VISITATION OF RODENTICIDE BAIT STATIONS BY WILDLIFE SPECIES AND COMMENSAL RODENTS IN SUBURBAN ORANGE COUNTY, CALIFORNIA

A Thesis By

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Abstract:

Native wildlife species are frequently exposed to rodenticides used to control commensal rodent pests, especially at the urban-wildland interface. However, the exact pathways by which non-target wildlife are exposed is not clear. I used camera traps to determine the use of rodenticide bait stations by wildlife in backyards in suburban Orange County, California. I also examined local (yard) and landscape-scale variables to identify factors that might increase exposure risk for non-target species. I monitored paired bait stations with digital cameras for approximately 30 consecutive days in each of 90 yards over a six-month period from December 2017 to August 2018, and in 64 of these yards from September 2018 to April 2019. One bait station was placed on the ground, whereas another was placed 1-1.5 m to determine if elevating bait stations could reduce exposure of non-target species. Fifteen different mammal species were detected at bait stations; however, commensal roof rats (*Rattus rattus*) were the most common and abundant visitors, being detected at 80% of yards. Native species overwhelmingly visited ground stations, suggesting that elevating stations could reduce non-target exposure. Alternatives to rodenticides should be considered in backyards with open fencing that are close to natural areas because these types of yards tended to be visited by native wildlife. Nonetheless, given the frequency of visits to bait stations and the fact that native wildlife species were photographed entering stations, native carnivores and scavengers could potentially be exposed to rodenticides secondarily by eating native or, more likely, commensal rodent prey.

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CHAPTER 1

USE OF BAIT STATIONS BY NON-TARGET WILDLIFE AS A POTENTIAL ROUTE OF RODENTICIDE EXPOSURE

Introduction

Anticoagulant rodenticides are commonly used in both urban and agricultural settings to control commensal rodent populations (Shore et al. 2014). These agents are highly toxic and can lead to death after a single feeding (Quinn et al. 2012). The use of these rodenticides, especially the more toxic second-generation anticoagulants (SGARs), has been heavily restricted in much of the U.S., including requiring that toxicant-laden bait be placed in tamper-resistant bait stations. Nonetheless, non-target wildlife species continue to show high-levels of rodenticide exposure (e.g., Cypher et al. 2014; Serieys et al. 2015; Hoare and Hare 2017). Rodents, birds, and invertebrates can be exposed directly by entering bait stations or by consuming spilled bait (primary exposure; Mason 1984, Brakes and Smith 2005; Sánchez-Barbudo et al. 2012; Geduhn et al. 2014; Elmeros et al. 2019). Secondary (or tertiary) exposure occurs when predators or scavengers, such as raptors or mammalian carnivores, consume moribund or dead prey that have ingested rodenticide-laden bait (Stone et al. 1999; Rattner et al. 2011; Cypher et al. 2014; Thompson et al. 2014; Poessel et al. 2015; Murray 2017).

Despite considerable evidence of secondary exposure of non-target wildlife, surprisingly little information is available on the pathways by which rodenticides enter natural food webs. For example, in the western U.S., medium-sized carnivores such as coyotes (Canis latrans) show high levels of rodenticide exposure in both urban and rural settings (e.g., Poessel et al. 2015; Prat-Mariet et al. 2017; Sainsbury et al. 2018). However, non-native mice (Mus sp.) and rats (Rattus sp.), typically the targets of pest control efforts in urban and suburban areas, seem to be consumed rarely by coyotes or other native carnivores (Murray et al. 2015; Larson et al. 2020). It is therefore unclear how coyotes and other carnivores are exposed to rodenticides, especially given the tighter restrictions on the use of SGARs compared to first-generation anticoagulants in urban areas (Quinn and Swift 2018). Previous field studies of routes of secondary exposure of carnivores have been conducted in agricultural settings in Europe, where baits are often applied in large quantities on the surface, e.g., Brakes and Smith (2005), Sánchez-Barbudo et al. (2012), Geduhn et al. (2014), Elmeros et al. (2019).

To identify potential ways that wildlife might be exposed to rodenticides in a suburban environment, I used camera-trapping to quantify visitation of rodenticide bait stations by commensal rodents and wildlife species in residential backyards in Orange County, California, U.S.A. Digital game cameras were used to monitor bait stations, baited with lures but no toxicants, in each yard continuously for approximately 30 consecutive days. Cameras were placed at two bait stations in each yard, one on the ground and one raised 1-1.5 m, to determine if elevating bait stations affected visitation by wildlife species. I recorded ecologically relevant characteristics in each yard to examine local-scale factors that might influence visitation, and used a geographic information systems (GIS) approach to describe landscape-scale characteristics in the areas around yards, with the aim of identifying differences between yards visited by native wildlife species and yards where those species were not detected.

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Methods

Study Sites

Reconyx™ PC800 digital cameras were deployed at 90 residential yards from December 2017 to August 2018 (Session 1; Fig. 1). A subset of 64 of these yards were surveyed again from September 2018 to March 2019 (Session 2). Yards were the residences of volunteers in the

University of California Cooperative Extension Master Gardeners of Orange County Program. Yards were, on average, 1.6 km from the nearest neighboring yard sampled (range = 0.1 - 50.2 km).

Two cameras were placed in each yard, with each one 1-2 m away from an Evo Protecta Ambush™ bait station. One camera was focused on a ground-level bait station placed along a fence or structure, whereas the other camera was focused on a bait station elevated 1-1.5 m off the ground and anchored to a fence or wall, or on a horizontal tree branch. Bait stations were baited with two non-toxic blocks (Bell Detex Blox™; labeled with a fluorescent marker) and two non-toxic soft baits (Liphatech Rat and Mouse Attractant™); these baits were the same as those commonly used in rodenticide applications except that the mixtures lacked the active ingredient. The cameras ran continuously. Volunteers checked bait stations approximately every seven days and replaced baits if they were consumed. Each yard was camera-trapped for approximately 30 consecutive days in each trapping session (31.3 $\pm$ 2.2 days (SD), range = 26-38 days). At the end of a camera-trapping session, stations were checked for fluorescent rodent droppings as an indicator that the bait was consumed by rodent species. Fifteen yards were usually trapped concurrently.

Yard and Landscape Variables

Local, yard-level characteristics were recorded in each yard when cameras were first deployed (Table 1). The variables were categorical and included vegetation density (estimated visually and qualitatively), yard size, the presence of fruit, vegetables, nuts, water, and structures that could be used by wildlife for shelter. I also recorded human-related variables such as the presence of pets (vs. free-roaming animals) and anthropogenic foods, and the use of rodent control methods, such as snap-trapping, live-trapping, and rodenticides.

To examine the effects of larger, landscape-scale characteristics on visitation, I used ArcGIS (version 10.6.1; ESRI 2011) to identify four landscape-scale variables: land-cover type, distance to nearest natural area ($\geq$2 ha in area), distance to open developed space (parks, school yard, and golf course; $\geq$2 ha in area), housing density, and road density (Table 1). I used the National Land Cover data layer (2011; 30-m resolution) to categorize land cover into four general cover types: water, natural areas, urban open space (Open Developed), and urban development (low-, medium-, and high-intensity uses combined). The percentage cover of each of the cover types were measured in a 500-m buffer (0.79 km^2) around each yard. This buffer size was selected as a proxy of the combined home ranges of the potential native mammal species within the study area (Wood et at. 2010; Grinder and Krausman 2001; Sunquist et al 1987). Housing and road densities within this buffer were calculated from a layer of Orange County parcel data (2016), whereas distance to natural area and distance to open devolved space (in km) was measured using ArcGIS tools on a satellite map of Orange County from 2011. Natural areas were defined as areas with natural vegetation, including woodlands and natural reserves (Taylor and Hochuli 2017).

Data Analysis

To discretize continuous camera data, I identified one day of trapping as the 24-hour period starting and ending at 1500 hours Pacific Standard Time. For each wildlife species photographed, I recorded whether it was present or absent at a bait station on a given hour on a given trapping day. Thus, if at least one individual was photographed at any time during that hour, I recorded that species' activity as "present" during that hour, regardless of the actual number of images taken or the number of individuals in a given image. I also recorded instances of individuals actually entering or exiting bait stations, which would indicate the potential for direct (primary) exposure to rodenticide.

For all species except roof rats (R. rattus), which were extremely widespread and abundant, I summed the number of hours of activity at each camera across the entire sampling period (typically, around 720 hours) in each yard to determine if a species visited elevated or ground bait stations more frequently. Chi-square goodness-of-fit tests were used to determine if visitation differed significantly by station placement. For roof rats, I used a paired t-test to determine, for each session separately, if the total number of hours of activity differed between elevated and ground stations across the yards sampled (see Chapter 2 for a more detailed analysis of roof rat activity).

To examine potential effects of yard- and landscape-scale variables on visitation, I used a Chi-square goodness-of-fit tests to examine differences in categorical variables between yards where a particular species or group was detected and where it was not. I used two-sample t-tests to compare means of continuous variables between yards where a species or group was detected and where it was not seen.

Results

Over the 12 months of camera-trapping, I collected a total of 514,171 digital images. Fifteen mammal species were detected, including 11 California native species [mule deer (Odocoileus hemionus), coyotes, bobcats (Lynx rufus), raccoons (Procyon lotor), striped skunks (Mephitis mephitis), desert cottontails (Sylvilagus audubonii), black-tailed jackrabbits (Lepus californicus), California ground squirrels (Otospermophilus beecheyi), woodrats (Neotoma sp.), deermice (Peromyscus sp.), kangaroo rats (Dipodomys sp.)], two naturalized species introduced from elsewhere in the U.S. [Virginia opossums (Didelphis virginiana, Eastern fox squirrel (Scurius niger)], and two non-native, commensal species [roof rat, free-roaming domestic cats (Felis catus)]. Neither house mice (Mus musculus) nor Norway or brown rats (R. norvegicus) were detected. The proportion of yards in which a species was seen varied greatly among species, but were similar between sessions (Fig. 2). During both sessions, roof rats were the most common species in yards (72, 80%), followed by fox squirrels, free-roaming cats, opossums, and raccoons (25-45% of yards). Native rodents, comprising four species (California ground squirrels, deermice, woodrats, kangaroo rats), were detected in 13% of yards. Coyotes, bobcats, and striped skunks were relatively uncommon (<10% of yards) and deer and jackrabbits were only detected at a single site each during Session 1 (1% of yards). Desert cottontails were photographed relatively frequently (24% and 18% of yards in Session 1 and Session 2, respectively), but they showed no interest in the bait stations in any of the images, and were excluded from subsequent analyses.

The number of activity-hours in which a given species was detected during Session 1 and 2, respectively, across all yards combined and both bait stations, was as follows: roof rat (4918, 2975), fox squirrel (343, 180), free-roaming cat (172, 144), opossum (244, 114), raccoon (80, 52), striped skunk (9, 9), coyote (9, 34), bobcat (16, 5), and native rodents (142, 138). Because roof rats were so widespread, effects of bait station placement on activity was tested with separate paired t-tests for Session 1 and 2 (N = 72 and 47 yards, respectively). Roof rats were detected at elevated and ground stations at similar frequencies in both sessions (Session 1: t = 1.07, d.f. = 51, P = 0.14; Session 2: t = 0.58, d.f. = 31, P = 0.28; Figure 3; also see Chapter 2). Fox squirrels were the only wildlife species that visited elevated stations significantly more than ground stations and only in Session 1 ($\chi2$ goodness-of-fit test, $\chi2 = 4.65$, d.f. = 1, P = 0.03; Figure 3). All other species were detected significantly more often at ground stations than elevated ones in both sessions ($P < 0.05$; Figure 3).

Other than roof rats, relatively few individuals of wildlife species were photographed actually entering bait stations, where they would encounter rodenticide if it were present. Woodrats entered bait stations most often (eight events in three yards in Session 1, 32 events in four yards in Session 2), followed by ground squirrels (13 events in six yards; nine events in four yards) and deermice (three images in four yards; one event in one yard). In one instance, a juvenile opossum was photographed entering a bait station (Fig. 4). Although the entrances to these bait stations were too small for adult fox squirrels to enter, in four yards in Session 1 (none in Session 2), fox squirrels were able to enter the station by gnawing and enlarging the entry holes or by gnawing large holes in the top of the station.

The extent to which local- and landscape-scale variables differed between yards where a wildlife species was detected and where it was apparently absent was highly species-specific. Yards where fox squirrels were detected tended to have a constant food sources (fruits and nuts), and were in areas that were near developed open spaces like parks and golf courses (Table 2) at the landscape scale. Almost all yards visited by opossums, another naturalized non-native species, had some of barrier to entry, either by wooden or stone fences. At the landscape scale, opossums tended to be recorded in areas with higher overall housing density and less open developed space (Table 3). Yards with roof rats present also shared similar characteristics; residents of yards with roof rats were significantly more likely to use rodent control either in the form of traps or rodenticide. At the landscape scale, roof rats were present in yards farther from natural areas (Table 4).

