrictions can impede potential efforts of baiting where habitations are too close to each other, which makes especially urgent to revisit them in the current PCO.

Only four species were recorded pulling the ejector: foxes, dogs, brush-tail possum, and domestic cat suggesting high target-specificity of the ejector. Three of these had been previously reported (Busana et al. 1998; Marks et al. 2003), however, there is no previous record of brush-tail possums

pulling up the ejector. It is uncertain if this species has enough strength to release the poison of an activated ejector. We also recorded a raven disassembling the ejector, mirroring previous findings (Kreplings et al. 2018). In our study we observed this behaviour only once, at a single sampling station, whereas in Kreplings et al. (2018), 6 from 10 ejectors suffered corvid interference. This type of interference by rapid-learning birds may affect the efficacy of the ejectors, and more importantly, could reduce the safety of this tool because of the release of the poison capsule from the ground stake. Finally, as elsewhere, in our study both rodents and birds fed on the bait of the ejector without pulling up (Van Polanen Petel et al. 2004).

The devastating impacts of introduced predators on native fauna and agriculture in Australia have led to large-scale control practices. These control practices have at times been questioned both for their effectiveness and due to possible negative effects. The efficacy of lethal control can be limited by multiple unintended consequences, such as release of herbivore and mesopredator populations, disruption of predator social systems, compensatory predator immigration, and ethical concerns (Doherty and Ritchie 2017). For example, in some areas fox control has resulted in the release of feral cat populations from predation pressure, and subsequent increases in cat predation on native prey populations (Risbey et al. 2000; Davey et al. 2006).

Given the current impacts of foxes on native fauna, developing and implementing an effective and humane control methods is urgent (Russell et al. 2016). The impacts of the foxes over the last 130 years in Australia suggest that without mitigating their impact, native fauna will continue to decline and more species will become extinct (Abbott et al. 2014). Twenty-one percent of Australian endemic land mammals are threatened and the main contributing factors are invasive predators – particularly feral cats and foxes – and changing fire regimes (Woinarski et al. 2015).

Although lethal control is widely accepted for certain species and is considered a good management approach, in the case of the red fox, the costs associated with lethal control were AU\$21.3m in Australia between 1998–2003 (Reddiex et al. 2006). Ideally, baiting efforts must be coordinated at a large scale in order to be effective, or at least isolated lethal control programs must involve follow-up campaigns to avoid population recovery (Newsome et al. 2014). This poses an extra challenge to baiting within urban areas, where stakeholder views and the social consequences of management actions can be more diverse than in rural contexts (Gaertner et al. 2016), making the coordination of baiting actions especially difficult.

Conclusions

There are places in cities where the risk of non-target casualties when deploying the canid pest ejector could be close to nil – i.e., sites with effectively enforced dog restrictions, properly fenced and signposted. Moreover, the distance from habitation does not make a difference for dog safety, at least within 250 m that this study evaluated. Finally, the high target-specificity of ejectors, even in urban and peri-urban environments, indicates that they are a suitable baiting control tool for urban areas.

General conclusions for the thesis as a whole

A combination of the results from both chapters could be used to design future control programs in urban areas that are both safe for dogs and effective in targeting foxes. Firstly, we found that foxes were more active during the night, especially in the city, whereas domestic dogs were mainly diurnal. Thus, the ejectors could be activated only by night in sites where dog presence is unpredictable. Furthermore, the effectiveness of the ejectors could be higher in sites with dense vegetation cover and within urban areas, given the more confident behaviour of foxes in these types of sites.

References

- Abbott I, Peacock D, Short J (2014) The new guard: the arrival and impacts of cats and foxes. In: Glen AS, Dickman CR (eds) *Carnivores of Australia: past, present and future*. Collingwood: CSIRO Publishing, pp 69–104
- Allsop SE, Dundas SJ, Adams PJ, et al (2017) Reduced efficacy of baiting programs for invasive species: some mechanisms and management implications. *Pacific Conserv Biol* 23:240–257. doi: 10.1071/PC17006
- Anderson DR, Link W a, Burnham KP (2001) Suggestions for presenting the results of data analyses. *J. Wildl. Manage.* 65:373–378. doi: 10.2307/3803088
- Australian Bureau of Statistics. 2018. Census QuickStats. www.abs.gov.au. Accessed 04 September 2018
- Banks PB, Smith HM (2015) The ecological impacts of commensal species: black rats, *Rattus rattus*, at the urban-bushland interface. *Wildl Res* 42:86–97. doi: 10.1071/WR15048
- Barton K (2018) MuMIn: Multi-model inference. R Package version 1404
- Bateman PW, Fleming PA (2012) Big city life: carnivores in urban environments. *J Zool* 287:1–23. doi: 10.1111/j.1469-7998.2011.00887.x

