

Evaluating the effect of food-based lure and predator scent on detectability of mainland rodents
with implications for biosecurity on the California Channel Islands

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ABSTRACT

Due to their tendency to outcompete and prey upon native species, rodents are among the most harmful of all invasive species found on islands around the globe. Therefore, it is critical for island managers to develop effective, proactive methods of preventing and rapidly detecting rodent incursions on islands before populations become established and cause irreversible damage to ecosystems. The goal of this study is to strengthen biosecurity camera trap monitoring protocols on the California Channel Islands by identifying potential invasive rodents on the mainland and evaluating if their behavior changes in the presence of native predator odors, and thus influences their camera trap detectability if introduced to the Channel Islands. We deployed 24 camera traps at a mainland California site (Coal Oil Point Reserve, CA) to measure rodent detectability in the presence of a food lure (peanut butter) with and without the addition of a novel Santa Cruz Island fox (*Urocyon littoralis santacruzae*) scent. Woodrats showed no detectable response to either treatment, while black rat detection increased following both treatments, and mouse detection increased only after fox scent was added to the food lure. Our findings indicate that while the presence of native predators like the island fox is unlikely to deter rodents from detection devices, biosecurity efforts need to account for the various behaviors of invasive rodent taxa, including dietary and habitat preferences.

Islands are home to some of the most unique taxa on the planet, and thus high priority for conservation (Russell & Kueffer 2019). Endemic island taxa often evolved independently from mainland species, leading to a lack of evolutionary adaptation and vulnerability to novel sources of competition, predation, disease, and disturbance (Fordham & Brook 2010, Myers et al. 2000). Many islands also have limited habitat sizes, small populations of native species, and low overall species richness, making them especially prone to impacts of introduced species (Denslow 2003, Spatz et al. 2017). Invasive species can dominate island ecosystems because they often have no natural predators or competitors in their new environment, and many island taxa have lost defense mechanisms against predation (Hess 2016, Fritts & Rodda 1998). Globalization has drastically increased the number of vectors contacting once isolated islands, resulting in a significant increase in invasion rates (Fordham & Brook 2010). By transporting invasive species to remote islands, humans have disrupted longstanding island isolation, changing native communities drastically (Denslow 2003, Mooney & Cleland 2001).

Rodents in the Muroidea superfamily are the most widespread invasive taxon and are thought to have cumulatively damaged island ecosystems more than any other species group (Towns et al. 2006). *Rattus* and *Mus spp.* are the first and second most common invasive vertebrates, respectively, and non-native *Rattus spp.* are thought to be responsible for 40-60% of all recorded bird and reptile extinctions since 1600 (Harper et al. 2019, Spatz et al. 2017). A variety of characteristics make *Rattus spp.* (referred to hereafter as rats) and *Mus musculus* (referred to as mice) highly adaptable and successful in new environments, and thus problematic as invasive species (Whitmer & Shiels 2018). Rats and mice are habitat generalists (Ewer 1971, Angel et al. 2009), opportunistic feeders (Fordham & Brook 2010), and have high reproduction rates (J. C. Russell et al. 2008). Rats have been observed swimming up to 2 km (Russell & Clout

2005), and mice are proficient swimmers as well (Hiadlovská et al. 2012). Both thrive in coastal cities and harbors, are known vectors of disease, and have cryptic behavior (Bonnefoy et al. 2008, Panti-May et al. 2016), further increasing their likelihood of reaching islands and causing significant damage before detection. While rats and mice remain the most notorious island invaders, other non-native rodents can become established on islands, as evidenced by a recent invasion of woodrats (*Neotoma albigula*) on Wake Island in Micronesia (Eisemann et al. 2022).

Developing and implementing robust biosecurity protocols is a proactive tactic that can reduce the risk of harm to natural resources by invasive species like rats and mice (Boser et al. 2014). However, developing effective biosecurity plans for rodents can be challenging given their ubiquity, cryptic nature, commensal behaviors, and generalist feeding habits (Russell et al. 2008). Camera trapping has been identified as an efficient and low-impact survey technique for detecting and monitoring invasive species on islands (Lamelas-López & Salgado 2021). However, motion triggered camera traps are subject to imperfections, such as not detecting all species present, especially smaller mammals (Fidino et al. 2020, Gracanin et al. 2022). Managers often use bait and lures to try to increase detectability of their target species by bringing the target animal to the camera.