At the yard level, native rodents were detected in smaller yards, closer to natural open space, and in those with no or low barriers to entry (Table 5). They were not found in yards with high housing density and high urban development. Raccoons were detected in 30% of yards, but there were no significant differences in either yard- or landscape-level variables between yards with raccoons and those where they were not detected (Table 6). There also were no differences between yard-level characteristics between yards with bobcats and coyotes and those that did not have these species (Table 7). At the landscape scale, bobcats and coyotes collectively were detected in yards with lower housing and road density.

Discussion

The overall aim of my thesis research was to determine pathways of exposure of non-target wildlife species to rodenticides. To accomplish this, I quantified visitation of elevated and ground-level rodenticide bait stations by both target (commensal rodents) and non-target wildlife species in suburban backyards in Orange County. I also examined how local yard traits and characteristics of the surrounding landscape differed between yards where particular species were detected and where they were not seen, as a way to assess if characteristics of yards or the surrounding area make them more likely to be visited by wildlife. Previous studies on pathways of rodenticide exposure of non-target species have mainly focused on farms or insular settings (e.g. Brakes and Smith 2005; Elliott et al. 2013; Hindmarch et al. 2017; Pitt et al. 2011; Howald et al. 2007). The results of these studies may not be applicable to southern California because, in those settings, rodenticide may be applied indiscriminately (e.g., broadcast baiting; Colvin and Jackson 1999), which results in large amounts of bait on the surface. In urban and suburban areas of the U.S., rodenticides are usually applied in tamper-proof bait stations to minimize exposure of children, pets and wildlife.

My results suggest that elevating bait stations off the ground may be a simple but effective way to reduce non-target exposure of wildlife. Except for fox squirrels during Session 1, native and naturalized species were detected much more frequently at ground-level bait stations than at elevated ones. Elevating stations will likely still be effective for controlling roof rats, which visited and entered elevated and ground stations at equivalent frequencies (see also Chapter 2). This approach may not be effective for Norway rats, which are less arboreal than roof rats (Leung and Clark 2005), but I did not detect any Norway rats, which are uncommon in Orange County (Penicks et al. 2020).

Although roof rats showed some degree of neophobia (see Chapter 2), they entered bait stations frequently, where they would have had access to rodenticide if my baits had contained toxicants. Native rodents, especially ground squirrels and deermice, were also photographed entering or leaving bait boxes, although much less frequently than roof rats. The small size of the entrance to the bait station likely prevented larger species from accessing the bait directly, although a juvenile opossum was detected entering one bait station and fox squirrels were able to access the bait by chewing through the plastic box. Given the scarcity of native rodents at and inside bait stations, my results suggest that the most likely route of secondary exposure of carnivores is through the consumption of commensal rodents. However, it is possible that they could be exposed by consuming dead or dying wild rodents that accessed rodenticide baits.

Native rodents were only detected at a small subset of yards (13%), however, which tended to be locations that had few or no physical outer-yard barriers (solid fences, walls) and in areas that were close to natural areas and less intensively urbanized. These were also the types of yards visited by bobcats and coyotes, although coyotes were detected much less frequently than I expected, given the abundance of coyotes in suburban southern California (Riley et al. 2003). This means that, in addition to elevating bait stations, exposure of non-target species could possibly be reduced by not permitting bait to be applied in yards with these types of characteristics, and in locations in close proximity to natural open space. This would also prevent native rodents from entering yards, consuming bait, and then moving back into natural areas, where they might be a source of rodenticide exposure for other mammalian and avian carnivores.

In contrast, fox squirrels and opossums seemed to be less discriminating in that yards where these species were detected were not significantly different from those where they were not detected. Other mesopredators such as raccoons and free-roaming cats were also commonly detected (40%

and 30%, respectively) and in a wide range of yards. This pattern was not surprising, given the success of these generalist and naturalized species in urban and suburban environments (Lever 1994; Hawkins et al. 2004; Bozek et al. 2007; Gehrt et al. 2013; Fidino et al. 2016). Because fox squirrels and to a lesser degree, opossums, both were capable of entering bait stations, they could possibly be a source of secondary (or tertiary) exposure to larger carnivores. Another mesopredator, the striped skunk, was only detected at a few yards (4%), but it tends to be less associated with urban areas than the other mesopredators (Connell et al. 2006).

Management Recommendations

Both native and introduced species frequent backyards of southern California; from a conservation standpoint, the native species are the species of greatest concern. However, in a multi-faceted problem such as rodenticide exposure, multiple species been involved in the movement and potential spread of rodenticide. Therefore, it is critical to integrate conservation concerns into the development of pest management approaches.

I was able to identify certain yard and landscape variables that influence the presence of wildlife species. These factors should be taken into account when pest management professionals or homeowners decide on what methods are appropriate for controlling commensal rodents. For example, in yards that are likely to be visited by native rodents and carnivores (no barrier to entry, close proximity to natural areas), alternatives to rodenticides should be considered to eliminate the potential for both primary and secondary exposure. In yards that tend to be visited by mesocarnivores (barriers to entry, high housing and road density, urbanized landscape), bait stations should be elevated and applicators should regularly check for and remove rat carcasses to avoid exposure through scavenging (Lotts and Stapp 2020). As a general rule, pest management professionals must consider the type of wildlife that are likely to encounter bait stations before deciding to apply rodenticides, which my results suggest can be estimated based on local- and landscape-level assessments. This is particularly true in southern California, as development pushes farther into natural areas. Lastly, it is important to note that, while my research focused specifically on pathways of exposure of mammals, rodenticide exposure is a significant conservation problem for owls, raptors, and other birds as well (Erickson and Urban 2004; Hindmarch et al. 2017), and, as has been increasingly recognized, for smaller vertebrates and invertebrates (Weir et al. 2016; Johnston et al. 2005). A better understanding of pathways of exposure of these other groups, each with their own challenges, is necessary to inform the public about the degree and potential risks of non-target rodenticide exposure, and to provide pest management professionals with knowledge and environmentally sensitive approaches to minimize those risks while still controlling rodents effectively.

CHAPTER 2

USE OF RODENTICIDE BAIT STATIONS BY COMMENSAL RODENTS AT THE URBAN-WILDLANDS INTERFACE: INSIGHTS FOR MANAGEMENT TO REDUCE NON-TARGET EXPOSURE

Introduction

Commensal rodents such as rats (Rattus sp.) and mice (Mus sp.) pose significant risks to human health and cause considerable damage to property and infrastructure (Brooks and Jackson 1973; Trawegar et al. 2006). Globally, rats consume billions of dollars' worth of human foods annually (Pimentel et al. 2000), making them one of the most costly introduced species in the world (Almeida et al. 2013). Moreover, rats and mice are carriers of diseases such as plague, salmonella, and tularemia that are harmful to humans, as well as diseases of native wildlife species (Lapuz et al. 2008; Himsworth et al. 2013).

A variety of methods have been used to control commensal rodent populations, ranging from habitat modification to live trapping to rodenticides (Colvin and Jackson 1999). The abundance of food in urban environments, combined with the innate tendency of rats for neophobia (Inglis et al. 1996), can make it difficult to attract animals to traps (Trawegar et al. 2006; Mughini et al. 2012). In most urban and suburban areas, rodenticides, particularly second-generation anticoagulant rodenticides, are widely used because of their relatively high efficacy and low cost (Colvin and Jackson 1999). Rodenticides are usually placed in tamper-resistant bait stations to prevent children, pets, and non-target wildlife from accessing the bait. The use of bait stations can be particularly important in residential and mixed-use settings at the urban-wildland interface, where non-target poisoning of wildlife is a significant conservation concern (Stone et al. 1999; Erickson and Urban 2004; Cypher et al. 2014). Mammalian carnivores and raptors can also be exposed secondarily by consuming rodents that have ingested rodenticide bait and died away from cover (Murray and Tseng 2008; Bautista et al. 2014; Riley et al. 2017).

Despite the effectiveness of rodenticides in urban settings, little is known of the behavioral response of commensal rodents to bait stations, presumably because of the challenges of research in urban areas (Parsons et al. 2017). Recent studies have tended to focus on agricultural applications, which may not be applicable to situations requiring the use of rodenticides in urban areas (Spurr et al. 2007). A better understanding of factors such as bait neophobia and the effects of placement and rat abundance on bait station use could help pest management professionals effectively control commensal rodents while being sensitive to environmental concerns.

To determine how commensal rodents respond to rodenticide bait stations in urban and suburban settings, I quantified the rate of discovery and entry of roof rats (Rattus rattus) in commercial bait stations in residential yards in Orange County, California, USA. I also compared visitation of bait stations placed on the ground to that of bait stations elevated 1-1.5 m off the ground. Because roof rats are excellent climbers, elevating bait stations may reduce exposure of native wildlife species to rodenticides (Erickson et al. 1990; Whisson 1998). Lastly, I examined characteristics of yards that were visited by rats and native rodents to determine if the use of anticoagulant rodenticides should be avoided in certain types of yards to reduce opportunities for non-target exposure.

Methods

Reconyx™ PC800 digital cameras were deployed at 90 residential yards across Orange County from December 2017 to August 2018 (Session 1; Figure 1). A subset of 64 of these yards were surveyed again from September 2018 to March 2019 (Session 2). Yards were the residences of volunteers in the University of California Cooperative Extension Master Gardeners of Orange County program. Yards were, on average, 1.6 km from the nearest neighboring yard sampled (range = 0.1-50.2 km).

Two cameras were placed in each yard, with each one 1-2 m away from a Bell PROTECTA EVO Ambush™ bait station. One camera was focused on a ground-level bait station placed along a fence or structure, whereas the other camera was focused on a bait station elevated 1-1.5 m off the ground and anchored to a fence or wall, or on a tree branch or trunk. Bait stations were baited with two non-toxic blocks (Bell Detex Blox™; labeled with a fluorescent marker) and two non-toxic soft attractant (Liphatech Rat and Mouse Attractant™); these matrices were the same as those commonly used in rodenticide applications except that they lacked the active ingredient. The cameras ran continuously. Volunteers checked bait stations approximately every seven days and replaced baits if they were missing. Each yard was camera-trapped for approximately 30 consecutive days in each trapping session (31.3 + 2.2 days (standard deviation, SD), range = 26-38 days, n = 154). To confirm that bait was consumed by rodents, at the end of a camera trapping session, stations were checked for the presence of fluorescent rodent droppings. Fifteen yards were usually sampled concurrently.

To discretize the continuous stream of camera images, I classified one day of camera-trapping as the 24-hour period starting and ending at 1500 hours Pacific Standard Time. Because rats were often very common, I estimated relative activity as the proportion of crepuscular/nocturnal hours in a day in which at least one rat was photographed at, though not necessarily entering, a given bait station (visitation). Because multiple individuals were sometimes present at a bait station at a time, I also tallied the maximum number of rats seen in a single image in a given hour as a measure of relative abundance. I defined time to discovery as the number of hours elapsed until the first image of a rat was recorded at a given station, and time to entry as the number of hours elapsed until a rat was first photographed actually entering or exiting the opening of a bait station. Unless otherwise noted, means are presented + 1 SD.

To examine differences among yards in the patterns of activity over the 30-day trapping period, I categorized yards based on the amount of activity per night. Sites were assigned either high activity (>4 hours of activity/night), intermediate activity (1-4 hours activity/night), or low activity (<1 hour of activity/night). To determine if there were any yard characteristics that influenced the level of rat activity, I recorded the presence of fruits or vegetables, anthropogenic food (pet food or bird seed), and any rodent control methods used at each site.

In addition, I examined the effect of yard barrier permeability on visitation to bait stations by both commensal and native small mammals. Yards with no exterior barrier or only a chain-link or wrought-iron fence were categorized as having permeable outer barriers, whereas those with brick, stone, or solid wood-slatted fences were considered impermeable. Similarly, to determine if yards close to natural open space tended to have higher rates of visitation by native rodents, I estimated the distance from each yard to the nearest patch of native or natural vegetation >2 ha in area using ArcGIS (version 10.6.1; ESRI 2011).

Results

Camera-trapping efforts yielded a total of 514,171 images. Of the non-native commensal species potentially present in the southern California region, I detected only roof rats, i.e., no Norway rats (R. norvegicus) or house mice (M. musculus) were seen. During Session 1, rats were recorded at 80% (72) of the 90 yards, and in 73% (47) of the 64 yards trapped in Session 2. Across both camera-trapping sessions, a total of 23,133 unique images contained at least one rat. Even where rats were common, it was unusual for an image to contain multiple individuals: 97.8% of all images with rats had only one rat, 2.1% had two rats, and 0.01% had three rats.