- Bates D, Mächler M, Bolker BM, Walker SC (2015) Fitting linear mixed-effects models using lme4. *J Stat Softw* 67:1–48. doi: 10.1126/science.1176170
- Bino G, Dolev A, Yosha D, et al (2010) Abrupt spatial and numerical responses of overabundant foxes to a reduction in anthropogenic resources. *J Appl Ecol* 47:1262–1271. doi: 10.1111/j.1365-2664.2010.01882.x
- Bozdogan H (1987) Model selection and Akaike's Information Criterion (AIC): The general theory and its analytical extensions. *Psychometrika* 52:345–370. doi: 10.1007/BF02294361
- Burbidge AA, McKenzie NL (1989) Patterns in the modern decline of Western Australia's vertebrate fauna: causes and conservation implications. *Biol Conserv* 50:143–198. doi: 10.1016/0006-3207(89)90009-8
- Busana F, Gigliotti F, Marks CA (1998) Modified M-44 cyanide ejector for the baiting of red foxes (*Vulpes vulpes*). *Wildl Res* 25:209–215. doi: 10.1071/WR96096
- Carter A, Luck GW (2013) Fox baiting in agricultural landscapes: preliminary findings on the importance of bait-site selection. *Wildl Res* 40:184–195. doi: 10.1071/WR12169
- Carthey AJR, Banks PB (2014) Naïveté in novel ecological interactions: lessons from theory and experimental evidence. *Biol Rev* 89:932–949. doi: 10.1111/brev.12087
- Coman BJ, Robinson J, Beaumont C (1991) Home range, dispersal and density of red foxes (*Vulpes vulpes* L.) in central Victoria. *Wildl Res* 18:215–223. doi: 10.1071/WR9910215
- Connolly G, Simmons GD (1984) Performance of sodium cyanide ejectors. *Proc Elev Vertebr Pest Control Conf* 114–121
- Contesse P, Hegglin D, Gloor S, et al (2004) The diet of urban foxes (*Vulpes vulpes*) and the availability of anthropogenic food in the city of Zurich, Switzerland. *Mamm Biol - Zeitschrift für Säugetierkd* 69:81–95. doi: 10.1078/1616-5047-00123
- Davey C, Sinclair ARE, Pech RP, et al (2006) Do exotic vertebrates structure the biota of Australia? An experimental test in New South Wales. *Ecosystems* 9:992–1008. doi: 10.1007/s10021-004-0173-0
- Davis NE, Forsyth DM, Triggs B, et al (2015) Interspecific and geographic variation in the diets of sympatric carnivores: dingoes/wild dogs and red foxes in south-eastern Australia. *PLoS One* 10:1–28. doi: 10.1371/journal.pone.0120975
- Díaz-Ruiz F, Caro J, Delibes-Mateos M, et al (2016) Drivers of red fox (*Vulpes vulpes*) daily activity: prey availability, human disturbance or habitat structure? *J Zool* 298:128–138. doi: 10.1111/jzo.12294
- Ditchkoff SS, Saalfeld ST, Gibson CJ (2006) Animal behavior in urban ecosystems: modifications due to human-induced stress. *Urban Ecosyst* 9:5–12. doi: 10.1007/s11252-006-3262-3
- Doherty TS, Dickman CR, Glen AS, et al (2017) The global impacts of domestic dogs on threatened vertebrates. *Biol Conserv* 210:56–59. doi: 10.1016/j.biocon.2017.04.007
- Doherty TS, Glen AS, Nimmo DG, et al (2016) Invasive predators and global biodiversity loss. *Proc Natl Acad Sci* 113:11261–11265. doi: 10.1073/pnas.1602480113

- Doherty TS, Ritchie EG (2017) Stop jumping the gun: a call for evidence-based invasive predator management. *Conserv Lett* 10:15–22. doi: 10.1111/conl.12251
- Dowding C V, Harris S, Poulton S, Baker PJ (2010) Nocturnal ranging behaviour of urban hedgehogs, *Erinaceus europaeus*, in relation to risk and reward. *Anim Behav* 80:13–21. doi: 10.1016/j.anbehav.2010.04.007
- Drygala F, Zoller H (2013) Spatial use and interaction of the invasive raccoon dog and the native red fox in Central Europe: competition or coexistence? *Eur J Wildl Res* 59:683–691. doi: 10.1007/s10344-013-0722-y
- Faeth SH, Marussich WA, Shochat E, Warren PS (2005) Trophic dynamics in urban communities. *Bioscience* 55:399. doi: 10.1641/0006-3568(2005)055[0399:TDIUC]2.0.CO;2
- Fischer JD, Cleeton SH, Lyons TP, Miller JR (2012) Urbanization and the predation paradox: the role of trophic dynamics in structuring vertebrate communities. *Bioscience* 62:809–818. doi: 10.1525/bio.2012.62.9.6
- Fischer JD, Schneider SC, Ahlers AA, Miller JR (2015) Categorizing wildlife responses to urbanization and conservation implications of terminology. *Conserv Biol* 29:1246–1248. doi: 10.1111/cobi.12451
- Foster VC, Sarmiento P, Sollman R, et al (2013) Jaguar and puma activity patterns and predator-prey interactions in four Brazilian biomes. *Biotropica* 0:1–7. doi: 10.1111/btp.12021
- Gaertner M, Larson BMH, Irlich UM, et al (2016) Managing invasive species in cities: a framework from Cape Town, South Africa? *Landsc Urban Plan* 151:1–9. doi: 10.1016/j.landurbplan.2016.03.010
- Gentle M, Allen BL, Speed J (2017) Peri-urban wild dogs in north-eastern Australia: ecology, impacts and management. Canberra, Australia
- Gentle MN, Saunders GR, Dickman CR (2007) Persistence of sodium monofluoroacetate (1080) in fox baits and implications for fox management in south-eastern Australia. *Wildl Res* 34:325–333. doi: 10.1071/WR06163
- George SL, Crooks KR (2006) Recreation and large mammal activity in an urban nature reserve. *Biol Conserv* 133:107–117. doi: 10.1016/j.biocon.2006.05.024
- Glen AS, Dickman CR (2005) Complex interactions among mammalian carnivores in Australia, and their implications for wildlife management. *Biol Rev Camb Philos Soc* 80:387–401. doi: 10.1017/s1464793105006718
- Glen AS, Pennay M, Dickman CR, et al (2011) Diets of sympatric native and introduced carnivores in the Barrington Tops, eastern Australia. *Austral Ecol* 36:290–296. doi: 10.1111/j.1442-9993.2010.02149.x
- Goldyn B, Hromada M, Surmacki A, Tryjanowski P (2003) Habitat use and diet of the red fox *Vulpes vulpes* in an agricultural landscape in Poland. *Z Jagdwiss* 49:191–200. doi: 10.1007/BF02189737
- Gong W, Sinden J, Braysher M, Jones R (2009) The economic impacts of vertebrate pests in Australia