Lures have mostly been used on large carnivores, and research on the effect of lures on small prey species is mixed (Parsons et al. 2023). Some studies have found that lures increased small mammal detection (Mills et al. 2019, Witmer et al. 2008, Rendall et al. 2014), while other studies have found that lures had no effect on prey species (Holinda et al. 2020), and still others have found that lures decreased small prey detectability, possibly due to increased mesocarnivore visitation and the subsequent introduction of predator scent (Fidino et al. 2020). Nonetheless, the use of lures is common practice for biosecurity camera monitoring (Davis et al., 2023).

Animals like rodents will use olfactory cues not just to identify potential rewards like food, but also to evaluate risk of predation. Thus rodents may be attracted to a lure in front of a camera, but forgo engaging because of a perceived risk of predation, thus leading to a missed detection. Studies have found predator scent is a deterrent for rodents (Russell & Banks 2007), others have found that while rodents do pay attention to predator odors, the effect on their behavior isn't clear (Groeneveld & McGuinness 2010, Mcevoy et al. 2008). Other studies showed high individual variability in rat behavior when encountering predator scents, and had mixed results with predator scent as a consistent deterrent (Bramley et al. 2000). Furthermore, some studies have found predator scent was not a deterrent in rats (Banks 1998, Stryjek et al. 2018), and Parsons et al. (2023) found that predator scent actually attracted some rodent species.

The Channel Islands off the coast of southern California are an eight island archipelago. They host unique biodiversity, making them a conservation priority to be protected from invasive species, specifically rodents (Blue et al. 2011). Therefore, island managers, The Nature Conservancy, National Parks Service, U.S. Navy and Catalina Island Conservancy, have invested in preventative and early detection measures as part of their biosecurity plan for the islands (Bachman et al. 2013). Because rodents are considered a high biosecurity risk, both prevention and early detection are necessary to address the risks they pose (Bachman et al. 2013).

Given the high risk of non-native rodent invasion on the Channel Islands, understanding how rodents might interact with 1) lured camera traps and 2) the presence of endemic island predators is essential to improve island biosecurity measures. Avoidance of predator scent is a point of concern because island foxes (*Urocyon littoralis*) currently exist at high densities, up to 10 individuals/km², on six of the eight the Channel Islands and have been observed interacting with and marking existing camera trap stations immediately after the addition of lure (TNC

2022). Therefore, lure stations deployed for long-term monitoring or in response to an immediate biosecurity threat are likely to become quickly saturated with fresh fox scent (Fig. 1).

Our goal was to identify southern California rodent species that are potential threats to the Channel Islands and to measure how they react to food based lures with and without the addition of a predator scent. We hypothesized that an anthropogenic food-based lure (peanut butter) will increase the number of detections of rodents when compared to no lure, while the addition of a predator-scent to the food lure will decrease detections when compared to food lure alone. Rats and mice are particularly successful invaders, so we focused on detections of rats, mice, and woodrats in the Muroidea superfamily. While woodrats do not have a long history as invasive species, their relative abundance on the mainland means they could also pose a risk to the Channel Islands. The species we focused on include the black rat (*Rattus rattus*), big-eared woodrat (*Neotoma macrotis*), dusky-footed woodrat (*Neotoma fuscipes*), deer mouse (*Peromyscus maniculatus*), western harvest mouse (*Reithrodontomys megalotis*), and house mouse (*Mus musculus*). These species are all known to be present or common in coastal southern California, which is where a potential the Channel Islands invader would most likely originate from (Callahan et al. 2023).

Figure 1. Santa Cruz Island Fox (*Urocyon littoralis santacruzae*) investigating and marking lure stations at camera traps on Santa Cruz Island.

METHODS

Study Area and Site Selection

The study was conducted from June 30th through August 15th, 2023 at Coal Oil Point Reserve (COPR), a 71 hectare nature preserve part of the UC Natural Reserve System. It is

located on the University of California, Santa Barbara's west campus (34.4113845°N, -119.8781941°W) (Fig. 2). While the surrounding area has experienced moderate human development, COPR serves as a refuge for a variety of southern California native taxa, including close relatives of species found on the Channel Islands. COPR is roughly 45 km north and directly across the Santa Barbara Channel from the western end of Santa Cruz Island, the largest of the Channel Islands. While there are notable differences, COPR serves as a comparable study site with the Channel Islands as many taxa overlap or have diverged in the near past, vegetation types are similar, and the reserve experiences similar coastal climatic patterns (Callahan et al. 2023, Hofman et al. 2015). All activities involving animals were reviewed and approved by the Institutional Animal Care and Use Committee of the University of California Santa Barbara (IACUC protocol number: 979).

Figure 2. Map of the Coal Oil Point Reserve (COPR) study site in Santa Barbara, California.