In Session 1, rats were detected at both ground and elevated stations in 43 yards, only ground stations in 16 yards, and only elevated stations in 13 yards. A similar pattern was observed in Session 2 (10 yards ground only, 7 yards elevated only, 30 yards with detections at both). In yards where rats were detected, ground-level bait stations were discovered by rats at 7.6 ± 8.7 days (n = 59, range = 1-31, median = 4, mode = 2) and first entered at 9.7 ± 8.9 days (n = 35, range = 1-35, median = 7, mode = 2). By comparison, elevated stations were discovered at 8.6 ± 7.3 days (n = 56, range = 1-31, median = 6, mode = 2) and first entered at 9.9 ± 8.6 days (n = 36, range = 1, median = 8, mode = 4). There was no significant difference between either time to discovery (t = 0.61, d.f. = 112, p = 0.27) or entry (t = -0.09, d.f. = 69, p = 0.92) between elevated and ground stations in Session 1 or Session 2 (discovery: t = -0.57, d.f. = 75, p = 0.28; entry: t = -0.32, d.f. = 44, p = 0.37; Table 1). Rats were detected actually entering 59% (35/59 ground) and 64% (36/56 elevated) of the stations visited in Session 1, and 63% (25/40 ground) and 70% (26/37 elevated) of the stations visited in Session 2 (Table 8). Focusing on only the first two weeks that a station was operational during Session 1, rats were detected entering ground stations, on average, 5.6 times per night, compared to

4.6 times per night at elevated stations, a difference that was not statistically significant (t = 1.07, d.f. = 51, p = 0.14). A similar result was seen in Session 2 (Table 1; t = 0.58, d.f. = 31, p = 0.28).

In yards where rats were detected, they were recorded on an average of 1.8 ± 2.7 hours per night during Session 1 (n = 72), and 1.4 ± 2.1 hours during Session 2 (n = 47). During the first trapping session, rats were active at ground stations, on average, for 1.4 ± 1.9 hours per night (n = 59), compared to 1.2 ± 1.4 hours at elevated stations (paired t-test, t = -0.56, d.f. = 110, p = 0.29; Table 1). Activity was similar in Session 2, with rats at ground and elevated stations active for 1.4 ± 1.8 hours (n = 40) and 1.1 ± 1.2 hours (n = 37), respectively. Pooling activity across elevated and ground stations, at the 42 yards with rats that were camera-trapped in both sessions, there was no significant difference in hours of activity per night between sessions (paired t-test, t = 1.03, d.f. = 82, p = 0.15). In both sessions, slightly more than half of the total activity at a site occurred at ground stations (Session 1: 55.7 ± 38.5%; Session 2: 56.5 ± 37.6%), but there was no significant difference in the proportion of activity in ground vs. elevated stations in either session (paired t-tests, p > 0.16).

During Session 1, yards where rats were detected at bait stations regularly tended to have the highest average levels of nightly activity, particularly at ground stations (Figure 5). Rats were detected on more than 24 of the 30 nights, and there was more than 4 hours of activity each night. I saw a similar pattern in Session 2 (Figure 5). In Session 1, in yards where rats were seen at stations very regularly (>50% of nights), rats discovered both elevated and ground stations almost immediately (Figure 5). For all but a handful of yards, time to discovery of ground stations was relatively short (<10 days) and largely independent of the frequency with which rats were photographed at ground stations during the 30-day trapping period. By comparison, it took slightly longer for rats to discover elevated stations, even in yards where rats were common, and the relationship between the frequency of activity and time to discovery was more linear (Figure 5).

The pattern of rat activity varied considerably among yards. In Session 1, most sites with rats had low levels of activity (n = 34 yards), followed by intermediate (23) and high activity (15). In Session 2, 23 sites were characterized as having low activity, 15 sites had intermediate activity, and 9 sites had high activity. At sites with high activity, the presence of rats tended to cycle with bait replenishment (about every 7 days), with a spike on the day of replenishment, followed by a sharp drop (Figure 6). Yards with intermediate levels of activity tended to be visited regularly across nights, whereas those with low activity were still visited on many nights but for fewer hours each night (Figure 6).

Perhaps unsurprisingly, nearly all yards of Master Gardeners had some level of fruit or vegetable production, but this did not seem to influence rat activity consistently (Table 9). Approximately one-third of yards with rats had anthropogenic foods, regardless of activity level, whereas yards with no rats tended to also lack anthropogenic foods. In most of the yards with no rat activity, either pest control method (rodenticide or trapping) was used (Table 9). There was no current effort to control rats in most of the yards with high rat activity either, although most (73%) of these residents had used some type of rat control in the past, and when shown images of the large numbers of rats, some expressed a desire to resume control measures. About half (53%) of residents with low levels of rat activity also did not attempt to directly manage rat numbers. Residents of yards with intermediate levels of activity tended to use control methods most often, and efforts were split between rodenticide and snap trapping (Table 9).

Native rodent species, including deer mice (Peromyscus spp.), woodrats (Neotoma spp.), ground squirrels (Otospermophilus beecheyi), and one kangaroo rat (Dipodomys spp.) visited relatively few yards ($n = 12$, 13.3%). Yards with native rodents tended to have permeable outer barriers ($X2 = 12.44$, d.f. = 1, $p < 0.0004$) and to be closer to areas of natural vegetation (t-test, $t = 3.01$, d.f. = 88, $p = 0.035$; Table 3). Rodenticides had been applied in only two of the yards with native rodents, and most of the yards (10/14) with native rodents had low levels of rat activity (only two yards had high rat activity). Most visits by these rodents were at ground rather than elevated stations (236/280 hours of activity, 84.3%). It is worth noting that diurnal fox squirrels (Sciurus niger), which are not native but are naturalized and common in suburban southern California, were detected in a total of 41 yards and were able to access the bait in four yards by chewing through the plastic bait box (all were elevated stations).

Discussion

Roof rats were very common in residential yards in Orange County, California, including yards of all types, sizes, and constructions. In total, rats were detected in 80% of the yards I sampled, although activity varied greatly among yards, both in terms of the number of nights rats were detected and the number of hours of activity per night. Bait stations were discovered quickly in yards where rats had highly levels of activity, especially at ground-level stations, where rats were recorded in nearly 90% of yards within 10 days of placement. Time to discovery did not differ significantly between ground and elevated stations, with mean times ranging from 7 to 10 days across both sampling sessions. Mean time to enter the bait station also did not differ between elevated and ground stations, varying from 10 days in Session 1 and 11-12 days in Session 2, although rats actually entered only 59-70% of the bait stations they visited, suggesting some degree of neophobia. Although time to discovery appeared to be slightly more sensitive to the amount of rat activity at elevated stations (Figure 3), overall, my results suggest that elevated bait stations would be as effective as ground stations as a way of providing rodenticide to rats.

The presence of fruits and vegetables in a given yard was a poor predictor of rat activity, as nearly all yards (87-100%) had some form of produce. Similarly, for yards with rats, the level of rat activity was independent of the proportion of yards with anthropogenic foods, though more of the rat-free yards also lacked anthropogenic foods, suggesting such resources might serve as an attractant. Most homeowners of yards with no rat activity did not apply any form of rodent control, but, surprisingly, control methods were also not currently used by residents of yards with high levels of rat activity. However, nearly three-fourths of these residents had used some form of pest management in the past, so it is apparent that some yards have a high propensity for rat infestation. Residents took active measures to control rat numbers in most of the yards where I detected intermediate levels of rat activity. As in other instances where control measures were applied, rodenticides and snap trapping were used approximately equally. Overall, although rats were present in 80% of yards, only about 45% of residents actively controlled them at the time of my study, suggesting that most residents (or, at least, Master Gardeners) either were unaware of the amount of rat activity in their yards or do not perceive it to be a problem warranting much direct, active management.

Yard characteristics may also influence the likelihood that a given yard will be visited by non-target wildlife species. Although native rodents were only detected at 13.3% of yards, these yards tended to have permeable outer barriers and to be in close proximity to patches of natural vegetation, where populations of these rodents likely persist. If my bait stations had contained anticoagulant rodenticides, native or commensal rodents that consumed bait in these yards and then subsequently died in a natural open space might have been eaten there by native scavengers and predators, exposing them to anticoagulant rodenticides secondarily. Of course, such yards, especially those without significant barriers, might also be visited by the carnivores themselves, where they might encounter rodenticide-laden carcasses of rats (Lotts and Stapp 2020). This underscores the need to monitor and remove rat carcasses promptly and regularly after applying rodenticides, particularly in yards that are close to natural areas and relatively accessible. Risk of primary exposure to native rodents would also be reduced significantly by simply elevating bait stations off the ground, with no apparent loss of rodenticide availability to target pest species. Rats actually entered elevated stations at a higher rate (64-70%) than ground stations (59-63%).

It is worth noting that although rat entry into bait stations was documented it was lower than expected, and even when rats discovered the bait station they were reluctant to enter. This is most likely due to the foraging patterns of roof rats, which tends to be a constant path, and the abundance of food sources in southern California, which deter the rats from entering and eating and potentially harmful food source.

Management Recommendations

My results have important implications for the control of roof rats and other rodent pests in residential areas of southern California and, possibly, other Mediterranean climates. I make the following recommendations for pest management professionals.

First, the high levels of rat activity in some yards may result in rapid depletion of bait and, potentially, loss of effectiveness. Rats clearly responded behaviorally to bait depletion and replenishment, so it may be useful to monitor bait consumption frequently during the first week of bait application and adjust levels accordingly. Failure to maintain sufficient bait levels may allow a target population to recover and thus result in a longer period of active control and more rodenticide-exposed animals in the environment than is necessary as well as development of rodenticide resistance. I emphasize, however, that the stations in my study had bait but lacked rodenticides, so I do not know how the presence of toxicant or the deaths of other rats might alter behavioral responses.

On the other hand, the fact that I photographed rats actually entering only 59-70% of the bait stations suggests either that cameras missed some of these events or that rats were reluctant to enter bait stations, even when no rodenticide was present. Even in yards where rats eventually entered stations, it took a median of 7-8 days for them to first directly encounter the bait. Because the first mortalities from anticoagulant rodenticide might not occur for several more days, pest management professionals should be prepared to communicate these possible delays to their customers to prevent them from becoming impatient and taking more drastic (and potentially illegal) measures if results are not immediate.

Lastly, given the mobility of the predators and scavengers that live at the urban-wildland interface in southern California, if anticoagulant rodenticides are the preferred option for effective pest control, special efforts should be made to search for and remove carcasses quickly, especially in yards that might be accessible to native wildlife or adjacent to areas where wild populations exist. In such yards, integrated-pest-control approaches other than rodenticides should be attempted first to minimize risk to non-target wildlife species. Most native rodents are not listed as potential targets on the labels of anticoagulant rodenticides and baits should not be placed in locations where there is significant risk of primary exposure. Care should be taken when deploying even non-chemical tactics for rodent management such as snap traps or glue traps, etc., which can also kill non-target species. If rodenticides must be used and semi-arboreal roof rats are the target species, bait stations should be elevated to try to prevent native rodents from gaining access to baits. This may have the additional benefit of reducing exposure to small children and other non-target animals, such as pets.

APPENDIX A

TABLES

Table 1. Description and abbreviations of yard and landscape variables recorded at 90 sites in Orange County, California, at the time when camera traps were established in Session 1.

Variable	Abbreviations	Description
Local-level		
Fruit	FRUIT	Presence of fruit or vegetables
Nuts	NUTS	Presence of nuts
Anthropogenic foods	ANTHRO	Presence of anthropogenic food
Water	WATER	Presence of water
Outdoor pets	PETS	Presence of outdoor pets
Livestock	LIVESTOCK	Presence of livestock, e.g., horses, chickens, quail
Rodent control	CONTROL	Presence and type of rodent control (traps/toxicant rodenticide)
Vegetation	VEG	Vegetation density (high/medium/low)
Fence	FENCE	Description of the type and size of fence surround yard (none N, permeable P, non-permeable NP)
Yard size	YARDSIZE	Total area (m^2) of surveyed yard area
Landscape-scale		
Distance to natural area	DISTANCE	Distance to nearest natural area ($\geq$2 ha in area; in km)
Distance to open developed space	ODS	Distance to nearest open developed land (parks/golf courses/ school yards)
Housing density	HOUSE	Housing density (km^{-1}) in a 0.79-km^2 radius buffer around yard
Road density	ROAD	Total km of paved road in a 0.79-km^2 radius buffer around yard
% Natural area	NATURAL	Percentage of 0.79-km^2 radius buffer with natural area/urban green space cover
% Urban	URBAN	Percentage of 0.79-km^2 radius buffer classified as urban development

Table 2. Local and landscape characteristics at yards where fox squirrels were detected in camera traps in 90 suburban yards in Orange County, California, during Session 1, compared to yards where they were not detected. For categorical local variables, values are the percentage of yards where these items were present, and P-values are the results of Chi-square tests of association. For continuous landscape variables, means are ± 1 SE and P-values are the results of t-tests.