- Gortázar C, Travaini A, Delibes M (2000) Habitat-related microgeography body size variation in two Mediterranean populations of red fox (*Vulpes vulpes*). *J Zool* 250:335–338. doi: 10.1111/j.1469-7998.2000.tb00778.x
- Goszczynski J (1974) Studies on the food of foxes. *Acta Theriol* 19:1–18. doi: 10.1019/B1002_2613_Cz-40-2_Acta-T19-nr1-1-18_o.pdf
- Greenberg JR, Holekamp KE (2017) Human disturbance affects personality development in a wild carnivore. *Anim Behav* 132:303–312. doi: 10.1016/j.anbehav.2017.08.023
- Greenberg R, Mettke-Hofmann C (2001) Ecological aspects of neophobia and neophilia in birds. In: Nolan Jr V, Thompson C (eds) *Current Ornithology*. pp 119–178
- Greggor AL, Clayton NS, Fulford AJC, Thornton A (2016) Street smart: faster approach towards litter in urban areas by highly neophobic corvids and less fearful birds. *Anim Behav* 117:123–133. doi: 10.1016/j.anbehav.2016.03.029
- Greggor AL, Thornton A, Clayton NS (2015) Neophobia is not only avoidance: improving neophobia tests by combining cognition and ecology. *Curr Opin Behav Sci* 6:82–89. doi: 10.1016/j.cobeha.2015.10.007
- Grinder MI, Krausman PR (2001) Home range, habitat use, and nocturnal activity of coyotes in an urban environment. *J Wildl Manage* 65:887–898. doi: 10.2307/3803038
- Harris S (1981) An estimation of the number of foxes (*Vulpes vulpes*) in the city of Bristol, and some possible factors affecting their distribution. *J Appl Ecol* 18:455–465. doi: 10.2307/2402406
- Harris S, Smith GC (1987) Demography of two urban fox (*Vulpes vulpes*) populations. *J Appl Ecol* 24:75–86. doi: 10.2307/2403788
- Harrison SWR, Cypher BL, Bremner-Harrison S, van Job CLH (2011) Resource use overlap between urban carnivores: implications for endangered San Joaquin kit foxes (*Vulpes macrotis mutica*). *Urban Ecosyst* 14:303–311. doi: 10.1007/s11252-011-0155-x
- Heffernan DJ, Andelt WF, Shivik JA (2007) Coyote investigative behavior following removal of novel stimuli. *J Wildl Manage* 71:587–593. doi: 10.2193/2005-505
- Hegglin D, Bontadina F, Gloor S, et al (2004) Baiting red foxes in an urban area: a camera trap study. *J Wildl Manage* 68:1010–1017. doi: 10.2193/0022-541X(2004)068[1010:BRFIAU]2.0.CO;2
- Hoffmann M, Sillero-Zubiri C (2016) *Vulpes vulpes*. In: IUCN Red List Threat. Species 2016 e.T23062A46190249. <http://dx.doi.org/10.2305/IUCN.UK.2016-1.RLTS.T23062A46190249.en>. Accessed 10 Sep 2018
- Hulme-Beaman A, Dobney K, Cucchi T, Searle JB (2016) An ecological and evolutionary framework for commensalism in anthropogenic environments. *Trends Ecol Evol* 31:633–645. doi: 10.1016/j.tree.2016.05.001
- Ives CD, Lentini PE, Threlfall CG, et al (2016) Cities are hotspots for threatened species. *Glob Ecol Biogeogr* 25:117–126. doi: 10.1111/geb.12404

- Janko C, Schröder W, Linke S, König A (2012) Space use and resting site selection of red foxes (*Vulpes vulpes*) living near villages and small towns in Southern Germany. *Acta Theriol (Warsz)* 57:245–250. doi: 10.1007/s13364-012-0074-0
- Johnson M, Munshi-South J (2017) Evolution of life in urban environments. *Science* 358: eaam8327. doi: 10.1126/science.aam8327
- Jokimäki J, Huhta E (2000) Artificial nest predation and abundance of birds along an urban gradient. *Condor* 102:838–847. doi: 10.1650/0010-5422(2000)102[0838:ANPAO]2.0.CO;2
- Kirkwood R, Sutherland D, Murphy S, Dann P (2014) Lessons from long-term predator control: a case study with the red fox. *Wildl Res* 41:222–232. doi: 10.1071/WR13196
- Krauze-Gryz D, Gryz JB, Goszczynski J, et al (2012) The good, the bad, and the ugly: space use and intraguild interactions among three opportunistic predators - cat (*Felis catus*), dog (*Canis lupus familiaris*), and red fox (*Vulpes vulpes*) - under human pressure. *Can J Zool* 90:1402–1413. doi: 10.1139/cjz-2012-0072
- Kreplings TL, Kennedy MS, Dundas SJ, et al (2018) Corvid interference with Canid Pest Ejectors in the southern rangelands of Western Australia. *Ecol Manag Restor* 0:1–4. doi: 10.1136/emj.2007.046078
- Kruskal WH, Wallis WA (1952) Use of ranks in one-criterion variance analysis. *J Am Stat Assoc* 47:583–621. doi: 10.1080/01621459.1952.10483441
- Lapiedra O, Chejanovski Z, Kolbe JJ (2017) Urbanization and biological invasion shape animal personalities. *Glob Chang Biol* 23:592–603. doi: 10.1111/gcb.13395
- Local Land Services of Greater Sydney. 2018. Regional Profile. <https://greater-sydney.lls.nsw.gov.au/our-region/region-profile>. Accessed 04 September 2018
- Lone K, Loe LE, Gobakken T, et al (2014) Living and dying in a multi-predator landscape of fear: roe deer are squeezed by contrasting pattern of predation risk imposed by lynx and humans. *Oikos* 123:641–651. doi: 10.1111/j.1600-0706.2013.00938.x
- Lovari S, Valier P, Lucchi MR (1994) Ranging behaviour and activity of red foxes (*Vulpes vulpes*: Mammalia) in relation to environmental variables, in a Mediterranean mixed pinewood. *J Zool* 232:323–339. doi: 10.1111/j.1469-7998.1994.tb01576.x
- Magle SB, Lehrer EW, Fidino M (2016) Urban mesopredator distribution: examining the relative effects of landscape and socioeconomic factors. *Anim Conserv* 19:163–175. doi: 10.1111/acv.12231
- Mallick S, Pauza M, Eason C, et al (2016) Assessment of non-target risks from sodium fluoroacetate (1080), para-aminopropiophenone (PAPP) and sodium cyanide (NaCN) for fox-incursion response in Tasmania. *Wildl Res* 43:140–152. doi: 10.1071/WR15040
- Marks CA, Bloomfield TE (1999) Distribution and density estimates for urban foxes (*Vulpes vulpes*) in Melbourne: implication for rabies control. *Wildl Res* 26:763–775. doi: 10.1071/WR98059