Study Design

We created a grid layer of randomly generated 0.5 hectare hexagons using ArcGIS Pro that spanned the entirety of COPR, with each hexagon representing an estimated home range for an individual black rat in southern California (Recht 1988, ESRI 2023). The black rat home range estimate was used as it was the largest compared to woodrats and mice (Lynch et al. 1994, Quadagno 1968). The 24 camera stations were placed within individual 0.5 ha hexagons to ensure spatial independence of homeranges. Rendall et al. (2014) and Yiu et al. (2022) found that rat detections were higher in structurally complex habitats with high vegetation densities, as microhabitats likely provide shelter and higher resource availability. Thus, stations were placed

in close proximity to complex woody structures (such as oak and eucalyptus trees) and/or bodies of water to maximize detections of rats and other small mammals (Cox et al. 2000, Harper et al. 2005, Madden et al. 2020).

Each station consisted of one camera trap and one lure station. The initial 12 camera placements were set for the first 25 days of the study (session 1), then relocated to new stations for the remaining 21 days (session 2), totaling 24 locations across 6 weeks. In session 1, each of the 12 stations was assigned a control treatment for the first 10 days to capture activity prior to treatments being implemented. Peanut butter (PB) lures were randomly assigned to 9 of the 12 stations where they remained for the 2nd week, and the other 3 stations remained control treatments. Combined peanut butter and fox scent lures (PB + fox) replaced 6 of the 9 existing PB stations for the 3rd week, while 3 stations remained PB treatments and 3 remained control treatments. On the 4th week, all 12 camera stations were retrieved and relocated to 12 new, independent stations in different hexagons across COPR, initiating session 2. Again, each station was assigned a control treatment for the 4th week. PB treatment was assigned to 9 of the 12 stations and 3 stations remained controls for the 5th week. All stations were assigned a combined PB + fox treatment for the 6th week in order to collect additional data on the effect of predator scent on rodent detections.

Camera Stations

Reconyx Hyperfire 2 and Reconyx HC500 Hyperfire model cameras were set with high sensitivity to take three photo bursts upon detection, with no lag time until motion detection ceased. Each station contained one camera trap that was either screwed into metal fencing posts and hammered into the ground or strapped to a tree trunk (Fig. 3). Cameras were locked to a

nearby tree using cable bike locks to prevent removal. 32-GB SD cards and rechargeable AA batteries were refreshed weekly in each camera, and camera lenses were wiped of any dirt or dust. Treatment lures were placed roughly one meter directly in front of camera traps at each station, in the middle of the camera's motion sensor range (Fig. 4). Vegetation was partially cleared around the camera's motion sensor range to prevent false triggers from wind or shadows where necessary.

Figure 3. Camera trap stations with lure rod.

Figure 4. (Left to right) Woodrat, black rats, and a deer mouse investigating lures.

Lure sticks were constructed from 8-inch polyvinyl chloride (PVC) pipes with a pipe cap on the top end. The pipes were spray painted dark brown for camouflage, and each had eight $\frac{1}{8}$ inch holes drilled through the top to allow airflow. Control stations contained the PVC pipe lure stick with an empty cotton pad. For the peanut butter treatment, roughly 1 teaspoon of lure was rolled up in a cotton pad and placed into the end of the PVC pipe with the cap on to prevent removal. The fox scent was applied by adding approximately 5 grams of soiled trap bedding (straw) collected during routine island fox monitoring efforts on Santa Cruz Island during summer 2023. To minimize the risk of contamination, bedding was frozen at -4°C for 48 hours, then heated to 100°C for six hours before being inserted into the PVC lure station. The freezing/heating regime did not noticeably reduce the odor of the bedding.

Environmental Variables

Environmental variables were recorded for each of the 24 sites. Percent leaf litter, bare ground, and woody debris at each station were estimated by placing a 1m x 1m quadrat in front of each camera trap with the lure directly in the center. Percent canopy cover was estimated from a visual assessment directly above the quadrat. Distance to nearest water source (m) and distance to nearest residential building (m) were calculated using ArcGIS Pro software (ESRI 2023). We used hydrology vector layers obtained from COPR stewards detailing the varying water levels of the slough and pond throughout the year (COPR 2014). The varying water levels, represented by different sizes of polygons, were averaged to produce a single polygon that best represented the current water level of the slough and pond. We used the geoprocessing tool Generate Near Table to determine the distance between each camera location and the nearest point of the slough or pond polygons (ESRI 2023). A similar process was used to determine distance to the nearest residential building. We used Google Earth imagery to draw polygons representing each building, and applied the same geoprocessing tool to get the distance between each camera location and the nearest residential building. A COPR habitat type vector layer provided by COPR stewards was used to assign a habitat type for each station using the Spatial Join geoprocessing tool (COPR 2014, ESRI 2023).

