EDEN LANDING ECOLOGICAL RESERVE PILOT STUDY ON PREDATORS OF WESTERN SNOWY PLOVERS AND CALIFORNIA LEAST TERNS FINAL REPORT

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EXECUTIVE SUMMARY

Eden Landing Ecological Reserve in California's San Francisco Bay is an important breeding site for the Recovery Unit (RU) 3 population of the Federally Threatened Western Snowy Plover (*Charadrius nivosus nivosus*; Snowy Plover) and Federally Endangered California Least Tern (*Sternula antillarum browni*; Least Tern). In recent years, survival rates of nests and fledging rates of chicks for both species have been very low. Low confirmed fledgling rates are likely caused by predation. The objectives of this study were to 1) determine whether avian and mammalian predator activity, density, and space use can be successfully detected and quantified using camera traps, 2) employ multiple field techniques to estimate the activity, density, and space use of the array of species that depredate snowy plovers, comprising both birds and mammals, 3) make a preliminary determination of the effect of predator removal on predation rates using camera-trap derived estimations in combination with existing data, and 4) conduct preliminary testing of 1-2 additional methods of predator management (i.e., fencing and raptor nest relocation) and measuring subsequent responses, if any, in predator activity and predation rates.

An array of 25 camera traps were deployed at Eden Landing Ecological Reserve on July 9, 2021 and remained through end of February, 2022; accounting for camera malfunctions, a total of n = 17 were successfully deployed. Images were classified into detections of 10 predator species and compared to field survey methods from March–September 2021 and 2022. Multi-season occupancy models were used to test for effects of predator trapping and removal efforts for three species that were both detected by camera traps and removed by trapping efforts in sufficient quantities to allow tests. Lastly, fencing was deployed to attempt non-lethal exclusion, and we report qualitative results from this effort.

Camera traps were active for nearly 36 weeks and captured approximately 90,000 photos. By the end of the first year, well over 1,000 animals were recorded by the cameras, most of which were known predators of Snowy Plover and Least Tern eggs and nestlings. A total of sixteen species (excluding humans) were identified in photos, including both terrestrial and avian predators and non-predators. The rate of detection of predators at Eden Landing exceeded all expectations and indicated that the cameras were an effective tool for characterizing predator populations.

There was very little agreement on relative predator abundance between field survey methods and camera trapping methods, but the two methods clearly complemented each other. Camera traps did much better at detecting mammalian predators while field surveyors were much better at detecting avian predators. These results are not surprising as the two methods were designed to capture mammalian and avian predator abundance, respectively.

Red Fox had the highest daily detection rates at camera traps, with three camera traps having >50%, the only species to do so, indicating a high density. Coyote had a widespread distribution with the greatest apparent densities in the center of the study area. Striped skunk were the most frequently trapped and removed predator and had correspondingly high naïve occupancy. The other mammalian species were rarer, with some (like feral cats) appearing to colonize Eden Landing Ecological Reserve midway through camera trapping efforts. Avian predators were generally widespread.

USDA personnel spent a total effort of 229.5 hours in 2021 and 242 hours in 2022 conducting predator control at Eden Landing. Nevertheless, our occupancy models did not suggest any evidence that trapping impacted site-level rates of occupancy or extinction. However, statistical power was likely low do to the small sample sizes and poor spatial resolution of the mammal trapping and removal data collection, which could not be linked to individual cameras. Occupancy models showed much higher detection rates for multiple species from camera traps that were placed on small, non-drivable levees with water on both sides, far from trailheads. This information can be used to guide placement of camera traps in future efforts in order to optimize detection rates for predator species.

Fencing effectiveness appeared to vary based on pond levels, with predators encroaching on ponds when water levels dropped low enough for predators to walk around fences. The Eden Landing management team should continue to work closely to manage predators and water levels at E14 (and all other ponds) to maximize efficacy of fences but not flood out Snowy Plover and Least Tern nests.

This work was only a pilot project, and has laid a foundation for improved use of camera trapping to monitor predators going forward. The large disparity between camera trap and field survey methods, and the complementary set of species detected by each, indicate that there would be value in continuing to deploy camera traps within Eden Landing and other parts of the Restoration Project in the future. For future data collection, it is imperative that monitoring and management actions be coordinated with precise spatial measurements so that data can be better utilized to answer management questions. To understand the effectiveness of efforts to reduce predation rates on Snowy Plover reproductive success, it is necessary to measure and quantify the causal links between predator management efforts (including removal, behavioral deterrents, or other actions), predator density, predation rates, and Snowy Plover reproductive success. Ultimately, a controlled experiment that manipulates predator management and measures the outcomes on each of these biological indicators will be necessary.