- Marks CA, Gigliotti F, Busana F (2003) Field performance of the M-44 ejector for red fox (*Vulpes vulpes*) control. *Wildl Res* 30:601–609. doi: 10.1071/WR01032
- Marks CA, Wilson R (2005) Predicting mammalian target-specificity of the M-44 ejector in south-eastern Australia. *Wildl Res* 32:151–156. doi: 10.1071/WR03102
- Marlow NJ, Thomson PC, Algar D, et al (2000) Demographic characteristics and social organisation of a population of red foxes in a rangeland area in Western Australia. *Wildl Res* 27:457. doi: 10.1071/WR99035
- Matheny RW (1976) Review and results of sodium cyanide spring loaded ejector mechanism (SCSLEM) experimental programs. In: *Proceedings of the 7th Vertebrate Pest Conference*. pp 161–177
- Mccleery RA (2009) Changes in fox squirrel anti-predator behaviors across the urban-rural gradient. *Landsc Ecol* 24:483–493. doi: 10.1007/s10980-009-9323-2
- McNeill AT, Leung LKP, Goullet MS, et al (2016) Dingoes at the doorstep: home range sizes and activity patterns of dingoes and other wild dogs around urban areas of North-Eastern Australia. *Animals* 6:1–12. doi: 10.3390/ani6080048
- Moretti L, Hentrup M, Kotrschal K, Range F (2015) The influence of relationships on neophobia and exploration in wolves and dogs. *Anim Behav* 107:159–173. doi: 10.1016/j.anbehav.2015.06.008
- Moseby KE, Read JL (2014) Using camera traps to compare poison bait uptake by invasive predators and non-target species. In: Meek P, Fleming P (eds) *Camera trapping: Wildlife management and research*. New South Wales, Australia, pp 131–139
- Newsome TM, Crowther MS, Dickman CR (2014) Rapid recolonisation by the European red fox: how effective are uncoordinated and isolated control programs? *Eur J Wildl Res* 60:749–757. doi: 10.1007/s10344-014-0844-x
- Newsome TM, Greenville AC, Ćirović D, et al (2017) Top predators constrain mesopredator distributions. *Nat Commun* 8:15469. doi: 10.1038/ncomms15469
- Nicholson E, Gigliotti F (2005) Increasing the target-specificity of the M-44 ejector by exploiting differences in head morphology between foxes and large dasyurids. *Wildl Res* 32:733–736. doi: 10.1071/WR05015
- Niedballa J, Sollmann R, Courtiol A, Wilting A (2016) camtrapR: an R package for efficient camera trap data management. *Methods Ecol Evol* 7:1457–1462. doi: 10.1111/2041-210X.12600
- Novoa A, Shackleton R, Canavan S, et al (2018) A framework for engaging stakeholders on the management of alien species. *J Environ Manage* 205:286–297. doi: 10.1016/j.jenvman.2017.09.059
- NSW Natural Resources Commission (2016) *Shared Problem, Shared Solutions*. State-wide review of pest animal management

- Ordiz A, Miguel OS, Swenson JE (2011) Predators or prey? Spatio-temporal discrimination of human-derived risk by brown bears. *Oecologia* 166:59–67. doi: 10.1007/s00442-011-1920-5
- Oro D, Genovart M, Tavecchia G, et al (2013) Ecological and evolutionary implications of food subsidies from humans. *Ecol Lett* 16:1501–1514. doi: 10.1111/ele.12187
- Panek M, Budny M (2017) Variation in the feeding pattern of red foxes in relation to changes in anthropogenic resource availability in a rural habitat of western Poland. *Mamm Biol* 82:1–7. doi: 10.1016/j.mambio.2016.09.002
- Parsons MH, Banks PB, Deutsch MA, Munshi-South J (2018) Temporal and space-use changes by rats in response to predation by feral cats in an urban ecosystem. *Front Ecol Evol* | www.frontiersin.org 6:146. doi: 10.3389/fevo.2018.00146
- Parsons AW, Bland C, Forrester T, et al (2016) The ecological impact of humans and dogs on wildlife in protected areas in eastern North America. *Biol Conserv* 203:75–88. doi: 10.1016/j.biocon.2016.09.001
- Penteriani V, Kuparinen A, del Mar Delgado M, et al (2013) Responses of a top and a meso predator and their prey to moon phases. *Oecologia* 173:753–766. doi: 10.1007/s00442-013-2651-6
- Penteriani V, Kuparinen A, Delgado M del M, et al (2011) Individual status, foraging effort and need for conspicuousness shape behavioural responses of a predator to moon phases. *Anim Behav* 82:413–420. doi: 10.1016/j.anbehav.2011.05.027
- Plumer L, Davison J, Saarma U, Cameron EZ (2014) Rapid urbanization of red foxes in Estonia: distribution, behaviour, attacks on domestic animals, and health-risks related to zoonotic diseases. *PLoS One* 9:1–15. doi: 10.1371/journal.pone.0115124
- Pratas-Santiago LP, Gonçalves ALS, da Maia Soares AM V., Spironello WR (2016) The moon cycle effect on the activity patterns of ocelots and their prey. *J Zool* 299:275–283. doi: 10.1111/jzo.12359
- Reddiex B, Forsyth DM, McDonald-Madden E, et al (2006) Control of pest mammals for biodiversity protection in Australia. II. Reliability of knowledge. *Wildl Res* 33:711–717. doi: 10.1071/WR05103
- Ridout MS, Linkie M (2009) Estimating overlap of daily activity patterns from camera trap data. *J Agric Biol Environ Stat* 14:322–337. doi: 10.1198/jabes.2009.08038
- Risbey DA, Calver MC, Short J, et al (2000) The impact of cats and foxes on the small vertebrate fauna of Heirisson Prong, Western Australia. II. A field experiment. *Wildl Res* 27:223–235. doi: 10.1071/WR98092
- Russell JC, Jones HP, Armstrong DP, et al (2016) Importance of lethal control of invasive predators for island conservation. *Conserv Biol* 30:670–672. doi: 10.1111/cobi.12666
- Saito MU, Koike F (2015) Trait-dependent changes in assemblages of mid-sized and large mammals along an Asian urban gradient. *Acta Oecologica* 67:34–39. doi: 10.1016/j.actao.2015.06.002