Analysis

Raw images from the cameras' SD cards were categorized and identified using Timelapse (V.2.3.0.8, Greenberg 2023). Images were labeled by station, treatment, species, and individual counts, which were then compiled and exported as a CSV file for further analysis. Due to small size, phenotypic similarity, and poor image quality, all mice (house, deer, and western harvest

mice) images were labeled “Mouse”, as the probability of misidentifying them was substantial. To minimize error, species identifications were cross-validated with multiple researchers for woodrats and black rats. Analysis of tabulated image data was performed in RStudio® in an RMarkdown file (V.2023.06.0+421, RStudio Team 2020). The package camtrapR was used to transform the CSV image data into independent records of observations for each species (Niedballa et al. 2016). All observations of the same species and station that were taken within a 10-minute time frame were considered to be a single independent record. Independent records were then used to create a species detection history matrix listing the species’ presence or absence (absent = 0; present = 1) within a twenty-four hour time period for each day the camera was armed. Each twenty-four hour interval was set to start at 8:00 am until 7:59 am the following morning, as rodent observations primarily occurred at night.

The detection history matrices were used to perform single-species occupancy analyses to estimate the detection and occupancy probabilities of woodrats, black rats, and mice using treatments and environmental variables as covariates. Analyses were performed by creating a variety of detection and occupancy models with treatment as the detection covariate and the environmental variables as the occupancy (or state) covariates. Model creation, selection, and analysis was performed in RStudio® using the Unmarked package (Fiske & Chandler 2011). The occupancy model employed is a generalized linear model with a logistic regression framework. It utilizes a logit link function to analyze the binary detection (p) and occupancy (ψ) data, taking into account imperfect detection. The model parameter outputs are expressed as log odds, estimating the species’ likelihood of detection and occupancy. Each model was then compared to choose the model with the lowest Akaike Information Criterion (AIC) value where lower AIC values indicate a better fit. This considers both the maximum likelihood estimation (MLE) as

well as the complexity of the model to find the best fit. Confidence intervals were set at 95% across models.

RESULTS

Detection

Camera traps were deployed for a total of 538 camera days. The first 12 cameras ran for 25 days (stations 1-12), the second 12 cameras ran for 21 days (stations 21-32), and two of the cameras were out of operation for seven days (stations 21 and 29). A total of 13,899 images of rodents were recorded, composed of 4,684 woodrat photos, 7,759 black rat photos, and 1,455 mice photos. 1,374 independent records (413 woodrats, 724 black rats, and 237 mice) were consolidated from raw images. Black rats and mice were observed at 19 of the 24 stations, and wood rats were observed at 21 of the 24 stations. No rodents were observed at station 28. All other animal groups observed were identified and recorded but were not included in the analysis.

Figure 5. Effect Sizes of Lures. The mean effect of treatments \pm standard error for each species. Effect size is represented as the log-odds detection probability estimates derived from the model output, utilizing the logit link function. The vertical bars represent the standard error associated with each mean estimate.

PB and PB + fox scent lures had no significant effect on altering detection probabilities of woodrats ($\beta = 0.03 \pm 0.39$ SE, $z = 0.08$, $p > 0.94$; $\beta = 0.31 \pm 0.40$ SE, $z = 0.77$, $p > 0.44$) (Fig. 5; Table 1). PB and PB + fox scent lures had a significant and positive effect on detection probability of black rats ($\beta = 0.73 \pm 0.32$ SE, $z = 2.26$, $p < 0.05$; $\beta = 0.74 \pm 0.33$ SE, $z = 2.27$, $p < 0.05$). While the model estimated both lure types to increase the detection probability of mice,

the PB + fox scent was the only lure to have a significant effect on increasing detection probabilities ($\beta = 0.82 \pm 0.38$ SE, $z = 2.13$, $p < 0.05$).