Variable	Present (N = 41)	Absent (N = 49)	P-value
Local			
FRUIT	100	100	0.09
NUTS	12	2	0.16
ANTHRO	39	30	0.35
WATER	59	60	0.70
PETS	49	65	0.56
LIVESTOCK	10	5	0.43
CONTROL (TOX/TRAP/NONE)	20/20/60	12/27/61	0.54
VEG (HI/MED/LOW)	20/31/49	22/33/45	0.91
FENCE (NA/P/NP)	3/24/63	14/20/66	0.14
YARDSIZE (m-2)	466.6 ± 554.6	317.1 ± 345.6	0.14
Landscape			
DISTANCE (km)	1.72 ± 1.27	1.38 ± 1.27	0.17
ODS (m)	207.56 ± 29.57	159.45 ± 28.58	0.16
HOUSE (km-2)	80.27 ± 4.12	70.19 ± 3.86	0.08
ROAD (m)	2.73 ± 0.12	2.61 ± 0.10	0.45
NATURAL (%)	1.72 ± 1.27	1.38 ± 1.27	0.17
URBAN (%)	94.62 ± 2.66	93.92 ± 1.37	0.82

Table 3. Local and landscape characteristics at yards where opossums were detected in camera traps in 90 suburban yards in Orange County, California, during Session 1, compared to yards where they were not detected. For categorical local variables, values are the percentage of yards where these items were present, and P-values are the results of Chi-square tests of association. For continuous landscape variables, means are ± 1 SE and P-values are the results of t-tests.

Variable	Present (N = 36)	Absent (N = 54)	P-value
Local			
FRUIT	94	93	0.79
NUTS	8	8	0.69
ANTHRO	33	47	0.89
WATER	53	86	0.74
PETS	50	83	0.69
LIVESTOCK	3	14	0.35
CONTROL (TOX/TRAP/NONE)	17/25/58	15/22/63	0.91
VEG (HI/MED/LOW)	25/41/34	19/26/55	0.11
FENCE (NA/P/NP)	0/6/30	15/26/59	**0.01**
YARDSIZE (m-2)	545.10 ± 474.87	355.96 ± 447.72	0.81
Landscape			
DISTANCE (km)	1.88 ± 1.35	1.30 ± 1.06	0.36
ODS (m)	218.5 ± 25.1	156.57 ± 25.32	0.1
HOUSE (km-2)	82.72 ± 3.75	69.48 ± 3.37	**0.01**
ROAD (km)	2.77 ± 0.11	2.59 ± 0.09	0.23
NATURAL (%)	1.88 ± 1.35	1.30 ± 1.06	0.36
URBAN (%)	96.13 ± 1.08	92.24 ± 1.95	0.21

Table 4. Local and landscape characteristics at yards where roof rats were detected in camera traps in 90 suburban yards in Orange County, California, during Session 1, compared to yards where they were not detected. For categorical local variables, values are the percentage of yards where these items were present, and P-values are the results of Chi-square tests of association. For continuous landscape variables, means are ± 1 SE and P-values are the results of t-tests.

Variable	Present (N = 72)	Absent (N = 18)	P-value
Local			
FRUIT	94	22.2	0.71
NUTS	8	0.0	0.57
ANTHRO	35	5.6	0.65
WATER	54	15.3	0.81
PETS	51	16.7	0.6
LIVESTOCK	8	0.0	0.57
CONTROL (TOX/TRAP/NONE)	18/27/55	6/6/88	**0.03**
VEG (HI/MED/LOW)	24/32/44	12/32/56	0.48
FENCE (NA/P/NP)	8/22/70	11/22/67	0.93
YARDSIZE (m-2)	184.24 ± 33.16	181.5 ± 24.89	0.96
Landscape			
DISTANCE (km)	1.54 ± 1.25	1.50 ± 1.08	0.87
ODS (m)	184.24 ± 33.16	181.5 ± 24.89	0.96
HOUSE (km-2)	75.05 ± 5.70	78.11 ± 3.39	0.68
ROAD (km)	2.70 ± 0.11	2.75 ± 0.01	0.75
NATURAL (%)	6.50 ± 1.68	4.90 ± 1.12	**0.05**
URBAN (%)	93.50 ± 1.68	95.10 ± 2.15	0.52

Table 5. Local and landscape characteristics at yards where native rodents were detected in camera traps in 90 suburban yards in Orange County, California, during Session 1, compared to yards where they were not detected. For categorical local variables, values are the percentage of yards where these items were present, and P-values are the results of Chi-square tests of association. For continuous landscape variables, means are ± 1 SE and P-values are the results of t-tests.

Variable	Present (N = 9)	Absent (N = 81)	P-value
Local			
FRUIT	89	94	0.59
NUTS	0	7	0.42
ANTHRO	44	31	0.43
WATER	44	57	0.50
PETS	33	56	0.23
LIVESTOCK	0	7	0.42
CONTROL (TOX/TRAP/NONE)	11/0/89	16/26/58	0.15
VEG (HI/MED/LOW)	11/22/67	22/33/45	0.44
FENCE (NA/P/NP)	11/56/33	9/19/72	**0.03**
YARDSIZE (m-2)	192.34 ± 108.24	406.85 ± 475.18	**0.001**
Landscape			
DISTANCE (km)	1.36 ± 1.74	1.55 ± 1.15	**0.03**
ODS	1.36 ± 1.74	125.29 ± 1.15	0.75
HOUSE (km-2)	55.90 ± 8.63	77.94 ± 3.02	**0.04**
ROAD (km)	7.73 ± 0.22	8.97 ± 0.08	0.14
NATURAL (%)	12.74 ± 3.54	5.43 ± 1.00	0.08
URBAN (%)	87.26 ± 3.54	94.57 ± 1.87	**0.04**

Table 6. Local and landscape characteristics at yards where raccoons were detected in camera traps in 90 suburban yards in Orange County, California, during Session 1, compared to yards where they were not detected. For categorical local variables, values are the percentage of yards where these items were present, and P-values are the results of Chi-square tests of association. For continuous landscape variables, means are ± 1 SE and P-values are the results of t-tests.

Variable	Present (N = 27)	Absent (N = 63)	P-value
Local			
FRUIT	96	92	0.54
NUTS	11	11	0.35
ANTHRO	30	78	0.77
WATER	59	126	0.70
PETS	59	119	0.54
LIVESTOCK	7	15	0.88
CONTROL (TOX/TRAP/NONE)	11/22/67	17/24/59	0.70
VEG (HI/MED/LOW)	11/48/41	25/50/25	0.19
FENCE (NA/P/NP)	7/33/60	10/27/63	0.25
YARDSIZE (m-2)	545.10 ± 514.05	355.96 ± 430.25	0.38
Landscape			
DISTANCE (km)	1.35 ± 2.09	1.61 ± 0.10	0.30
ODS	170.40 ± 36.52	183.54 ± 21.09	0.74
HOUSE (km-2)	72.33 ± 4.67	74.72 ± 3.05	0.67
ROAD (km)	2.55 ± 0. 14	2.67 ± 0.07	0.40
NATURAL (%)	1.35 ± 2.09	1.61 ± 0.10	0.30
URBAN (%)	92.59 + 2.09	94.55 ± 1.01	0.44

Table 7. Local and landscape characteristics at yards where bobcats and coyotes were detected in camera traps in 90 suburban yards in Orange County, California, during Session 1, compared to yards where they were not detected. For categorical local variables, values are the percentage of yards where these items were present, and P-values are the results of Chi-square tests of association. For continuous landscape variables, means are ± 1 SE and P-values are the results of t-tests.

Variable	Present (N = 9)	Absent (N = 81)	P-value
Local			
FRUIT	89	94	0.59
NUTS	33	4	**0**
ANTHRO	56	30	0.13
WATER	67	54	0.50
PETS	56	53	0.89
LIVESTOCK	22	5	0.06
CONTROL (TOX/TRAP/NONE)	11/22/67	15/25/60	0.92
VEG (HI/MED/LOW)	22/22/66	21/33/46	0.78
FENCE (NA/P/NP)	22/33/45	7/21/72	0.18
YARDSIZE (m-2)	925.23 ± 955.04	325.42 ± 322.46	0.10
Landscape			
DISTANCE (km)	0.91 ± 1.13	1.61 ± 1.21	0.11
ODS	0.91 ± 1.13	1.61 ± 1.21	0.11
HOUSE (km-2)	58.09 ± 3.09	77.69 ± 7.20	**0.03**
ROAD (m)	6.69 ± 0.08	9.09 ± 2.24	**0.01**
NATURAL (%)	10.68 ± 0.96	4.00 ± 4.90	0.34
URBAN (%)	89.32 ± 1.84	96.00 ± 4.90	0.23

Table 8. Mean (± 1 *SD*) time to discovery, time to entry, activity time, and number of entry events for roof rats detected at ground and elevated bait stations in Orange County, California, USA. Cell values in parentheses denote the number of yards. A total of 72 (80%) of the 90 yards were visited by rats in Session 1, whereas rats were recorded in 47 (73%) of 64 yards trapped in Session 2. The mean number of entry events refers only to entries during the first two weeks that the stations were operational, and only includes yards where one or both stations were entered within the first two weeks.

Session Station placement	Time to discovery (days)	Time to entry (days)	Activity per night (h)	Entry events per night
Session 1 (72 yards)				
Ground	7.6 ± 8.7 (59)	9.7 ± 8.9 (35)	1.4 ± 1.9 (59)	5.6 ± 3.0 (26)
Elevated	8.3 ± 7.2 (56)	9.9 ± 8.6 (36)	1.2 ± 1.4 (56)	4.8 ± 2.6 (28)
Session 2 (47 yards)				
Ground	9.3 ± 8.7 (40)	11.9 ± 8.8 (25)	1.4 ± 1.8 (40)	6.3 ± 3.7 (15)
Elevated	8.3 ± 7.6 (37)	11.1 ± 7.6 (26)	1.1 ± 1.2 (37)	5.7 ± 2.9 (18)

Table 9. Roof rat activity in Session 1 (December 2017-August 2018) across Orange County, California, USA, yards with different characteristics (n = 90). High activity = ≥4 hours of activity/night, intermediate activity = 1-4 hours/night, low activity = <1 hour/night. Note that percentages do not sum to 100% within rows because yards may have more than one of these characteristics. For rodent control measures, the top value refers to rodent control used at the time of my study, and the lower value (in parentheses) refers to rodent control practices used during the six months prior to sampling.

	Yard characteristics (% of yards)				Vegetation density			Rodent control measures used		
Level of rat activity (n)	Permeable barriers	Water	Fruits or vegetables	Anthropogenic foods	High	Medium	Low	Trapping	Rodenticide	No control
High (13)	15.4	61.5	84.6	38.5	30.8	46.2	23.1	23.1 (53.8)	7.7 (15.4)	69.2 (30.8)
Intermediate (25)	36.0	56.0	96.0	36.0	20.0	36.0	44.0	40.0 (32.0)	12.0 (24.0)	48.0 (44.0)
Low (34)	32.4	50.0	97.1	32.4	23.5	23.5	52.9	20.6 (23.5)	26.5 (41.2)	52.9 (35.3)

Table 10. Characteristics of yards where native rodents visited bait stations in suburban southern California, USA. Native rodents were detected more often in yards with permeable barriers (as described in the Methods text) than in those with impermeable barriers and in yards closer to developed open space. Values for yard size and distance to developed open space are means $\pm$ 1 *SD*. Data described in this table cover both session one and two.