- Šálek M, Drahníková L, Tkadlec E (2015) Changes in home range sizes and population densities of carnivore species along the natural to urban habitat gradient. *Mamm Rev* 45:1–14. doi: 10.1111/mam.12027
- Sánchez-Ferrer JC, Servín J, Muñoz-Delgado J, et al (2016) Variations in the locomotor activity of the Mexican wolf (*Canis lupus baileyi*) respect to moon periodicity: A study in an outdoor enclosure. *Biol Rhythm Res* 47:539–551. doi: 10.1080/09291016.2016.1164281
- Saunders GR, Gentle MN, Dickman CR (2010) The impacts and management of foxes *Vulpes vulpes* in Australia. *Mamm Rev* 40:181–211. doi: 10.1111/j.1365-2907.2010.00159.x
- Scott DM, Berg MJ, Tolhurst BA, et al (2014) Changes in the distribution of red foxes (*Vulpes vulpes*) in urban areas in Great Britain: findings and limitations of a media-driven nationwide survey. *PLoS One* 9:e99059. doi: 10.1371/journal.pone.0099059
- Shivik JA, Mastro L, Young JK (2014) Animal attendance at M-44 sodium cyanide ejector sites for coyotes. *Wildl Soc Bull* 38:217–220. doi: 10.1002/wsb.361
- Short J (1998) The extinction of rat-kangaroos (Marsupialia: Potoroidae) in New South Wales, Australia. *Biol Conserv* 86:365–377. doi: 10.1016/S0006-3207(98)00026-3
- Sol D, González-Lagos C, Lapiedra O, Díaz M (2017) Why are exotic birds so successful in urbanized environments? In: Murgui E, Hedblom M (eds) *Ecology and Conservation of Birds in Urban Environments*. Springer International Publishing, pp 1–525
- Soulsbury CD, White PCL (2015) Human-wildlife interactions in urban areas: a review of conflicts, benefits and opportunities. *Wildl Res* 42:541–553. doi: 10.1071/WR14229
- Southwell D, Boero V, Mewett O, et al (2013) Understanding the drivers and barriers to participation in wild canid management in Australia: Implications for the adoption of a new toxin, para-aminopropiophenone. *Int J Pest Manag* 59:35–46. doi: 10.1080/09670874.2012.744493
- Soysal A, Hooper-Bui LM, Laws EA (2016) Mapping and studying an urban red fox (*Vulpes vulpes*) population using social media. *PeerJ Prepr*. doi: 10.7287/peerj.preprints.2623v1
- Stepkovitch B (2017) Feeding ecology of an invasive predator across and urban land use gradient. Western Sydney University
- Teagle WG (1967) The fox in the London suburbs. *London Nat* 46:44–68
- Thompson MJ, Evans JC, Parsons S, Morand-Ferron J (2018) Urbanization and individual differences in exploration and plasticity. *Behav Ecol* 1–11. doi: 10.1093/beheco/ary103
- Thompson JA, Fleming PJS (1994) Evaluation of the efficacy of 1080 poisoning of red foxes using visitation to non-toxic baits as an index of fox abundance. *Wildl Res* 21:91–104. doi: 10.1071/WR9940027
- Towerton AL, Kavanagh RP, Penman TD, Dickman CR (2016) Ranging behaviour and movements of the red fox in remnant forest habitats. *Wildl Res* 43:492–506. doi: 10.1071/WR15133
- Towerton AL, Penman TD, Kavanagh RP, Dickman CR (2011) Detecting pest and prey responses to fox control across the landscape using remote cameras. *Wildl Res* 38:208–220. doi: 10.1071/WR10213

- Travaini A, Vassallo AI, García GO, et al (2013) Evaluation of neophobia and its potential impact upon predator control techniques: a study on two sympatric foxes in southern Patagonia. *Behav Processes* 92:79–87. doi: 10.1016/j.beproc.2012.10.008
- Trehwella WJ, Harris S (1988) A Simulation model of the pattern of dispersal in urban fox (*Vulpes vulpes*) populations and its application for rabies control. *J Appl Ecol* 25:435–450. doi: 10.2307/2403835
- van Heezik Y, Seddon PJ (2018) Animal reintroductions in peopled landscapes: moving towards urban-based species restorations in New Zealand. *Pacific Conserv Biol*. doi: 10.1071/PC18026
- Van Polanen Petel AM, Kirkwood R, Gigliotti F, Marks C (2004) Adaptation and assessment of M-44 ejectors in a fox-control program on Phillip Island, Victoria. *Wildl Res* 31:143–147. doi: 10.1071/WR02057
- Vuorisalo T, Talvitie K, Kauhala K, et al (2014) Urban red foxes (*Vulpes vulpes* L.) in Finland: a historical perspective. *Landsc Urban Plan* 124:109–117. doi: 10.1016/j.landurbplan.2013.12.002
- Welch RJ, Périquet S, Petelle MB, Le Roux A (2017) Hunter or hunted? Perceptions of risk and reward in a small mesopredator. *J Mammal* 98:1531–1537. doi: 10.1093/jmammal/gyx100
- West P, Saunders G (2003) Pest animal survey 2002: an analysis of pest animal distribution across NSW and the ACT. NSW Agriculture
- Woinarski JCZ, Burbidge A a., Harrison PL (2015) Ongoing unraveling of a continental fauna: decline and extinction of Australian mammals since European settlement. *Proc Natl Acad Sci* 112:4531–4540. doi: 10.1073/pnas.1417301112
- Yom-Tov Y, Geffen E (2011) Recent spatial and temporal changes in body size of terrestrial vertebrates: probable causes and pitfalls. *Biol Rev* 86:531–541. doi: 10.1111/j.1469-185X.2010.00168.x

Supplementary material

Appendix 1. Ethogram used to classify the behaviour of the species visiting the canid pest ejector area

Category	Behaviour	Description
Confident	Scent mark	The animal is marking the area with urine or faeces.
	Bit ejector	The animal abruptly bites the ejector, but does not pull, nor chew.
	Remove ejector	The animal pulls the ejector up and completely out of the ground.
	Chew ejector bait head	The animal is actively chewing the ejector without pulling it.
	Dig close to the ejector	The animal is digging or disturbing the ground around the ejector.
	Pull up the ejector	The animal is evidently pulling up the ejector with its mouth. In the case of the canids, this could be noticeable by the arching of the spine, upwards or downwards. It is not a brief display; therefore, it is possible to see more than one picture of the canid pulling up the ejector.
Timid	Camera-shy reaction	The animal runs away from the camera suddenly, which could be due to the camera trigger sound.
	Cautious toward the ejector	The animal looks shyly or cautiously at the ejector. In the case of dogs or foxes, the animal stares at the ejector and even pulls the head back, stretching the front. The animal's body is rigidly maintained close to the ground.
Not used	Smell the area	The animal smells and explores the area, but not the ejector.
	Smell ejector	The animal is smelling the ejector directly and close.
	Aware of the camera trap	The animal is conscious of the presence of the camera and is looking directly at it.
	Pass by	The animal walks by, without smelling or paying any attention to the ejector