Detection probability was lowest in controls, higher in PB treatment sites, and highest in PB + fox scent sites for woodrats, black rats, and mice. However, 95% confidence intervals overlap significantly for all woodrat observations in all treatments and control. Daily detection probability predictions varied greatly across sites and treatments for woodrats, black rats, and mice. Woodrats had 37.1% (95% CI = 22.9-54.0), 37.9% (95% CI = 30.2-46.2), and 44.5% (95% CI = 35.9-53.5) chances of being detected when control, peanut butter, and peanut butter + fox treatments were implemented respectively. Black rats had 42.9% (95% CI = 31.3-55.2), 61.0% (95% CI = 51.3-69.8), and 61.2% (95% CI = 51.3-70.3) chances of being detected when control, peanut butter, and peanut butter + fox treatments were implemented respectively. Mice had 26.5% (95% CI = 16.0-40.5), 28.6% (95% CI = 21.2-37.3), and 44.9% (95% CI = 35.3-54.8) chances of being detected when control, peanut butter, and peanut butter + fox treatments were implemented respectively.

Occupancy

Although not significant, percent woody debris was used as a predictor variable for estimating woodrat and mice occupancy in the chosen model as the covariate supported a better fit model than without it for both species. The chosen black rat occupancy model included both percent canopy cover and distance to nearest building as predictor variables (Table 2). While percent canopy cover did not show any significant effects on explaining black rat occupancy, it supported a better fit model than without the covariate. Distance to buildings had a significant negative effect on black rat occupancy probability ($z = -2.23$, $p < 0.05$) (Table 2).

Table 1. Model Output Summary (p). Parameter estimates and standard errors for the effects of predictor variables (Control, PB, and PB + fox) on detection probability (p) for species specific models.

Table 2. Model Output Summary (ψ). Parameter estimates and standard errors for the effects of predictor variables (percent woody debris, distance to building, and percent canopy cover) on occupancy (ψ) for species specific models.

DISCUSSION

Our results indicate that fox scent is not a deterrent for rodents interacting with lured camera traps. We did find differences in detectability between black rats, wood rats and mice perhaps due to competition and or diet preferences. While model estimates of detection probability were higher for woodrats when PB and PB + fox scent treatments were implemented, neither treatment had a significant effect on detecting woodrats. Measured environmental variables also did not explain woodrat occupancy across sites. However, percent woody debris was included as a covariate explaining woodrat occupancy in the chosen model, as it supported a lower AIC value. Detection probabilities of black rats significantly increased at sites with PB or PB + fox scent treatments, with near identical results for both treatment types. Black rat occupancy had a negative relationship to distance to nearest building (m), indicating higher likelihood of occupancy in close proximity to human activity. While percent canopy cover was not found to have a significant effect on black rat occupancy, it supported a better fit model where increased canopy cover decreased the probability of an individual occupying a site. PB + fox scent treatments significantly increased the probability of detecting mice across stations, but

PB alone had no effect. While no environmental variables had a significant effect on mice occupancy probability, percent woody debris was included in the model because it improved the model's fit.

These results suggest that woodrats are not as attracted to peanut butter scent lures when compared to other rodents. Atsatt & Ingram (1983) found that, compared to other *Neotoma spp.*, *N. macrotis* have an unusually specialized diet consisting mainly of the leaves of coast live oaks (*Quercus agrifolia*). It is possible that human food is not an effective lure in attracting *N. macrotis* due to their preference for oak vegetation. While *Rattus* seems to be the most likely rodent taxon to appear on the Channel Islands given their history of invasions and affinity for human settlements, the recent invasion of *Neotoma albigula* on Wake Island suggests that *Neotoma* are capable of surviving long distance transport and establishing on islands once introduced (Eisemann et al. 2022).

It is well established that black rats are commensal rodents, preferring to live in close proximity to humans and displaying opportunistic feeding behaviors (Traweger & Slotta-Bachmayr 2005). These commensal behaviors likely drive our results that anthropogenic food lures and development increase black rat detection and occupancy. Other studies have shown that black rats are more adapted to coastal regions compared to other species in the *Rattus* genus, which was evident in this study as they were the most commonly detected rodent on camera traps (Bonney et al. 2008). Stryjek et al. (2018) found that *Rattus sp.* were not deterred from investigating a food source when introduced to a predator's olfactory cues in a familiar environment. Similarly, Banks (1998) found that predator scent similarly wasn't a deterrent for *Rattus sp.*, which could explain why detection probabilities remained high at sites with peanut butter regardless of whether island fox scent was present or not. The gray fox (*Urocyon*

cinereoargenteus) is a close relative of the island fox and was documented at COPR during this study. Therefore, it is likely that black rats were already familiar with a close analogue of the fox scent lure used in this study.