Presence of native rodents	Barrier		Yard size (m^2)	Distance to nearest developed open space (m)
	Permeable	Impermeable		
Native rodents detected (12)	9	3	397.9 $\pm$ 594.4	45.4 $\pm$ 62.2
No native rodents detected (78)	19	59	383.5 $\pm$ 436.1	200.2 $\pm$ 176.0

APPENDIX B

FIGURES

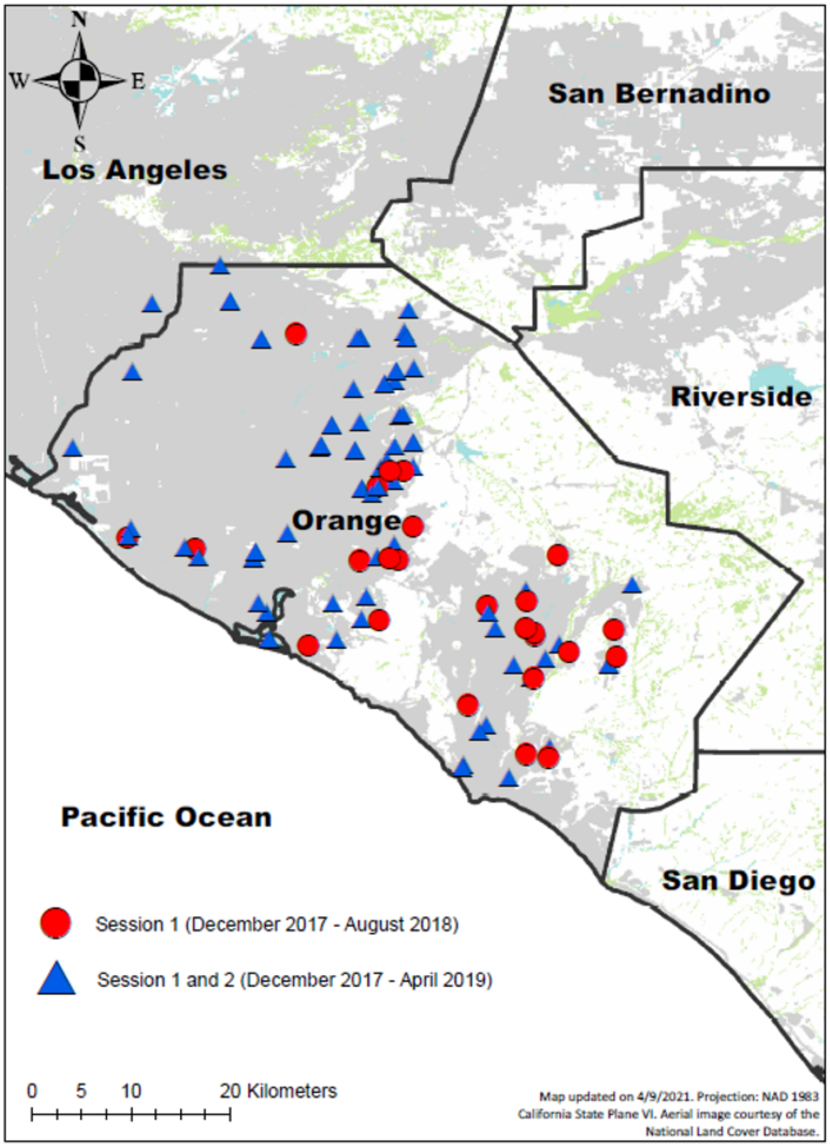

Figure 1. Locations of yards camera-trapped for visitation of rodenticide bait stations by wildlife species in Orange County, California. Circles denote yards sampled only in Session 1 (December 2017 to August 2018, 26 yards), whereas triangles show yards sampled in both Session 1 and Session 2 (September 2018 to March 2019, 64 yards). Map created in ArcGIS

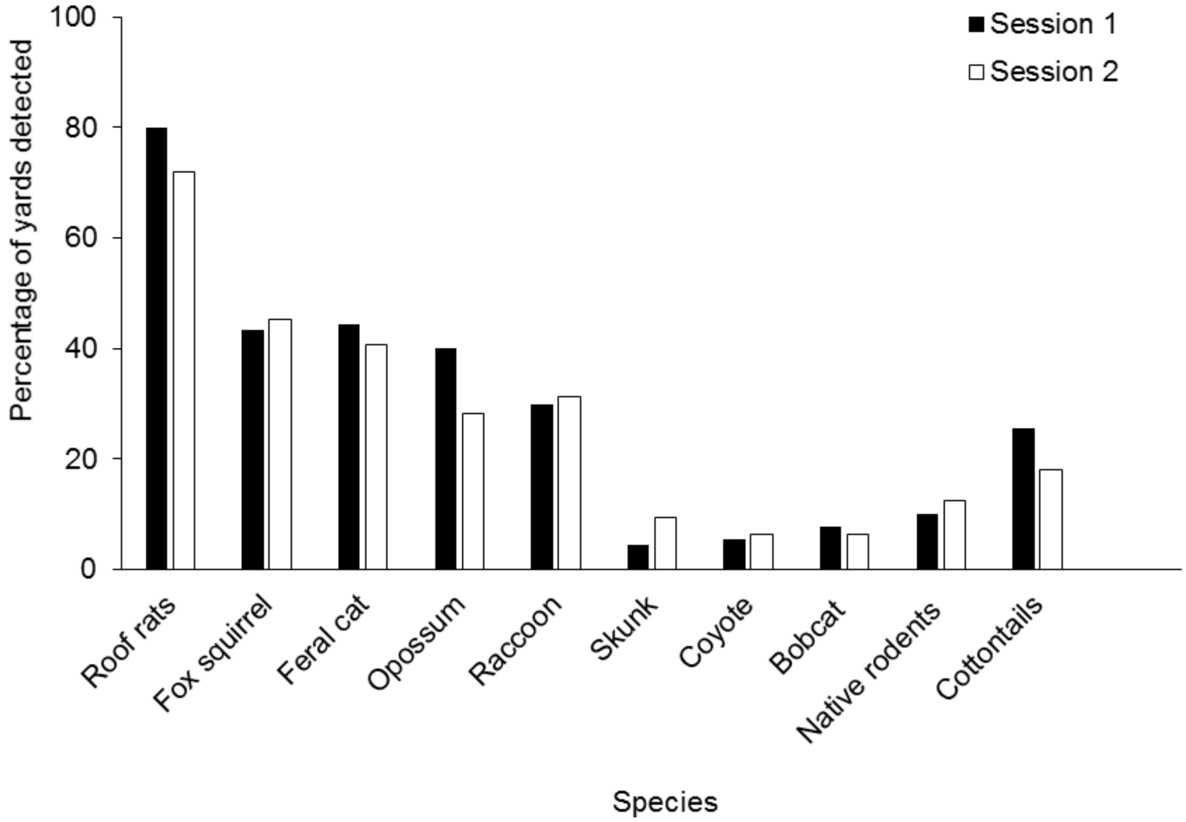

Figure 2. Percentage of suburban backyards in which wildlife species were detected by camera trapping at bait stations in Orange County, California. A total of 90 yards were camera-trapped during Session 1 (December 2017 to August 2018); 64 of these sites were re-trapped in Session 2 (September 2018 to March 2019). Native rodents includes four taxa (wood rats, deermice, kangaroo rats, and California ground squirrels). Black-tailed jackrabbits and mule deer were each detected in one yard in Session 1 and are not shown.

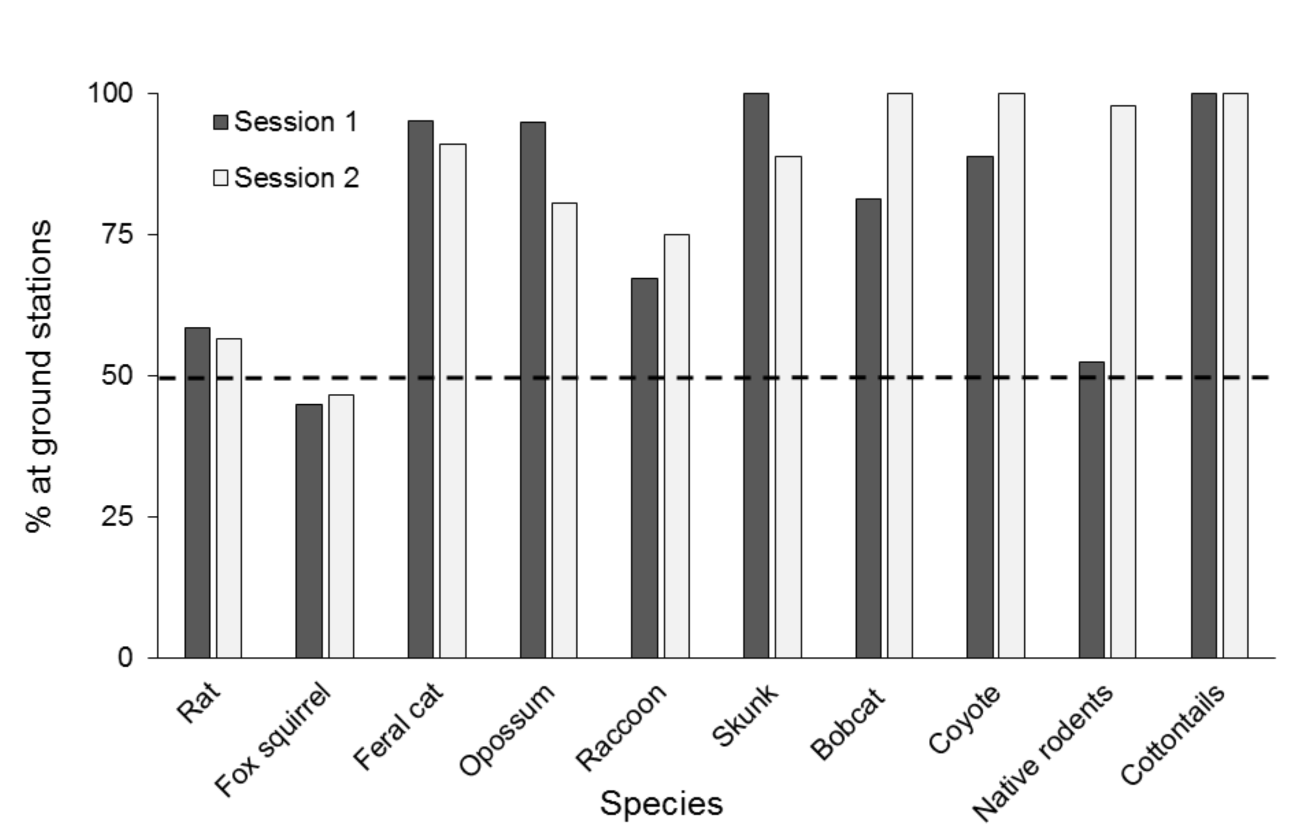

Figure 3. Effect of bait station placement on activity of wildlife species in yards in Orange County, California, between December 2017 to August 2018 (Session 1, 90 yards) and September 2018 to March 2019 (Session 2, 64 yards). Values represent the percentage of total activity-hours in which at least one individual was detected at ground bait stations vs. elevated bait stations. Thus, a value of 50% would denote equivalent use of ground and elevated stations.

Figure 4. Digital camera image showing a juvenile opossum exiting a rodenticide bait station in a backyard in Orange County, California. Most of the wildlife species that entered bait stations were native rodents, although fox squirrels were able to access bait by gnawing through the bait station.

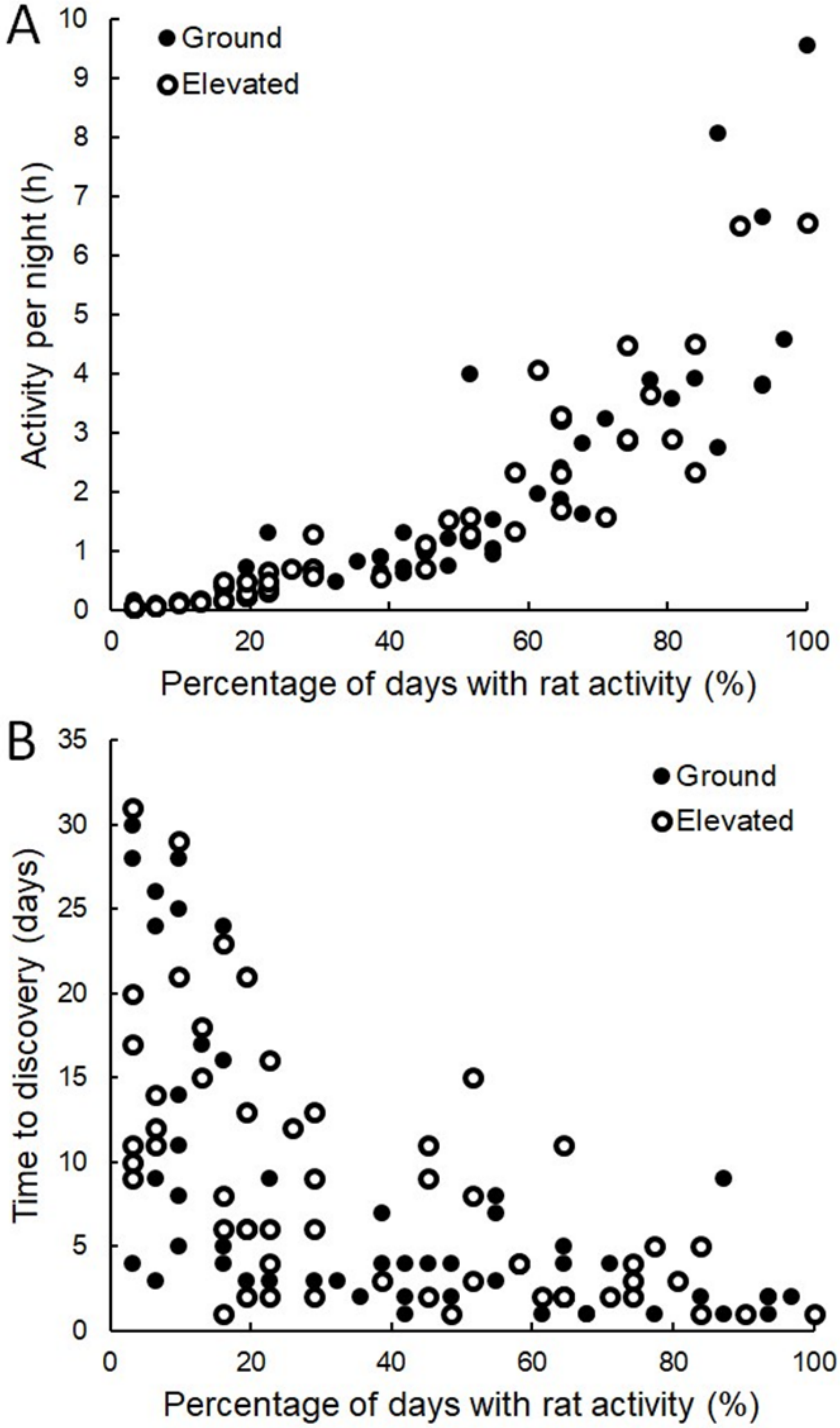

Figure 5. Relationships between the frequency of rat detections in a given yard and A) mean levels of nightly roof rat activity, and B) time to discovery of ground-level and elevated bait stations. Data are from Session 1, in which camera traps were set in 90 yards in Orange County, California, USA, between December 2017 and August 2018. Trapping periods lasted approximately 30 days. Rats were detected at ground stations in 59 yards and elevated stations in 56 yards.