Appendix 2. List of species included on each potential prey group

Potential prey group	Species
Native bird prey	<i>Alectura lathamii</i>
	<i>Calyptorhynchus funereus</i>
	<i>Chenonetta jubata</i>
	<i>Chroicocephalus novaehollandiae</i>
	<i>Colluricincla harmonica</i>
	<i>Corcorax melanorhamphos</i>
	<i>Corvus coronoides</i>
	<i>Corvus mellori</i>
	<i>Cracticus torquatus</i>
	<i>Dacelo novaeguineae</i>
	<i>Egretta novaehollandiae</i>
	<i>Falco berigora</i>
	<i>Gallinula tenebrosa</i>
	<i>Grallina cyanoleuca</i>
	<i>Gymnorhyna tibicen</i>
	<i>Leucosarcia melanoleuca</i>
	<i>Malurus cyaneus</i>
	<i>Manorina melanocephala</i>
	<i>Ocyphaps lophotes</i>
	<i>Platycercus elegans</i>
	<i>Platycercus eximius</i>
	<i>Porphyrio melanotus</i>
	<i>Psophodes olivaceus</i>
	<i>Rhipidura leucophrys</i>
	<i>Strepera graculina</i>
	<i>Threskiornis molucca</i>
	<i>Vanellus miles</i>
	<i>Varanus varius</i>
Introduced bird species	<i>Acridotheres tristis</i>
	<i>Anser anser</i>
	<i>Columba livia</i>
	<i>Spilopelia chinensis</i>
	<i>Sturnus vulgaris</i>
Native mammalian prey	<i>Turdus merula</i>
	<i>Perameles nasuta</i>
	<i>Tachyglossus aculeatus</i>
	<i>Trichosurus vulpecula</i>
	<i>Wallabia bicolor</i>
Introduced mammalian prey	<i>Lepus europeus</i>
	<i>Oryctolagus cuniculus</i>
	<i>Rattus rattus</i>

Appendix 3. Species recorded in the study and their interactions with the ejector

Species	Scent mark	Smell ejector	Bit ejector	Remove ejector	Cautious toward ejector	Chew ejector	Dig around ejector	Pull up ejector	Aware of the camera	Camera-shy response	Smell the area	Indifferent response
<i>Acridotheres tristis</i>	0	0	0	0	0	0	0	0	1	0	0	52
<i>Alectura lathamii</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Anser anser</i>	0	0	0	0	0	0	0	0	1	0	0	0
<i>Bos taurus</i>	0	7	0	0	0	0	0	0	2	0	2	2
<i>Calyptrorhynchus funereus</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Canis lupus familiaris</i>	12	44	7	10	1	10	1	21	0	0	56	22
<i>Chenonetta jubata</i>	0	0	0	0	0	0	0	0	5	0	0	30
<i>Chroicocephalus novaehollandiae</i>	0	0	0	0	0	0	0	0	0	0	0	6
<i>Colluricincla harmonica</i>	0	0	0	0	0	0	0	0	0	0	0	2
<i>Columba livia</i>	0	0	0	0	0	0	0	0	1	0	0	15
<i>Corcorax melanorhamphos</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Corvus coronoides</i>	0	0	8	1	3	1	0	0	1	0	0	10
<i>Corvus mellori</i>	0	0	0	0	0	0	0	0	0	0	0	3
<i>Cracticus torquatus</i>	0	0	0	0	0	0	0	0	0	0	0	2
<i>Dacelo novaeguineae</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Dama dama</i>	0	1	0	0	0	0	0	0	0	0	3	2
<i>Egretta novaehollandiae</i>	0	0	0	0	0	0	0	0	1	0	0	3
<i>Falco berigora</i>	0	0	0	0	0	1	0	0	1	0	0	0
<i>Felis catus</i>	0	22	2	0	6	4	0	1	17	0	18	24
<i>Gallinula tenebrosa</i>	0	0	0	0	0	0	0	0	1	0	0	5
<i>Grallina cyanoleuca</i>	0	0	0	0	0	0	0	0	1	0	0	42
<i>Gymnorhina tibicen</i>	0	11	0	0	0	29	0	0	24	0	6	44

<i>Lepus europeaus</i>	0	0	0	0	0	0	0	0	4	0	3	11
<i>Leucosarcia melanoleuca</i>	0	0	0	0	0	0	0	0	0	0	0	2
<i>Macropus giganteus</i>	0	14	0	0	1	0	0	0	17	0	40	41
<i>Macropus robustus</i>	0	10	0	0	0	0	0	0	20	0	38	19
<i>Macropus sp.</i>	0	0	0	0	0	0	0	0	1	0	1	11
<i>Malurus cyaneus</i>	0	0	0	0	0	0	0	0	0	0	0	5
<i>Manorina melanocephala</i>	0	0	0	0	0	0	0	0	0	0	0	10
<i>Ocyphaps lophotes</i>	0	1	0	0	0	0	0	0	1	0	0	16
<i>Oryctolagus cuniculus</i>	0	1	0	0	1	0	0	0	7	3	7	33
<i>Ovis orientalis</i>	0	1	0	0	0	0	0	0	0	0	0	0
<i>Perameles nasuta</i>	0	1	0	0	0	0	0	0	0	0	6	0
<i>Platycercus elegans</i>	0	0	0	0	0	0	0	0	0	0	0	0
<i>Platycercus eximius</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Porphyrio melanotus</i>	0	0	0	0	0	0	0	0	0	0	0	4
<i>Psophodes olivaceus</i>	0	0	0	0	0	0	0	0	1	0	0	2
<i>Rattus rattus</i>	0	59	3	0	3	120	0	0	84	1	166	142
<i>Rhipidura leucophrys</i>	0	0	0	0	0	0	0	0	1	0	0	0
<i>Spilopelia chinensis</i>	0	0	0	0	0	0	0	0	1	0	0	5
<i>Strepera graculina</i>	0	0	0	0	0	1	0	0	1	0	0	0
<i>Streptopelia chinensis</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Sturnus vulgaris</i>	0	0	0	0	0	0	0	0	0	0	0	6
<i>Sus scrofa</i>	0	0	0	0	0	0	0	0	0	0	1	0
<i>Tachyglossus aculeatus</i>	0	0	0	0	0	0	0	0	0	0	0	2
<i>Threskiornis molucca</i>	0	1	1	0	0	5	0	0	5	0	0	49
<i>Tiliqua scincoides</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Trichosurus vulpecula</i>	4	18	2	0	10	8	0	1	17	0	42	27
<i>Turdus merula</i>	0	0	0	0	0	0	0	0	0	0	0	1
<i>Vanellus miles</i>	0	0	0	0	0	0	0	0	2	0	0	28