Contrary to our hypotheses, mice showed an affinity for peanut butter only when fox scent was added. Parsons et al. (2023) found that wild mice in the *Apodemus* genus spent more time in chambers with predator scent, and proposed that prey animals may benefit from conducting “risk assessments” in a familiar and presumed-to-be safe environment. Because we were not able to consistently differentiate mice species on camera traps images, some species-specific behaviors may not have surfaced during this study. Compared to house mice, which are known to live amongst humans, western harvest mice and deer mice have cryptic behaviors and inhabit areas more removed from human activity (Nowak 1999). This could suggest that human food sources may not be of as much interest to either species as they have more specialized diets and are influenced less by anthropogenic activity, similar to woodrats.

These findings indicate that woodrats, black rats, and mice each pose different detection challenges and threats to island resources. Woodrat behavior implies that they may not respond to traditional food-based lures, potentially making them more difficult to detect in the event of an invasion. Woodrats may also favor undeveloped habitat on the Channel Islands (e.g. oak woodlands), making them strong competitors to endemic species and difficult to remove once established. Black rats were the most abundant and commensal potential invader, and therefore are the most likely to make it to the islands. However, black rats are attracted to food lures regardless of the presence of predator scent, and thus may be detected more readily using biosecurity methods than other, more cryptic rodent species. Mice were detected less frequently than wood rats and black rats, and deer mice are already found on all eight the Channel Islands.

However, mice still can act as a vector for disease, and thus remain of biosecurity concern for the Channel Islands.

This study provides insights on how potential invasive rodents respond to human food sources and predator scents. These findings should be taken into consideration when developing island biosecurity plans and used to predict how potential invaders may respond to both human and predator presence. Rodent species' responses to detection efforts are influenced by their varying life-history traits; thus it is critical that biosecurity protocols consider individual species of concern. While this study took place in a mainland environment where multiple rodent species are well-established, our results provide useful insight about general rodent behavior when introduced to a novel environment like the Channel Islands, and strengthen confidence that fox scent will not deter interaction with lured cameras. To further strengthen our understanding of potentially invasive rodent behavior future studies should investigate 1) the effectiveness of a variety of non-olfactory lures on rodent behavior, e.g. acoustic, and 2) species composition at sites that are closer to harbors with direct pathways to the neighboring islands.

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LITERATURE CITED

- Russell, J. C., & Kueffer, C. (2019). Island biodiversity in the Anthropocene. *Annual Review of Environment and Resources*, 44, 31-60.
- Angel, A., Wanless, R. M., & Cooper, J. (2009). Review of impacts of the introduced house mouse on islands in the Southern Ocean: Are mice equivalent to rats? *Biological Invasions*, 11(7), 1743–1754.
- Atsatt, P. R., & Ingram, T. (1983). Adaptation to oak and other fibrous, phenolic-rich foliage by a small mammal, *Neotoma fuscipes*. *Oecologia*, 60(1), 135–142.
- Bachman, K., Booker, M., Boser, C., & Bridges, A. (2013). *California Islands Biosecurity Program*. California Islands.
- Banks, P. B. (1998). Responses of Australian Bush Rats, *Rattus fuscipes*, to the Odor of Introduced *Vulpes vulpes*. *Journal of Mammalogy*, 79(4), 1260–1264.
- Blue, A., McKnight, S., Moore, C., Sanneman, C., & Sheehan, E. (2011). *Santa Cruz Island Biosecurity: Development of a Comprehensive Biosecurity Plan to Prevent the Establishment and Spread of Invasive Organisms*. UCSB Bren School of Environmental Science & Management.
- Bonnefoy, X., Kampen, H., & Sweeney, K. (2008). *Public Health Significance of Urban Pests*. World Health Organization.
- Bramley, G. N., Waas, J. R., & Henderson, H. V. (2000). Responses of Wild Norway Rats (*Rattus norvegicus*) to Predator Odors. *Journal of Chemical Ecology*, 26(3), 705–719.
- Callahan, K., Jennings, L., Sharp, M., & Ma, A. (2023). *Mammals of Coal Oil Point Reserve*. iNaturalist.
- COPR. (2014). *COPR Hydrology and Habitat Types*.