INTRODUCTION

Eden Landing Ecological Reserve (Eden Landing) in California's San Francisco Bay is an important breeding site for the Recovery Unit (RU) 3 population of the Federally Threatened Western Snowy Plover (*Charadrius nivosus nivosus*; Snowy Plover) and Federally Endangered California Least Tern (*Sternula antillarum browni*; Least Tern). In the South Bay Salt Pond Restoration Project (Restoration Project) footprint, Snowy Plovers breed on salt pannes in former salt evaporation ponds and lose breeding habitat as salt ponds are converted into tidal wetlands.

For Snowy Plovers particularly, Eden Landing is the most important regional breeding site. Unfortunately, in recent years, survival rates of nests and fledging rates of chicks for both species have been very low. In 2020 and 2021, 51 and 72 percent of nests in Eden Landing were depredated, respectively (Pearl et al., 2021; Pearl et al., 2022). While the fate of hatched chicks cannot be accurately determined, confirmed fledgling rates remain low and predation is likely the major factor. Known egg and chick predators include, but are not limited to, red fox (*Vulpes vulpes*), coyote (*Canis latrans*), striped skunk (*Mephitis mephitis*), feral cat (*Felis domesticus*), virginia opossum (*Didelphis virginiana*), California Gull (*Larus californicus*), Peregrine Falcon (*Falco peregrinus*), American Crow (*Corvus brachyrhynchos*), Common Raven (*Corvus corax*), Northern Harrier (*Circus hudsonius*), Red-Tailed Hawk (*Buteo jamaicensis*; see Table 1 for a comprehensive list).

Least Terns were listed as endangered in 1970 and six sites support 70–75% of the breeding population (Pearl et al. 2022a). Species that have limited breeding sites are more vulnerable to extinction, and thus increasing breeding site diversity and availability is critical to delisting species. Least Terns were first observed breeding at Eden Landing in 2017, likely attracted by the habitat enhancement aimed at improving Snowy Plover breeding success. After initial successes, Least Tern nesting has proved very vulnerable to predators and near-total colony failures have been observed from 2019-2021 (Pearl et al. 2022a).

Both avian and mammalian predator species may target breeding birds at Eden Landing, but require different management strategies. While predator management activities currently occur at some Snowy Plover breeding sites, they often do not cover the entire breeding season or are missing in some years due to funding challenges. Clear research to determine the impact of different predator management strategies on the targeted species as well as on Snowy Plover and Least Tern breeding success is severely limited.

After identifying these issues and gaps, the San Francisco Bay Bird Observatory (SFBBO) partnered with Dr. Justin Brashares' research group at University of California Berkeley (UC Berkeley) to conduct a pilot project to study predator movement patterns, occupancy and response to predator management activities. This report outlines our findings after 18 months of camera monitoring field work at Eden Landing.

The objectives of this study were to 1) determine whether avian and mammalian predator activity, density, and space use can be successfully detected and quantified using camera traps, 2) employ multiple field techniques to estimate the activity, density, and space use of the array of species that depredate snowy plovers, comprising both birds and mammals, 3) make a preliminary determination of the effect of predator removal on predation rates using camera-trap derived estimations in combination with existing data, and 4) conduct preliminary testing of 1-2 additional methods of predator management (i.e., fencing and raptor nest relocation) and measuring subsequent responses, if any, in predator activity and predation rates. Estimates of predator activity and density resulting from this study will also serve as the baseline to compare with responses to experimental manipulation of predator control effort and/or habitat modifications in future studies.

METHODS

Study Area

The study area for this pilot Predator Research study is located at Eden Landing Ecological Reserve (Eden Landing) ponds (Figure 1), which are owned and managed by California Department of Fish and Wildlife (CDFW). Eden Landing (formerly known as Baumberg), includes approximately 6,400 acres of former salt ponds, marsh, and tidal habitat.