<i>Varanus varius</i>	0	0	0	0	0	0	0	0	1	0	0	1
<i>Vombatus ursinus</i>	0	1	0	0	0	0	0	0	0	0	0	2
<i>Vulpes vulpes</i>	24	52	12	9	49	19	12	34	55	16	64	34
<i>Wallabia bicolor</i>	0	32	3	0	12	0	0	0	21	0	82	24

For the elaboration of this table records of behaviour separated one hour from each other were considered as independent, due to the diversity of species and differences in ranging behaviours.

Appendix 4. Animal Ethics Approval

ANIMAL RESEARCH AUTHORITY (ARA)



MACQUARIE
University

AEC Reference No.: 2018/001

Date of Expiry: 28 February 2019

Full Approval Duration: 01 March 2018 to 31 March 2019

This ARA remains in force until the Date of Expiry (unless suspended, cancelled or surrendered) and will only be renewed upon receipt of a satisfactory Progress Report before expiry (see Approval email for submission details).

Principal Investigator:

Dr Alexandra Carthey
Department of Biological Sciences
Macquarie University NSW 2109
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0421 319 443

Associate Investigators:

Margarita Gil Fernández 0452 411 409
Thomas Newsome 0476 042 069
Alison Towerton 0457 511 715

In case of emergency, please contact:
the Principal Investigator / Associate Investigator named above or Animal
Welfare Officer - 9850 7758 / 0439 497 383

The above-named are authorised by MACQUARIE UNIVERSITY ANIMAL ETHICS COMMITTEE to conduct the following research:

Title of the project: Urban fox densities: lures, traps and feral control **Purpose:** 4 - Research: Human or Animal Biology

Aims: 1. Evaluate risk of Canid Pest Ejectors (CPEs) to domestic dogs in natural, urban and peri-urban areas

Determine variables that make CPE use safe or unsafe to use (i.e. risk to domestic dogs) in natural, urban and peri-urban areas

Design protocol for CPE use in urban and peri-urban areas that results in minimal risk to domestic dogs **Procedure category:** 1 - Observation
Involving Minor Interference

All procedures must be performed as per the AEC-approved protocol, unless stated otherwise by the AEC and/or AWO. Maximum numbers approved (for the Full Approval Duration):

Species	Age/Sex/Weight	Total	Supplier/Source
55B - Foxes	Any	100	In Situ/Wild
32 - Dogs		100	
55A - Dingo/Wild Dog		50	
31 - Domestic Cats		50	
46 - Feral Cats		50	
TOTAL		350	

Location of research:

Locations in conjunction with Greater Sydney Local Land Services	
Randwick Racecourse (Randwick)	Taronga Zoo
Centennial Park (Moore Park)	Oxford Falls
Bradley's Head (Mosman)	Rookwood Cemetery
Elizabeth Macarthur Agricultural Research Institute	Hawkesbury Wetlands
Wollaroo Mulgoa	The Oaks cluster
Bilpin Pest Animal Group lands	Mulgoa Pest Animal Group
Sydney Airport	Nectarbrook
Towra Point RAMSAR Wetland	Wanda Beach
Wedderburn cluster	Greendale Cluster
Razorback cluster	

Amendments approved by the AEC since initial approval: N/A Conditions of Approval: N/A

Being animal research carried out in accordance with the Code of Practice for a recognised research purpose and in connection with animals (other than exempt animals) that have been obtained from the holder of an animal suppliers licence.

Associate Professor Nathan Hart (Chair, Animal Ethics Committee)

Approval Date: 15 February 2018

Appendix 5. Instructions for the authors

Note to the examiners: We have selected the series of instructions within the article that have given the format to this thesis. However, we still have to follow Macquarie University requirements, therefore, the thesis will be modified before submission in several aspects. We included some notes in the following instructions to indicate what may change.

If you need further information about the instructions in the journal, please consult:

https://www.springer.com/life+sciences/ecology/journal/10530?detailsPage=pltc1_1060750

Biological Invasions Journal

Biological Invasions publishes research and synthesis papers on patterns and processes of biological invasions in terrestrial, freshwater, and marine (including brackish) ecosystems. Also of interest are scholarly papers on management and policy issues as they relate to observation programs and the global amelioration or control of invasions. The journal will consider proposals for special issues resulting from conferences or workshops on invasions.

Paper Categories

Original papers

Novel empirical and theoretical research on topics in invasion biology, such as ecological consequences of invasions (including changes in community and ecosystem structure and processes), factors that influence transport, establishment, and spread of invasions, mechanisms that control the abundance and distribution of invasive species, biogeography, genetics of invaders (as genetics casts light on processes and pathways of invasions), dispersal vectors, evolutionary consequences of invasions in both historical and geological time, innovative management techniques, and analytical syntheses and overviews of invasive biotas. Authors must, in their cover letters, explain how the reported research is novel and exciting.

NOTE: We chose the category of Original Paper.

Paper Length

Papers must be concise and well written. While there are no specific page or word limits for any paper category except Invasion Notes, as a guide the average original paper contains approximately 8,000 words. Longer papers may be considered if the information justifies the length.

NOTE: We are slightly above the word limit in the first chapter, however once to be submitted, the paper will be shortened.

General Instructions

1) Please recall that Biological Invasions is read by specialists in invasion biology, so that introductory material pointing to the general importance of invasions is unnecessary and inappropriate.

NOTE: As this thesis will be available for a broader audience, we decided to keep very basic definition and a wide introductory material. However, for the final submission, the introduction will be considerably shortened.