- Cox, M. P. G., Dickman, C. R., & Cox, W. G. (2000). Use of habitat by the black rat (*Rattus rattus*) at North Head, New South Wales: An observational and experimental study. *Austral Ecology*, 25(4), 375–385.
- Davis, R. A., Seddon, P. J., Craig, M. D., & Russell, J. C. (2023). A review of methods for detecting rats at low densities, with implications for surveillance. *Biological Invasions*, 25(12), 3773–3791.
- Denslow, J. S. (2003). Weeds in Paradise: Thoughts on the Invasibility of Tropical Islands. *Annals of the Missouri Botanical Garden*, 90, 119–127.
- Eisemann, J. D., Hall, T., Collins, A., Figuerola, C., Lanners, E., & Leinbach, I. (2022). *Wake Air Force Base Rat Eradication Project*. USDA Wildlife Services.
- ESRI. (2023). *ArcGIS Pro* (2.9). Environmental Systems Research Institute, Inc.
- Ewer, R. F. (1971). The biology and behaviour of a free-living population of black rats (*Rattus rattus*). *Animal Behaviour Monographs*, 4(3), 127–174.
- Fidino, M., Barnas, G. R., Lehrer, E. W., Murray, M. H., & Magle, S. B. (2020). Effect of Lure on Detecting Mammals with Camera Traps. *Wildlife Society Bulletin*, 44(3), 543–552.
- Fiske, I., & Chandler, R. (2011). unmarked: An R Package for Fitting Hierarchical Models of Wildlife Occurrence and Abundance. *Journal of Statistical Software*, 43, 1–23.
- Fordham, D. A., & Brook, B. W. (2010). Why tropical island endemics are acutely susceptible to global change. *Biodiversity and Conservation*, 19(2), 329–342.
- Fritts, T. H., & Rodda, G. H. (1998). The role of introduced species in the degradation of island ecosystems: A case history of guam. In *Annual Review of Ecology and Systematics* (Vol. 29, p. 28).
- Gracanin, A., Minchinton, T. E., & Mikac, K. M. (2022). Estimating the density of small

- mammals using the selfie trap is an effective camera trapping method. *Mammal Research*, 67(4), 467–482.
- Greenberg, S. (2023). *Timelapse: An Image Analyser for Camera Traps* (2.3.0.8).
- Groeneveld, B., & McGuinness, R. (2010). *Effects of red fox urine on foraging behavior in forest and residential populations of nocturnal rodents*. [Unpublished manuscript] University of Michigan.
- Harper, G. A., Carr, P., & Pitman, H. (2019). Eradicating black rats from the Chagos – working towards the whole archipelago. *Island Invasives: Scaling up to Meet the Challenge*.
- Harper, G., Seddon, P., & Dickinson, K. (2005). Habitat use by three rat species (*Rattus* sp.) on Stewart Island/Rakiura, New Zealand. *New Zealand Journal of Ecology*, 29, 251–260.
- Hess, S. C. (2016). A Tour de Force by Hawaii's Invasive Mammals: Establishment, Takeover, and Ecosystem Restoration through Eradication. *Mammal Study*, 41(2), 47–60.
- Hiadlovská, Z., Strnadová, M., Macholán, M., & Bímová, B. V. (2012). Is water really a barrier for the house mouse? A comparative study of two mouse subspecies. *Folia Zoologica*, 61(3–4), 319–329.
- Hofman, C. A., Rick, T. C., Hawkins, M. T. R., Funk, W. C., Ralls, K., Boser, C. L., Collins, P. W., Coonan, T., King, J. L., Morrison, S. A., Newsome, S. D., Sillett, T. S., Fleischer, R. C., & Maldonado, J. E. (2015). Mitochondrial Genomes Suggest Rapid Evolution of Dwarf California Channel Islands Foxes (*Urocyon littoralis*). *PLoS ONE*, 10(2), e0118240.
- Holinda, D., Burgar, J. M., & Burton, A. C. (2020). Effects of scent lure on camera trap detections vary across mammalian predator and prey species. *PLOS ONE*, 15(5), e0229055.

- Lamelas-López, L., & Salgado, I. (2021). Applying camera traps to detect and monitor introduced mammals on oceanic islands. *Oryx*, 55(2), 181–188.
- Lynch, M. F., Fesnock, A. L., & Van Vuren, D. (1994). Home Range and Social Structure of the Dusky-Footed Woodrat (*Neotoma fuscipes*). *Northwestern Naturalist*, 75(2), 73–75.
- Madden, H., Eggermont, E., & Verdel, K. (2020). Micro- and Macrohabitat Preferences of Invasive Rodents on St. Eustatius, Caribbean Netherlands. *Caribbean Journal of Science*, 50(2), 202–211.
- Mcevoy, J., Sinn, D. L., & Wapstra, E. (2008). Know thy enemy: Behavioural response of a native mammal (*Rattus lutreolus velutinus*) to predators of different coexistence histories. *Austral Ecology*, 33(7), 922–931.
- Mills, D., Fattebert, J., Hunter, L., & Slotow, R. (2019). Maximising camera trap data: Using attractants to improve detection of elusive species in multi-species surveys. *PLOS ONE*, 14(5), e0216447.
- Mooney, H. A., & Cleland, E. E. (2001). The evolutionary impact of invasive species. *Proceedings of the National Academy of Sciences*, 98(10), 5446–5451.
- Myers, N., Mittermeier, R. A., Mittermeier, C. G., da Fonseca, G. A. B., & Kent, J. (2000). Biodiversity hotspots for conservation priorities. *Nature*, 403(6772), Article 6772.
- Niedballa, J., Sollmann, R., Courtiol, A., & Wilting, A. (2016). camtrapR: An R package for efficient camera trap data management. *Methods in Ecology and Evolution*, 7(12), 1457–1462.
- Nowak, R. M. (1999). *Walker's Mammals of the World*. Johns Hopkins University Press.
- Panti-May, J., Hernández-Betancourt, S., Torres-Castro, M., Machaín-Williams, C., Cigarroa-Toledo, N., Sodá, L., López-Manzanero, G., Meza-Sulú, J., & Vidal-Martínez,