Predator Management Activities

Predator Management activities occurred from May 27, 2021 through September 17, 2021 and from April 26, 2022 through September 30, 2022. These services were contracted to the United States Department of Agriculture (USDA) Wildlife Services personnel, who have been conducting predator control at Eden Landing for many years. In total, USDA conducted 229.5 and 242.0 hours of trapping and removal fieldwork in 2021 and 2022, respectively. Control methods used were shooting, spotlighting, cage traps and padded jaw leg holds (Tables 1–4).

In March 2022 approximately 585 feet of steel fence designed to keep mammalian predators out of E14 and surrounding levees was installed by a contractor in nine different stretches (Figure 2). The fence is 6 feet tall to prevent large mammals from jumping over, the chain link diameter is 2 ⅞ inches and designed to prevent smaller mammals from squeezing through, and the fence is buried 6 inches underground to prevent digging underneath. Coyote rollers were installed along the top of the fence to further prevent mammals from climbing over.

Field Predator Surveys

From March–September of each year, SFBBO biologists conduct weekly field surveys of avian predators at Snowy Plover ponds concurrently with Snowy Plover surveys (Figure 1, triangles). During these surveys, observers choose survey points that provide a comprehensive scan of the site for avian predators. At each point, the location, start time, and stop time are recorded. Observers record the number, species, behavior, and habitat type at the time of sighting any predators present. The approximate locations of the predators are also marked on a map. When applicable, observers also record any presence of avian predator nests. Although sign (i.e., scat, prints, and dens) and sightings of mammalian predators are opportunistically recorded, these surveys are not designed to capture mammalian predator presence, particularly since most mammalian predators are nocturnal.

Northern Harriers (harriers) were observed at Eden Landing in 2021, and believed to be nesting there. Therefore, SFBBO staff also surveyed for nesting harriers in March 2022, but then stopped in April 2022 due to staff time constraints and de-prioritization, as no harrier breeding activity was spotted on surveys. However, SFBBO staff continued regular weekly predator surveys, of which Northern Harriers were a targeted species, from March 1 through September 15, 2022.

Because the main novelty of this study was the use of camera trap data, in this report we generally focus on the set of field surveys data collected during the same time as the camera traps were operational. The field predator survey data is summarized more fully in the Snowy Plover annual reports (Pearl et al. 2022b, Pearl et al. 2023).

Camera Trap Deployment

In order to collect data on mammalian predator activity at Eden Landing an array of 25 camera traps were deployed on July 9, 2021 (Figure 1, circles). Cameras were semi-randomized, and placement considered a) road, fence, levee and embankment configurations; b) proximity to potential source populations of predators; and c) priority plover and tern nesting areas. Sites strategically sampled high use locations, such as trail intersections and high ground in inundated areas. To minimize impacts to nesting Snowy Plovers and other ground nesting birds, cameras were not baited, nor were they placed within 600 feet of nests. A 1x1 km grid was then overlaid onto the landscape, and cameras were then placed on the closest internal road or berm that was closest to the centroid of each grid cell.

Each camera (Browning Spec Ops Elite HP4) was set to take a burst of 3 photos at 8 megapixels with a recapture delay of 30 seconds. The camera's sensitivity was set to moderate. Cameras were placed on T-posts and positioned about 2-3 feet above the ground, facing north to south in order to avoid glare at sunrise and sunset. In two instances the cameras were drilled into an existing structure.

Cameras were visited monthly from September through February 2022 to change batteries and memory cards. The SD cards and batteries were replaced as needed and photos downloaded so they could be tagged in the metadata. Errors with cameras and physical damage led to data from 8 cameras being unusable, resulting in a final set of n = 17 camera traps. Some cameras remained up after February 2022, but were not serviced and remaining cameras and SD cards were not collected until fall 2023. Any images from after February 2022 were not analyzed for this report.

Field Survey and Camera Trap Comparisons

Memory cards were transported to the UC Berkeley campus where trained research technicians manually classified each photo by species (Figure 1). The final dataset consisted of each classified photo (n = 7098; excluding plovers) and its associated metadata (date, time, temp, camera ID) were then added to the full camera dataset in program R (package *camtrapR*).