2) Authors must submit, with their manuscripts, names and e-mail addresses of 4 unbiased, expert potential referees who have not previously read the manuscript. Authors may submit names of potential referees that they request not be used and may also request a particular handling editor.

Title Page

The title page should include:

- The name(s) of the author(s)
- A concise and informative title
- The affiliation(s) and address(es) of the author(s)
- The e-mail address, and telephone number(s) of the corresponding author
- If available, the 16-digit ORCID of the author(s)

Abstract

Please provide an abstract of 150 to 250 words. The abstract should not contain any undefined abbreviations or unspecified references.

Keywords

Please provide 4 to 6 keywords which can be used for indexing purposes.

Text Formatting

- Manuscripts should be submitted in Word.
- Use a normal, plain font (e.g., 10-point Times Roman) for text.
- Use italics for emphasis.
- Use the automatic page numbering function to number the pages.
- Do not use field functions.
- Use tab stops or other commands for indents, not the space bar.
- Use the table function, not spreadsheets, to make tables.
- Use the equation editor or MathType for equations.
- Save your file in docx format (Word 2007 or higher) or doc format (older Word versions)

Citation

Cite references in the text by name and year in parentheses. Some examples:

Negotiation research spans many disciplines (Thompson 1990).

This result was later contradicted by Becker and Seligman (1996).

This effect has been widely studied (Abbott 1991; Barakat et al. 1995a, b; Kelso and Smith 1998; Medvec et al. 1999, 2000).

Reference list

The list of references should only include works that are cited in the text and that have been published or accepted for publication. Personal communications and unpublished works should only be mentioned in the text. Do not use footnotes or endnotes as a substitute for a reference list.

Reference list entries should be alphabetized by the last names of the first author of each work. Order multi-author publications of the same first author alphabetically with respect to second, third, etc. author. Publications of exactly the same author(s) must be ordered chronologically.

Journal article

Gamelin FX, Baquet G, Berthoin S, Thevenet D, Nourry C, Nottin S, Bosquet L (2009) Effect of high intensity intermittent training on heart rate variability in prepubescent children. *Eur J Appl Physiol* 105:731-738. <https://doi.org/10.1007/s00421-008-0955-8>

Ideally, the names of all authors should be provided, but the usage of “et al” in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al (1999) Future of health insurance. *N Engl J Med* 341:325–329

Article by DOI

Slifka MK, Whitton JL (2000) Clinical implications of dysregulated cytokine production. *J Mol Med*. <https://doi.org/10.1007/s001090000086>

Book

South J, Blass B (2001) *The future of modern genomics*. Blackwell, London

Book chapter

Brown B, Aaron M (2001) The politics of nature. In: Smith J (ed) *The rise of modern genomics*, 3rd edn. Wiley, New York, pp 230-257

Online document

Cartwright J (2007) Big stars have weather too. IOP Publishing PhysicsWeb. <http://physicsweb.org/articles/news/11/6/16/1>. Accessed 26 June 2007

Dissertation

Trent JW (1975) *Experimental acute renal failure*. Dissertation, University of California

Always use the standard abbreviation of a journal's name according to the ISSN List of Title Word Abbreviations, see

[ISSN LTWA](#)

If you are unsure, please use the full journal title.

For authors using EndNote, Springer provides an output style that supports the formatting of in-text citations and reference list.

[EndNote style \(zip, 2 kB\)](#)

Tables

- All tables are to be numbered using Arabic numerals.
- Tables should always be cited in text in consecutive numerical order.
- For each table, please supply a table caption (title) explaining the components of the table.
- Identify any previously published material by giving the original source in the form of a reference at the end of the table caption.
- Footnotes to tables should be indicated by superscript lower-case letters (or asterisks for significance values and other statistical data) and included beneath the table body.

Figures

Figure Lettering

- To add lettering, it is best to use Helvetica or Arial (sans serif fonts).
- Keep lettering consistently sized throughout your final-sized artwork, usually about 2–3 mm (8–12 pt).
- Variance of type size within an illustration should be minimal, e.g., do not use 8-pt type on an axis and 20-pt type for the axis label.
- Avoid effects such as shading, outline letters, etc.
- Do not include titles or captions within your illustrations.

NOTE: We decided to keep the shading on the activity overlap graph because it seems like a good way to show the actual overlap of both densities.

Figure Numbering

- All figures are to be numbered using Arabic numerals.
- Figures should always be cited in text in consecutive numerical order.
- Figure parts should be denoted by lowercase letters (a, b, c, etc.).
- If an appendix appears in your article and it contains one or more figures, continue the consecutive numbering of the main text. Do not number the appendix figures,
- "A1, A2, A3, etc." Figures in online appendices (Electronic Supplementary Material) should, however, be numbered separately.

Figure Captions

- Each figure should have a concise caption describing accurately what the figure depicts. Include the captions in the text file of the manuscript, not in the figure file.
- Figure captions begin with the term **Fig.** in bold type, followed by the figure number, also in bold type.
- No punctuation is to be included after the number, nor is any punctuation to be placed at the end of the caption.
- Identify all elements found in the figure in the figure caption; and use boxes, circles, etc., as coordinate points in graphs.
- Identify previously published material by giving the original source in the form of a reference citation at the end of the figure caption

Figure Placement and Size

- Figures should be submitted separately from the text, if possible.
- When preparing your figures, size figures to fit in the column width.
- For most journals the figures should be 39 mm, 84 mm, 129 mm, or 174 mm wide and not higher than 234 mm.
- For books and book-sized journals, the figures should be 80 mm or 122 mm wide and not higher than 198 mm.

NOTE: Figures are including in the text, close to the reference in the text to make it easier for the general reader. This will be modified before submission.

Permissions

If you include figures that have already been published elsewhere, you must obtain permission from the copyright owner(s) for both the print and online format. Please be aware that some publishers do not grant electronic rights for free and that Springer will not be able to refund any costs that may have occurred to receive these permissions. In such cases, material from other sources should be used.

Accessibility

In order to give people of all abilities and disabilities access to the content of your figures, please make sure that

All figures have descriptive captions (blind users could then use a text-to-speech software or a text-to-Braille hardware)

Patterns are used instead of or in addition to colours for conveying information (colour-blind users would then be able to distinguish the visual elements)

Any figure lettering has a contrast ratio of at least 4.5:1