- V. (2016). Population Characteristics of Human-Commensal Rodents Present in Households from Mérida, Yucatán, México. *MANTER: Journal of Parasite Biodiversity*.
- Parsons, M. H., Stryjek, R., Bebas, P., Fendt, M., Blumstein, D. T., Kiyokawa, Y., Chrzanowski, M. M., & Munshi-South, J. (2023). Why are predator cues in the field not more evocative? A ‘real world’ assay elicits subtle, but meaningful, responses by wild rodents to predator scents. *Frontiers in Ecology and Evolution*, 10.
- Quadagno, D. M. (1968). Home Range Size in Feral House Mice. *Journal of Mammalogy*, 49(1), 149–151.
- Rendall, A., Sutherland, D., Cooke, R., & White, J. (2014). Camera Trapping: A Contemporary Approach to Monitoring Invasive Rodents in High Conservation Priority Ecosystems. *PloS One*, 9, e86592.
- RStudio Team. (2020). *RStudio: Integrated Development for R Studio* (2023.06.0+421), PBC, Boston, MA.
- Russell, B. G., & Banks, P. B. (2007). Do Australian small mammals respond to native and introduced predator odours? *Austral Ecology*, 32(3), 277–286.
- Russell, J. C., Towns, D., & Clout, M. (2008). Review of rat invasion biology: Implications for island biosecurity. *Science for Conservation*, 1–53.
- Russell, J., & Clout, M. (2005). *Rodent Incursions on New Zealand Islands*.
- Spatz, D. R., Zilliacus, K. M., Holmes, N. D., Butchart, S. H. M., Genovesi, P., Ceballos, G., Tershy, B. R., & Croll, D. A. (2017). Globally threatened vertebrates on islands with invasive species. *Science Advances*, 3(10), e1603080.
- Stryjek, R., Mioduszevska, B., Spaltabaka-Gędek, E., & Juszczak, G. R. (2018). Wild Norway Rats Do Not Avoid Predator Scents When Collecting Food in a Familiar Habitat: A Field

- Study. *Scientific Reports*, 8(1), Article 1.
- Tershy, B. R., Shen, K.-W., Newton, K. M., Holmes, N. D., & Croll, D. A. (2015). The Importance of Islands for the Protection of Biological and Linguistic Diversity. *BioScience*, 65(6), 592–597.
- TNC. (2022). *Santa Cruz Island Fox and Island Spotted Skunk Monitoring Report* (Report to California Department of Fish & Wildlife.). The Nature Conservancy.
- Towns, D. R., Atkinson, I. A. E., & Daugherty, C. H. (2006). Have the Harmful Effects of Introduced Rats on Islands been Exaggerated? *Biological Invasions*, 8(4), 863–891.
- Traweger, D., & Slotta-Bachmayr, L. (2005). Introducing GIS-modelling into the management of a brown rat (*Rattus norvegicus* Berk.) (Mamm. Rodentia Muridae) population in an urban habitat. *Journal of Pest Science*, 78, 17–24.
- Whitmer, G. W., & Shiels, A. B. (2018). Ecology, Impacts, and Management of Invasive Rodents in the United States. *United States Department of Agriculture*.
- Witmer, G., Burke, P., & Jojola, S. (2008). An Evaluation of the Effectiveness of Potential Norway Rat Attractants. *Proceedings of the Vertebrate Pest Conference*, 23.
- Yiu, S. W., Gronwald, M., Russell, J. C., Gronwald, M., & Russell, J. C. (2022). Reliable detection of low-density Pacific rats by using camera trapping. *Wildlife Research*, 50(5), 398–411.