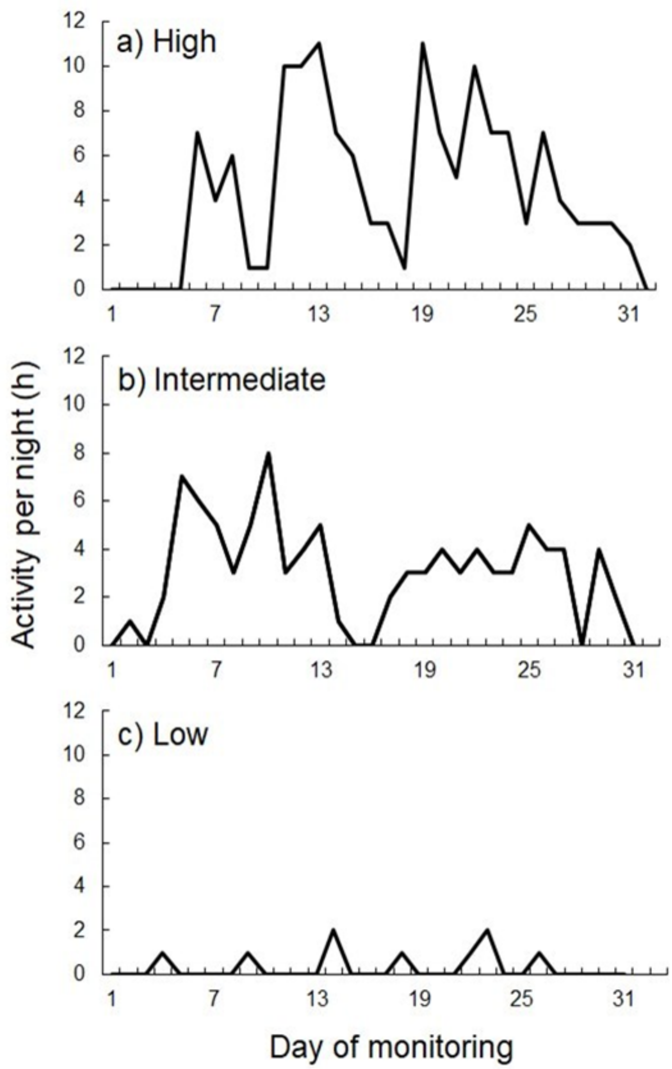

Figure 6. Representative plots of nightly roof rat activity categorized in three activity groups (high activity = >4 hours of activity/night, *n* = 15; intermediate activity = 1-4 hours/night, *n* = 23, low activity = <1 hours/night, *n* = 34) from 90 yards in Orange County, California, USA, between December 2017 and August 2018 (Session 1). There was no rat activity in 18 yards.

APPENDIX C

SITE-LEVEL VARIABLES

Table A1. Yard characteristics of 90 sites trapped in Orange County, California, between December 2017 to August 2018 (Session 1, 90 yards) and September 2018 to March 2019 (Session 2, 64 yards). Bolded text indicated sites trapped in both Session 1 and 2.

Yard	Fruit	Nuts	Yard size (m^{-2})	Vegetation density	Anthropogenic food	Water	Pets	Livestock	Fence type	Rodent control	RC type
1	**Yes**	**No**	**347.23**	**Low**	**No**	**No**	**No**	**No**	**Non-permeable**	**No**	**None**
2	**Yes**	**No**	**99.50**	**High**	**No**	**No**	**No**	**No**	**Non-permeable**	**Yes**	**Trap**
3	**No**	**No**	**168.90**	**Low**	**No**	**Yes**	**No**	**No**	**None**	**No**	**None**
4	Yes	No	503.91	High	Yes	Yes	Yes	Yes	Non-permeable	Yes	Rodenticide
5	**Yes**	**No**	**186.92**	**Low**	**No**	**No**	**No**	**No**	**None**	**No**	**None**
6	**Yes**	**No**	**802.96**	**Moderate**	**Yes**	**Yes**	**No**	**No**	**Non-permeable**	**Yes**	**Trap**
7	**Yes**	**No**	**131.18**	**Low**	**Yes**	**Yes**	**Yes**	**No**	**Permeable**	**No**	**None**
8	**Yes**	**No**	**282.89**	**Low**	**Yes**	**Yes**	**No**	**No**	**Non-permeable**	**No**	**None**
9	**Yes**	**No**	**828.51**	**Low**	**No**	**Yes**	**No**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
10	**Yes**	**No**	**235.70**	**Low**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**No**	**None**
11	**Yes**	**No**	**218.04**	**High**	**No**	**Yes**	**Yes**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
12	**Yes**	**No**	**1217.87**	**Moderate**	**Yes**	**Yes**	**Yes**	**No**	**Permeable**	**Yes**	**Trap**
13	**Yes**	**No**	**461.45**	**Moderate**	**No**	**Yes**	**No**	**No**	**Non-permeable**	**No**	**None**
14	**Yes**	**No**	**499.54**	**Moderate**	**No**	**Yes**	**Yes**	**No**	**Non-permeable**	**No**	**None**
15	**Yes**	**No**	**146.79**	**Moderate**	**Yes**	**Yes**	**Yes**	**No**	**Non-permeable**	**Yes**	**Trap**
16	**No**	**No**	**27.96**	**High**	**Yes**	**Yes**	**Yes**	**No**	**Non-permeable**	**No**	**None**
17	Yes	No	243.03	High	No	No	Yes	No	Non-permeable	Yes	Rodenticide
18	**Yes**	**No**	**220.46**	**Moderate**	**Yes**	**Yes**	**No**	**No**	**Permeable**	**No**	**None**
19	Yes	No	263.47	Low	No	Yes	No	No	Non-permeable	No	None
20	Yes	No	108.98	Low	Yes	Yes	No	No	Non-permeable	No	None

Yard	Fruit	Nuts	Yard size (m^{-2})	Vegetation density	Anthropogenic food	Water	Pets	Livestock	Fence type	Rodent control	RC type
21	**Yes**	**No**	**378.02**	**Low**	**No**	**Yes**	**Yes**	**No**	**Permeable**	**No**	**None**
22	**Yes**	**No**	**786.24**	**Moderate**	**No**	**Yes**	**No**	**No**	**Non-permeable**	**Yes**	**Trap**
23	**Yes**	**No**	**187.57**	**Moderate**	**No**	**Yes**	**Yes**	**No**	**Non-permeable**	**No**	**None**
24	Yes	No	184.88	High	No	Yes	No	No	Non-permeable	Yes	Trap
25	**Yes**	**Yes**	**956.34**	**Moderate**	**Yes**	**Yes**	**Yes**	**Yes**	**Non-permeable**	**Yes**	**Trap**
26	**Yes**	**Yes**	**125.79**	**Moderate**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**Yes**	**Trap**
27	**Yes**	**No**	**240.34**	**Low**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**No**	**None**
28	Yes	No	259.01	Moderate	Yes	Yes	No	No	Non-permeable	No	None
29	Yes	No	72.19	Low	No	No	No	No	Non-permeable	No	None
30	**Yes**	**Yes**	**868.64**	**High**	**No**	**Yes**	**No**	**No**	**Non-permeable**	**No**	**None**
31	**Yes**	**No**	**196.21**	**High**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**Yes**	**Trap**
32	**Yes**	**No**	**139.73**	**Moderate**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**No**	**None**
33	**Yes**	**No**	**150.87**	**Low**	**No**	**No**	**No**	**No**	**Non-permeable**	**No**	**None**
34	Yes	No	114.27	Low	No	Yes	Yes	No	Permeable	Yes	Trap
35	**Yes**	**No**	**609.91**	**Moderate**	**No**	**No**	**Yes**	**No**	**Permeable**	**Yes**	**Trap**
36	**Yes**	**No**	**273.60**	**Moderate**	**Yes**	**Yes**	**Yes**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
37	**No**	**No**	**301.01**	**Moderate**	**No**	**Yes**	**No**	**No**	**None**	**Yes**	**Rodenticide**
38	**Yes**	**Yes**	**2675.42**	**Moderate**	**Yes**	**Yes**	**Yes**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
39	Yes	No	80.08	High	No	No	No	No	Non-permeable	Yes	Trap
40	**Yes**	**No**	**159.05**	**Moderate**	**No**	**Yes**	**No**	**No**	**Non-permeable**	**No**	**None**
41	Yes	No	236.81	Low	Yes	Yes	No	No	Non-permeable	No	None
42	**Yes**	**No**	**103.12**	**Moderate**	**No**	**No**	**No**	**No**	**Non-permeable**	**No**	**None**
43	**Yes**	**Yes**	**968.70**	**High**	**Yes**	**No**	**No**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
44	**Yes**	**No**	**126.44**	**High**	**Yes**	**No**	**No**	**No**	**Non-permeable**	**Yes**	**Trap**
45	Yes	No	395.67	Moderate	No	Yes	Yes	No	Non-permeable	No	None

Yard	Fruit	Nuts	Yard size (m^{-2})	Vegetation density	Anthropogenic food	Water	Pets	Livestock	Fence type	Rodent control	RC type
46	**Yes**	**No**	**368.55**	**Low**	**No**	**Yes**	**Yes**	**No**	**Permeable**	**No**	**None**
47	**Yes**	**No**	**254.37**	**High**	**No**	**Yes**	**Yes**	**No**	**Permeable**	**No**	**None**
48	Yes	No	99.22	Low	No	No	Yes	No	Non-permeable	No	None
49	**Yes**	**No**	**321.91**	**Low**	**Yes**	**Yes**	**Yes**	**No**	**Permeable**	**No**	**None**
50	**Yes**	**No**	**92.53**	**Moderate**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**Yes**	**Trap**
51	Yes	No	172.24	Moderate	Yes	Yes	Yes	Yes	Non-permeable	No	None
52	Yes	No	1050.36	Low	Yes	Yes	No	Yes	Permeable	Yes	Trap
53	**Yes**	**No**	**2217.13**	**Low**	**No**	**No**	**Yes**	**No**	**None**	**Yes**	**Trap**
54	No	No	284.28	Moderate	Yes	No	Yes	No	Non-permeable	No	None
55	**Yes**	**No**	**688.69**	**Moderate**	**No**	**Yes**	**Yes**	**No**	**Non-permeable**	**Yes**	**Trap**
56	**Yes**	**No**	**382.76**	**High**	**Yes**	**No**	**Yes**	**No**	**Permeable**	**No**	**None**
57	Yes	No	285.86	Moderate	No	Yes	Yes	No	Permeable	No	None
58	**Yes**	**No**	**319.21**	**High**	**No**	**No**	**No**	**No**	**Non-permeable**	**No**	**None**
59	**Yes**	**No**	**303.61**	**Low**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**Yes**	**Trap**
60	**Yes**	**Yes**	**146.69**	**Moderate**	**No**	**No**	**Yes**	**No**	**Permeable**	**Yes**	**Rodenticide**
61	**Yes**	**No**	**144.65**	**Low**	**No**	**Yes**	**Yes**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
62	**Yes**	**No**	**154.68**	**Low**	**Yes**	**Yes**	**Yes**	**No**	**Non-permeable**	**No**	**None**
63	**Yes**	**No**	**2346.45**	**Low**	**Yes**	**Yes**	**Yes**	**Yes**	**Permeable**	**No**	**None**
64	**Yes**	**No**	**255.95**	**High**	**No**	**No**	**No**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
65	Yes	No	319.03	Low	No	Yes	No	No	Non-permeable	No	None
66	Yes	No	98.11	Moderate	No	No	No	No	Non-permeable	No	None
67	Yes	No	529.45	Low	No	No	No	No	Non-permeable	No	None
68	**Yes**	**No**	**43.94**	**Low**	**No**	**No**	**No**	**No**	**Permeable**	**No**	**None**
69	**Yes**	**No**	**59.74**	**High**	**Yes**	**Yes**	**Yes**	**No**	**Non-permeable**	**No**	**None**
70	Yes	No	541.81	Low	No	No	No	No	None	No	None