We compared the two predator survey methods (camera trap and field survey) to identify the degree to which the datasets agreed with or complemented each other. While data was collected for camera traps from July 2021–February 2022, field surveys for that year ceased after September 30th 2021 and several traps began to malfunction after the first few months. We therefore limited this analysis to only the first summer, when both types of survey methodology were in use. We calculated the detection rate as the proportion of survey-days on which a species was detected in a survey (for camera traps, this is equivalent to the daily photographic rate), as an index of relative abundance or density. We calculated detection rates for each of the three months (July, August, and September), and an overall rate for all three months combined. We then compared the data from each camera trap station to the Snowy Plover pond it was adjacent to (if any). In some cases a camera trap was on the levee between two different Snowy Plover ponds, in which case, we calculated the field survey's detection rate as the mean of the two ponds' rates.

There was little overlap between the two datasets, so options for statistical comparisons were limited. We computed basic correlation coefficients (R^2) between observations at both the monthly and overall rates to determine congruence between the two datasets. We also mapped the spatial locations of overall detection rate.

Occupancy Modeling of Predators

Overview and Preliminary Analysis

We used multi-season occupancy models (MacKenzie et al. 2003) to assess changes in predator presence over time, test for landscape-scale covariates of predator occupancy or detection probability, and assess whether predator removal resulted in a statistically significant reduction in occupancy in the two Eden Landing zones (North and South). Detection/non-detection data are biased to underrepresented occupancy because a species that is undetected may be present but simply missed by the survey method. Occupancy modeling allows estimates of true occurrence probability (occupancy) using detection/non-detection data by correcting for imperfect detection rates with a second parameter (p). Occupancy in the first sampling period (Ψ) is estimated directly. Importantly, in subsequent periods, changes in occupancy are estimated as the rate of an unoccupied site being colonized (γ) or an occupied site going extinct (ε). This allows the effect of trapping and removal efforts for a species to be directly tested on whether it relates to site-level extinction. Covariates can be fit to each of these four parameters via logit link functions (i.e., logistic regression).

Initial analyses by UC Berkeley analyzed red fox camera trap detections using a single-season, single-species occupancy modeling approach (only estimating Ψ and p; MacKenzie et al. 2002). UC Berkeley used the R package *camptrapR* (Niedballa et al. 2022) to organize the data into detection histories which were used as objects in the R package *unmarked* (Chandler et al. 2022) where the single-season, single species occupancy models were run. UC Berkeley ran the occupancy models for two different time periods, one during the breeding season and one during the winter when a mix of Western and Interior Snowy Plovers are wintering at Eden Landing. The breeding season time period consisted of 6 weeks of data from July 16, 2021 through August 27, 2021. The winter time period consisted of 6 weeks' worth of data from November 5, 2021 through December 17, 2021. The report resulting from these preliminary models is included as Appendix 2.

Multi-Season Occupancy Modeling

Final analyses built off of this foundation by extending modeling efforts across the full range of sampled dates (July 2021–February 2022) to all ten predator species detected by the camera traps: coyote, feral cat, raccoon (*Procyon lotor*), red fox, river otter (*Lontra canadensis*), striped skunk, Virginia opossum, Northern Harrier, Great Blue Heron (*Ardea herodias*), and Great Egret (*Ardea alba*). Rather than using a single-season occupancy model, we used a multi-season occupancy model.

We first divided the survey window into 8 equal 4-week periods, beginning on July 9, 2021 and ending February 17, 2022 (data from after this date were discarded). These roughly corresponded to each month. We calculated "naïve occupancy" (i.e., raw detection rates uncorrected for imperfect detection) across all seven months. Individual days were treated as the secondary sampling unit, with occupancy and turnover (colonization/extinction) estimated for the 4-week periods. We attempted to fit simple models with month-specific intercepts to examine detection-corrected month-to-month trends in occupancy, however, because some months had no detections these models would not converge.