Yard	Fruit	Nuts	Yard size (m^{-2})	Vegetation density	Anthropogenic food	Water	Pets	Livestock	Fence type	Rodent control	RC type
71	**Yes**	**No**	**523.79**	**High**	**No**	**No**	**No**	**No**	**Non-permeable**	**Yes**	**Trap**
72	**Yes**	**No**	**283.91**	**Low**	**No**	**No**	**No**	**No**	**Non-permeable**	**No**	**None**
73	**Yes**	**No**	**380.07**	**Low**	**No**	**No**	**Yes**	**No**	**None**	**Yes**	**Trap**
74	Yes	No	146.97	Low	No	No	Yes	No	Non-permeable	No	None
75	**Yes**	**No**	**190.17**	**Moderate**	**Yes**	**Yes**	**No**	**No**	**Non-permeable**	**Yes**	**Trap**
76	Yes	No	416.76	Moderate	No	Yes	Yes	No	Non-permeable	No	None
77	**Yes**	**No**	**133.59**	**Low**	**No**	**No**	**Yes**	**No**	**None**	**No**	**None**
78	**Yes**	**No**	**18.77**	**Low**	**No**	**No**	**No**	**No**	**Non-permeable**	**No**	**None**
79	No	No	108.98	Low	Yes	Yes	Yes	Yes	None	Yes	Rodenticide
80	No	No	60.57	Low	No	Yes	No	No	Non-permeable	No	None
81	**Yes**	**No**	**312.43**	**Low**	**No**	**Yes**	**No**	**No**	**Non-permeable**	**No**	**None**
82	**Yes**	**No**	**411.10**	**Low**	**Yes**	**Yes**	**Yes**	**No**	**Non-permeable**	**Yes**	**Rodenticide**
83	**Yes**	**No**	**168.53**	**Low**	**Yes**	**No**	**No**	**No**	**Non-permeable**	**No**	**None**
84	**Yes**	**No**	**603.50**	**Low**	**No**	**Yes**	**No**	**No**	**Permeable**	**No**	**None**
85	**Yes**	**No**	**879.98**	**Low**	**No**	**Yes**	**Yes**	**No**	**Permeable**	**No**	**None**
86	Yes	No	379.88	Low	No	No	No	No	Permeable	No	None
87	**Yes**	**No**	**185.43**	**Moderate**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**No**	**None**
88	Yes	No	75.44	Low	No	No	No	No	Permeable	No	None
89	**Yes**	**No**	**182.00**	**High**	**Yes**	**Yes**	**Yes**	**No**	**Permeable**	**Yes**	**Rodenticide**
90	**Yes**	**No**	**157.84**	**High**	**No**	**No**	**Yes**	**No**	**Non-permeable**	**No**	**None**

APPENDIX D

LANDSCAPE CHARACTERISTICS

Table A2. Landscape characteristics of 90 sites trapped in Orange County, California, between December 2017 to August 2018 (Session 1, 90 yards) and September 2018 to March 2019 (Session 2, 64 yards). Bolded text indicated sites trapped in both session one and two.

Yard	Distance to Natural area (km)	Distance to ODS (m)	Housing density (km^{-2})	Road length (km)	Urban (%)	Wild (%)
1	**1.51**	**237**	**90.90**	**8.80**	**99.31**	**0.69**
2	**0.19**	**177**	**70.68**	**9.14**	**82.93**	**12.94**
3	**0.55**	**98**	**66.64**	**8.46**	**90.34**	**9.66**
4	3.86	341	95.80	10.46	100.00	0.00
5	**0.86**	**146**	**69.56**	**7.54**	**95.18**	**4.82**
6	**0.67**	**85**	**63.32**	**6.50**	**100.00**	**0.00**
7	**0.93**	**140**	**51.33**	**5.46**	**90.71**	**9.29**
8	**3.55**	**351**	**100.00**	**6.61**	**100.00**	**0.00**
9	**3.18**	**116**	**38.81**	**5.79**	**90.30**	**9.70**
10	**2.56**	**425**	**100.00**	**9.48**	**100.00**	**0.00**
11	**3.94**	**172**	**78.15**	**8.98**	**96.10**	**1.38**
12	**0.77**	**353**	**64.93**	**6.91**	**99.31**	**0.69**
13	**0.89**	**241**	**89.73**	**9.01**	**98.74**	**1.26**
14	**0.51**	**348**	**79.18**	**9.90**	**100.00**	**0.00**
15	**2.16**	**334**	**86.25**	**8.07**	**91.82**	**1.61**
16	**0.35**	**20**	**94.29**	**10.59**	**100.00**	**0.00**
17	2.48	270	77.11	10.02	98.51	1.49
18	**0.28**	**0**	**49.61**	**7.53**	**83.63**	**16.37**
19	3.02	123	99.82	10.93	100.00	0.00
20	2.07	117	100.00	10.58	94.27	0.57
21	**0.09**	**10**	**75.61**	**7.86**	**98.62**	**1.38**
22	**1.69**	**95**	**80.49**	**8.20**	**88.85**	**1.26**

Yard	Distance to Natural area (km)	Distance to ODS (m)	Housing density (km^{-2})	Road length (km)	Urban (%)	Wild (%)
23	**3.74**	**454**	**100.00**	**7.84**	**98.51**	**1.49**
24	2.80	106	100.00	11.84	98.05	1.95
25	**0.73**	**58**	**61.67**	**7.84**	**96.44**	**3.56**
26	**2.31**	**356**	**100.00**	**12.27**	**100.00**	**0.00**
27	**0.76**	**387**	**100.00**	**8.25**	**100.00**	**0.00**
28	2.56	209	100.00	10.30	100.00	0.00
29	0.61	0	31.07	5.28	91.22	8.78
30	**3.30**	**645**	**95.78**	**10.30**	**100.00**	**0.00**
31	**3.32**	**558**	**96.66**	**10.61**	**100.00**	**0.00**
32	**2.96**	**63**	**93.23**	**9.97**	**97.56**	**2.44**
33	**4.78**	**50**	**87.85**	**10.43**	**95.98**	**4.02**
34	0.44	0	31.60	5.24	86.63	13.37
35	**0.00**	**0**	**42.55**	**6.88**	**66.55**	**33.45**
36	**0.26**	**0**	**60.88**	**7.36**	**84.29**	**15.71**
37	**0.33**	**50**	**63.36**	**8.47**	**86.77**	**13.23**
38	**0.19**	**59**	**46.86**	**5.17**	**98.62**	**1.38**
39	1.98	331	72.88	6.76	96.54	3.46
40	**2.24**	**151**	**70.70**	**9.08**	**95.51**	**4.49**
41	3.42	149	94.36	10.29	100.00	0.00
42	**1.61**	**279**	**100.00**	**13.82**	**98.85**	**1.15**
43	**1.28**	**187**	**84.93**	**6.84**	**99.77**	**0.23**
44	**1.12**	**93**	**97.27**	**10.25**	**100.00**	**0.00**
45	0.83	161	100.00	12.09	99.20	0.80
46	**1.57**	**0**	**47.66**	**6.60**	**95.31**	**4.69**
47	**0.13**	**84**	**38.73**	**6.77**	**77.32**	**22.68**
48	0.14	128	33.22	5.87	78.19	21.81
49	**1.61**	**380**	**99.66**	**10.51**	**100.00**	**0.00**
50	**1.18**	**116**	**66.32**	**9.27**	**100.00**	**0.00**

Yard	Distance to Natural area (km)	Distance to ODS (m)	Housing density (km^{-2})	Road length (km)	Urban (%)	Wild (%)
51	2.87	0	46.82	5.42	80.74	19.26
52	1.37	0	67.16	8.78	80.74	19.26
53	**0.00**	**0**	**33.77**	**5.63**	**79.41**	**20.59**
54	0.62	0	63.04	8.60	89.24	10.76
55	**0.65**	**90**	**100.00**	**10.00**	**100.00**	**0.00**
56	**1.62**	**164**	**11.51**	**8.65**	**98.62**	**1.38**
57	0.66	153	53.45	7.44	95.10	4.90
58	2.02	230	72.09	5.70	97.82	2.18
59	2.21	234	85.43	10.95	100.00	0.00
60	**1.56**	**0**	**70.34**	**8.13**	**83.41**	**16.59**
61	**1.92**	**250**	**69.83**	**9.41**	**100.00**	**0.00**
62	**3.12**	**113**	**70.67**	**9.13**	**89.09**	**10.91**
63	**0.26**	**261**	**48.18**	**5.55**	**96.79**	**3.21**
64	**2.18**	**357**	**100.00**	**10.79**	**99.88**	**0.12**
65	0.46	84	98.66	10.12	96.68	3.32
66	2.72	301	97.62	11.90	99.65	0.35
67	3.88	147	57.55	9.56	94.38	5.39
68	**0.00**	**0**	**45.39**	**6.43**	**68.88**	**31.12**
69	**0.74**	**128**	**76.58**	**10.08**	**95.31**	**4.69**
70	0.28	0	28.73	3.27	54.86	45.14
71	**0.09**	**0**	**48.51**	**6.84**	**78.83**	**21.17**
72	**3.74**	**268**	**95.77**	**10.89**	**99.06**	**0.94**
73	**0.00**	**0**	**50.71**	**5.98**	**90.71**	**9.29**
74	2.29	110	64.33	8.22	95.16	4.84
75	**1.46**	**235**	**99.70**	**10.91**	**100.00**	**0.00**
76	1.49	101	66.53	9.69	100.00	0.00
77	**0.32**	**0**	**77.27**	**9.09**	**95.54**	**4.46**
78	**1.80**	**839**	**88.80**	**14.10**	**61.47**	**0.00**

Yard	Distance to Natural area (km)	Distance to ODS (m)	Housing density (km^{-2})	Road length (km)	Urban (%)	Wild (%)
79	0.36	85	41.32	8.04	90.21	9.79
80	0.71	151	79.21	9.89	95.43	4.57
81	**1.58**	**495**	**98.90**	**10.77**	**100.00**	**0.00**
82	**1.17**	**121**	**78.78**	**9.52**	**97.59**	**2.41**
83	**1.64**	**44**	**80.94**	**10.34**	**98.51**	**0.00**
84	**0.57**	**0**	**44.54**	**7.01**	**92.46**	**7.54**
85	**1.98**	**625**	**95.96**	**8.09**	**100.00**	**0.00**
86	2.35	624	77.88	9.95	99.77	0.23
87	**4.03**	**165**	**100.00**	**9.91**	**99.42**	**0.58**
88	0.08	0	34.17	4.41	73.82	26.18
89	**0.88**	**347**	**75.83**	**9.51**	**97.48**	**2.52**
90	**0.21**	**189**	**43.29**	**6.35**	**82.01**	**17.99**

REFERENCES

Almeida, A., R. Corrigan, and Sarno. 2013. The economic impact of commensal rodents on small businesses in Manhattan's Chinatown: trends and possible causes. Suburban Sustainability 1:1-11.

Barthelmess, E. L., and M. S. Brooks. 2010. The influence of body-size and diet on road-kill trends in mammals. Biodiversity and Conservation 19:1611-1629.

Bautista, A. C., L.W. Woods, M. S. Filigenzi and B. Puschner. 2014. Bromethalin poisoning in a raccoon (*Procyon lotor*): diagnostic considerations and relevance to nontarget wildlife. Journal of Veterinary Diagnostic Investigation 26:154-157.

Bozek, C. K., S. Prange, and S. D. Gehrt. 2007. The influence of anthropogenic resources on multi-scale habitat selection by raccoons. Urban Ecosystems 10:413-425.

Brakes, C. R., and R. H. Smith. 2005. Exposure of non-target small mammals to rodenticides: short-term effects, recovery and implications for secondary poisoning. Journal of Applied Ecology 42:118-128.

Brooks, J. E., and W. B. Jackson. 1973. A review of commensal rodents and their control. CRC Critical Reviews in Environmental Control 3:405-453.

Colvin BA and Jackson WB, Urban rodent control programs for the 21st century, in Ecologically-based rodent management of rodent pests, ed. by Singleton GR, Australian Centre for International Agricultural Research, Canberra, Australia, pp. 243-257 (1999).