Covariates

For this study, UC Berkeley developed a series of covariates to test hypotheses about predator occupancy dynamics. The first covariate, *Plover*, investigated the correlation between red fox occurrence and Snowy Plover nest occurrence. This model was developed in order to see whether or not Snowy Plovers as prey drove predator occupancy. In order to quantify this, UC Berkeley measured the distance to the closest plover nest from each camera and assigned that value to the camera. The second covariate, *Urban*, tested if predator occupancy was influenced by the distance to an urban area bordering Eden Landing (e.g., freeways, driveways, and backyards outside the reserve). The third covariate, *Human*, represented human space use at the reserve as the photographic rate. This model did not account for the difference in the number of humans per photo (i.e., 4 vs 1, just the fact that humans were present). Since cameras took photos in bursts of 3 photos, the photographic rate was calculated by dividing the total number of photos taken by 3 in situations where there were more than 100 records. In situations where there were less, photos were counted exactly. UC Berkeley's preliminary models also assessed whether coyote abundance influenced the presence of other predators. However, it was not found to be important and brought up confounding study design questions due to imperfect detection, so we excluded it from the final modelset. Three detection covariates were also tested: (1) *Trailhead*, which hypothesized that animals are more or less likely to be photographed at trailheads because they act as areas where animals may converge on established paths; (2) *WaterBothSides*, which hypothesizes that if there is water on both sides of a camera it may cause animals to funnel in front of the camera or deter them because there is less open space to move around, and (3) *Drivable*, which hypothesized that space use may be lower on drivable roads where there is less cover and more potential disturbance from vehicles.

We also developed a fourth occupancy covariate, *Trap01,* which represented whether one or more members of the focal predator species had been removed in that zone (North Eden Landing or South Eden Landing) within the *previous* 4-week period. We hypothesized trapping could reduce initial predator occupancy and increase extinction rates; we did not fit models that had trapping effects on the colonization rate, as this seemed implausible. We used a one-period lag because occupancy models would assume closure within the sampling period (i.e., the species occupancy does not change within a given 4-week period, and if it was detected in the first half and then removed in the second half, it would still be modeled as "present"). In reality, trapping efforts likely violated the assumption of closure to some degree, but this was a necessary simplification. For the initial occupancy parameter, we used the presence of any removal year-to-date by July 9, 2021. Unfortunately, trapping efforts did not collect UTM coordinates of removed individuals, only spatial zone, so removals could not be linked to specific cameras. Only three species had both sufficient camera trap detections and sufficient removal events (i.e., ≥3) to fit models for: red fox, Virginia opossum, and striped skunk. The other seven predator species could not be assessed. These limitations likely reduced the statistical power of this covariate, so results should be interpreted with caution.

Model Selection

We then ran a modelset of all combinations of these covariates. Due to the low sample size (n = *17* cameras and 7 possible turnover events), we restricted the modelset to have at most two covariates per parameter. The resulting final set of candidate models had 2,401 models for the seven species without associated trapping removal data, and 5,929 models for the three species with the *Trap01* covariate. We used corrected Akaike's Information Criterion (AICc) to identify and report the best 20 models.

RESULTS & DISCUSSION

Camera Trap Surveys

The UC Berkeley team spent a total of 305 hours in close coordination with SFBBO staff to design, purchase, install and maintain the trail camera array consisting of 24 cameras. Camera traps were active for a total of 36 weeks and captured approximately 90,000 photos. By the end of the first year, well over 1,000 animals were recorded by the cameras, most of which were known predators of Snowy Plover and Least Tern eggs and nestlings. A total of sixteen species (excluding humans) were identified in photos, including both terrestrial and avian predators and non-predators. Ten species of mammal were identified, seven of which are known predators: striped skunk, raccoon, river otter, Virginia opossum, feral cat, coyote, and red fox. The most commonly photographed mammalian predator was the red fox (*Vulpes vulpes*) which was photographed >2,300 times across 13 cameras. Other species included California ground squirrel (*Otospermophilus beecheyi*), mule deer (*Odocoileus hemionus*), and black-tailed jackrabbit (*Lepus californicus*), which was the most common species photographed (>15,000 detections across 16 of the 17 cameras). Five species of bird were captured, three of which were considered Snowy Plover predators (Northern Harrier, Great Blue Heron, and Great Egret). Great Egret and Great Blue Heron are not considered a major threat to Snowy Plovers, but are included in this report as they are a highly visible and abundant potential predator. The remaining two bird species were Black-crowned Night-Heron (*Nycticorax nycticorax*) and American White Pelican (*Pelecanus erythrorhynchos*), which were excluded from analysis as they are believed to be, if anything, only incidental predators of Snowy Plover. Humans were captured >10,000 times across all 17 cameras used during data analysis. The rate of detection of predators at Eden Landing exceeded all expectations and indicated that the cameras were an effective tool for characterizing predator populations.