Cypher, B. L., T. L. Westall, and C. V. H. Job. 2014. Rodenticide exposure among endangered kit foxes relative to habitat use in an urban landscape. Cities and the Environment 7:1-18.

Elliott, J., S. Hindmarch, S. A. Albert, J. Emery, P. Mineau, and F. Maisonneuve. 2013. Exposure pathways of anticoagulant rodenticides to nontarget wildlife to nontarget wildlife. Environmental Monitoring and Assessment 186:895-906

Erickson, W., and D. Urban. 2004. Potential risks of nine rodenticides to birds and nontarget mammals: a comparative approach, Office of Prevention, Pesticides and Toxic Substances, U.S. Environmental Protection Agency, Washington DC

Erickson, W.A., R. E. Marsh, and W. L. Halvorson. 1990. A roof rat bait station that excludes deer mice. Wildlife Society Bulletin 18:319-325.

ESRI 2011. ArcGIS Desktop: Release 10. Redlands, CA: Environmental Systems Research Institute.

Fidino, M. A., E. W. Lehrer, and S. B. Magle. 2016. Habitat dynamics of the Virginia opossum in a highly urban landscape. The American Midland Naturalist 175:155-167.

Fitch, H. S. 1953. Comparison from radiotracking of movements and denning habits of the raccoon, striped skunk, and opossum in northwest Kansas. Journal of Mammalogy 51:491-503.

Fiske, I., and R. Chandler. 2011. Unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance. Journal of Statistical Software, 43:1-2.

Gehrt, S. D., E. C. Wilson, J. L. Brown, and C. Anchor. 2013. Population ecology of free-roaming cats and interference competition by coyotes in urban parks. PLoS ONE 8:1-11.

Grinder, M. I., and P. R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. The Journal of Wildlife Management 887-898.

Hawkins, C. C., W. E. Grant, and M. T. Longnecker. 2004. Effect of house cats, being fed in parks, on California birds and rodents. Proceedings 4th International Urban Wildlife Symposium 164-170.

Himsworth, C.G., K. L. Parsons, C. Jardine, and D. M. Patrick. 2013. Rats, cities, people, and pathogens: A systematic review and narrative synthesis of literature regarding the ecology of rat-associated zoonoses in urban centers. Vector-Borne Zoonotic Diseases 13:349-359.

Hindmarch, S., J. E. Elliott, S. McCann, and P. Levesque. 2017. Habitat use by barn owls across a rural to urban gradient and an assessment of stressors including, habitat loss, rodenticide exposure and road mortality. Landscape and Urban Planning 164:132-143.

Hoare, J. M., and K. M. Hare. 2017. The impact of brodifacoum on non-target wildlife: gaps in knowledge. New Zealand Journal of Ecology 30:157-167.

Howald, G. C., C. J. Donoan, J. P. Galván, J. C. Russel, J. Parkes, A. Samaniego, Y. Wang, D. Veitch, P. Genovesi, M. Pascal, and A. Saunders. 2007. Invasive rodent eradication on islands. Conservation Biology 21:1258-1268.

Inglis, I. R., D. S. Shepherd, P. Smith, P. F. Haynes, D. S. Bull, D. P. Cowan, and D. Whitehead. 1996. Foraging behaviour of wild rats (*Rattus norvegicus*) towards new foods and bait containers. Applications of Animal Behavior Science 47:175-190.

Johnston, J. J., W. C. Pitt, R. T. Sugihara, J. D. Eisemann, T. M. Primus, M. J. Holmes, J. Crocker, and A. Hart. 2005. Probabilistic risk assessment for snails, slugs, and endangered honeycreepers in diphacinone rodenticide baited areas on Hawaii, USA. Environmental Toxicology and Chemistry: An International Journal 24:1557-1567.

Lapuz, R., H. Tani, K. Sasai, K. Shirota, H. Katoh, and E. Baba. 2008. The role of roof rats (*Rattus rattus*) in the spread of *Salmonella enteritidis* and *S. infantis* contamination in layer farms in eastern Japan. Epidemiology and Infection 136:1235-1243.

Larson, R. H. J. L. Brown, T. Karels, and S. P. D. Riley. 2020. Effects of urbanization on resource use and individual specialization in coyotes (*Canis Latrans*) in southern California. PloS One 15: e0228881.

Leung, L. K. P., and N. M. Clark. 2005. Bait avoidance and habitat use by the roof rat, *Rattus rattus*, in a piggery. International Biodeterioration and Biodegradation 55:77-84.

Lever, C. 1994. Naturalized animals: the ecology of successfully introduced species. T & AD Poyser Ltd.

Lotts, B., and P. Stapp. 2020. Consumption of rat carcasses as a pathway of rodenticide exposure of wildlife in southern California, in Proceedings of the 29th Vertebrate Pest Conference, ed. by D. M. Woods and R. M. Timm, University of California, Davis, Paper 63, pp. 1-3.

Mason, M. H., R. E. Byers, and D. E. Kaukeinen. 1984. Residues of the rodenticide brodifacoum in voles and raptors after orchard treatment. Journal of Wildlife Management 48:212-216.

Mccleery, R. A., R. R. Lopez, N. J. Silvy, & D. L. Gallant. 2008. Fox squirrel survival in urban and rural environments. The Journal of wildlife management 72:133-137.

Mughini Gras, L., M. Patergnani, and M. Farina. 2012. Poison-based commensal rodent control strategies in urban ecosystems: Some evidence against sewer-baiting. Ecohealth 9:75-79.

Murray, M. 2017. Anticoagulant rodenticide exposure and toxicosis in four species of prey presented to a wildlife clinic in Massachusetts, 2006–2010. Journal of Zoo and Wildlife Medicine 42:88-97.

Murray, M., A. Cembrowski, A. D. M. Latham, V. M. Lukasik, S. Pruss, and C. C. St Clair. 2015. Greater consumption of protein-poor anthropogenic food by urban relative to rural coyotes increases diet breadth and potential for human-wildlife conflict. Ecography 38:1235-1242.

Murray, M., and F. Tseng. 2008. Diagnosis and treatment of secondary anticoagulant rodenticide toxicosis in a Red-tailed Hawk (*Buteo jamaicensis*). Journal of Avian Medicine and Surgery 22:41-46.

Parsons, M. H., P. B. Banks, M.A. Deutsch, R. F. Corriga, and J. Munshi-South. 2017. Trends in urban rat ecology: a framework to define the prevailing knowledge gaps and incentives for academia, pest management professionals (PMPs) and public health agencies to participate. Journal of Urban Ecology 3:1-8.

Penicks, A., L. Krueger, J. Campbell, C. Fogarty, D. Rangel, K. Nguyen, and R. Cummings. Flea abundance, species composition and prevalence of Rickettsioses from urban wildlife in Orange County, California, 2015-2019. , in Proceedings of the 29th Vertebrate Pest Conference: Paper 69, pp. 1-7.

Pitt, W. C., L. C. Driscoll, and R. T. Sugihara. 2011. Efficacy of rodenticide baits for the control of three invasive rodent species in Hawaii. Archives of Environmental Contamination and Toxicology 60:533-542.

Poessel, S. A., S. W. Breck, K. A. Fox, and E. M. Gese. 2015. Anticoagulant rodenticide exposure and toxicosis in coyotes (*Canis latrans*) in the Denver Metropolitan Area. Journal of Wildlife Diseases 51:265-268.

Pimentel, D., L. Lach, R. Zuniga, and D. Morrison. 2000. Environmental and economic costs of nonindigenous species in the United States. BioScience 50:53-65.

Prat-Mariret, Y. I. Fourel, J. Barrat, M. Sage, P. Giraudoux, and M. Coeurdassier. 2017. Non-invasive monitoring of red fox exposure to rodenticides from scat. Ecological Indicators 72:777-783.

Quinn, J. H., Y. A. Girard, K. Gilardi, Y. Hernandez, R. Poppenga, and B. Bruno. 2012. Pathogen and rodenticide exposure in American badgers (*Taxidea taxus*) in California. Journal of Wildlife Diseases 48:467-472.

Quinn, N. and C. Swift. 2018. What do we need to know to assess individual and population-level effects on wildlife from rodenticides? Proceedings of the Vertebrate Pest Conference 28:235-242.

Rattner, B. A., K. E. Horak, S. E. Warner, D. D. Day, C. U. Meteyer, S. F. Volker, J. Eisemann, and J. J. Johnston. 2011. Acute toxicity, histopathology, and coagulopathy in American kestrels (*Falco sparverius*) following administration of the rodenticide diphacinone. Environmental Toxicology and Chemistry 30:1213-1222.

Riley, S. P. D., R. M. Sauvajot, T. K. Fuller, E. C. York, D. A. Kamradt, C. Bromley, and R. K. Wayne. 2003. Effects of urbanization and habitat fragmentation on bobcats and coyotes in southern California. Conservation Biology 17:566-576.

Riley, S. P. D., C. Bromley, R. H. Poppenga, F. A. Uzal, L. Whited, and R. M. Sauvajot. 2017. Southern California anticoagulant exposure and notoedric mange in bobcats and mountain lions in urban southern California. The Journal of Wildlife Management 71:1874-1884.

Sainsbury, K. A., R. F. Shore, H. Schofield, E. Croose, M. G. Pereira, D. Sleep, A. C. Kitchener, G. Hantke, and R. A. McDonald. 2018. Long-term increase in secondary exposure to anticoagulant rodenticides in European polecats *Mustela putorius* in Great Britain. Environmental Pollution 236:689-698.

Serieys, L. E. K., T. C. Armenta, J. G. Moriarty, E. E. Boydston, L. M. Lyren, R. H. Poppenga, K. R. Crooks, R. K. Wayne, and S. P. Riley. 2015. Anticoagulant rodenticides in urban bobcats: exposure, risk factors and potential effects based on a 16-year study. Ecotoxicology 24:844-862.

Shore, R. F., P. A. Henrys, and L. A. Walker. 2014. Power analysis of liver second generation anticoagulant rodenticide (SGAR) residue data in barn owls from Britain: a predatory bird monitoring scheme (PBMS) report. CEH contract report to the Health & Safety Executive. 45.

Spurr, E. B., G. Morriss, J. Turner, C. E. O'Connor, and P. Fisher. 2007. Bait station preferences of ship rats. DOC Research and Development Series 271:1-20.

Stansley, W., M. Cummings, D. Vudathala, and L. A. Murphy. 2014. Anticoagulant rodenticides in red-tailed hawks, *Buteo jamaicensis*, and great horned owls, *Bubo virginianus*, from New Jersey, USA, 2008–2010. Bulletin of Environmental Contamination and Toxicology 92:6-9.

Stone, W. B., J. C. Okoniewski, and J. R. Stedelin. 1999. Poisoning of wildlife with anticoagulant rodenticide in New York. Journal of Wildlife Diseases 35:187-193.

Sunquist, M. E., S. N. Adams, and F. Sunquist. 1987. Movement patterns and home ranges in common opossums (*Didelphis marsupialis*). Journal of Mammalogy 68:173-176.

Taylor, L., and D. F. Hochuli. 2017. Defining greenspace: Multiple uses across multiple disciplines. Landscape and Urban Planning 158:25-38.

Thompson, C., R. Sweitzer, M. Gabriel, K. Purcell, R. Barrett, and R. Poppenga. 2014. Impacts of rodenticide and insecticide toxicants from marijuana cultivation sites on fisher survival rates in the Sierra National Forest, California. Conservation Letters 7:91-102.

Traweger, D., R. Travnitzky, C. Moser, C. Walzer, and G. Bernatzky. 2006. Habitat preferences and distribution of the brown rat (*Rattus norvegicus* Berk.) in the city of Salzburg (Austria): implications for an urban rat management. Journal of Pest Science 79:113-125.

Quinn, T. 1997. Coyote (*Canis latrans*) food habits in three urban habitat types of western Washington. Northwest Science 71:1-5.

Weir, S. M., S. Yu, A. Knox, L. G. Talent, J. M. Monks, and C. J. Salice. 2016. Acute toxicity and risk to lizards of rodenticides and herbicides commonly used in New Zealand. New Zealand Journal of Ecology, 40:342-350.

Whisson, D. A. 1998. Modified bait stations for California ground squirrel control in endangered kangaroo rat habitat, in Proceedings of the 18th Vertebrate Pest Conference, ed. by R. O. Baker R.O. and A. C. Crabb, University of California, Davis, pp. 233-235

Williams, D. E., and R. M. Corrigan. 1994. The handbook: prevention and control of wildlife damage. University of Nebraska, Lincoln, USA.

Witmer, G., and J. D. Eisemann. 2007. Rodenticide use in rodent management in the United States: an overview. Proceedings of the 12th Wildlife Damage Management Conference 114-118.

Wood, B. A., L. Cao, and M. D. Dearing. 2010. Deer mouse (*Peromyscus maniculatus*) home-range size and fidelity in sage-steppe habitat. Western North American Naturalist 70:345-354.