Comparison between Methods

There was very little agreement on relative predator abundance between field survey methods and camera trapping methods, but the two methods clearly complemented each other (Table 5).

Broadly, camera traps did much better at detecting mammalian predators (Tables 5, 6, Figs. 3–16), while field surveyors were much better at detecting avian predators (Tables 5, 7, Figs. 17–22). Field surveyors also detected a much wider range of predator species (27 out of 31; 87%), with 25 species not detected by camera traps (Table 5).

In contrast, camera traps detected only 4 species not detected by field surveyors (all mammals; Table 5), and the remaining mammalian species were detected <10 times across both years by field surveyors. Because detections were so rare, no mammals were observed during the same three-month period when field surveys and camera traps overlapped (July–September 2021). Therefore, correlations between the two methods could not be calculated. For avian predators, correlations between estimated site-scale abundance between the two methods were very low for the site's monthly detection rate (-0.148, 0.081, and 0.203 for Northern Harrier, Great Blue Heron, and Great Egret, respectively) The overall detection rates across all three months showed improved agreement, but still low (-0.113, 0.242, and 0.384, respectively).

Snowy Egrets (*Egretta thula*) had nearly twice the number of detections in field surveys than Great Egrets (Table 5), but were absent from the camera trap records. Along with California Gull (*Larus californicus*), these two species were by far the most abundant predators and the only two to reach >1000 detections per year. It is not clear if the absence of these species from the camera trap data is due to behavioral differences (i.e., proclivity to perch on wide levees) or the imagery classification approach.

It is perhaps unsurprising that flying (and thus highly visible) avian predators are better detected by field surveyors, while secretive and nocturnal mammalian predators are better detected by camera traps. However, it is worth noting that not only the relative abundance between these taxa differed significantly, the spatial pattern of detection *within* a species also differed markedly between the two methods (see for example, Fig. 17). The clear division in the data highlights the obvious value of continuing monitoring with both methods. Neither approach by itself is sufficient to capture spatial patterns and relative density of all different predator taxa.

Activity, Density, and Space Use of Predators

We here summarize mapped detections for each species detected by the camera traps. Note importantly that maps (i.e., Fig. 3) show only the pattern from summer (July–September) when confidence in data was highest. See associated tile plots (i.e., Fig. 4b) for spatial patterns of occupancy later in the season. As mentioned, for all mammal species, no field surveyors detected the species during the July–September survey window.

Red Fox

Red Fox had the highest daily detection rates at camera traps, with three camera traps having >50%, the only species to do so, indicating a high density. They were highly concentrated in

North Eden Landing, particular around pond E10 (Fig. 3). Overall naïve occupancy was fairly stable over the period, reaching a low in September but increasing to 50% of sites by February (Fig. 4a) as the species appeared to newly colonize southern Eden Landing (Fig. 4b).

Coyote

Coyote had a widespread distribution with the greatest apparent densities in the center of the study area (Fig. 5). Naïve occupancy of sites appeared to increase notably from August to September, possibly showcasing increased movements, as this rapidly declined back to low levels by December (Fig. 6).

Striped Skunk

Striped skunk were the most frequently trapped and removed predator (Tables 1–4) and had correspondingly high naïve occupancy (Fig. 8). However, their site-specific detection rates were not as high as red foxes or coyotes (Fig. 7), indicating a widespread distribution with lower density.

Raccoon

Raccoons were concentrated in North Eden Landing, with the exception of one site along Alameda Creek which had the highest number of detections (Fig. 9). They appeared absent from the rest of the South Eden Landing. Overall naïve occupancy rate was remarkably consistent over time, hovering around 25% of sites (Fig. 10a), though the individual sites used in North Eden Landing shifted frequently (Fig. 10b).

Feral Cat

Feral cats appeared to colonize both North Eden Landing and South Eden Landing in November (Fig. 12b); prior to this, they appeared absent except for a single station in September (camera #13) which was not adjacent to a Snowy Plover pond (Fig. 11; note that because this map only shows July–September data, the later South Eden Landing occupancy is under-represented, see Fig. 12b). After colonizing the reserve, they occupancy increased remarkably consistently through February. Based on the very disjointed spatial pattern, this appears to represent at least two colonizations, one in South Eden Landing (camera #6) and one or more in North Eden Landing.

Virginia Opossum

Virginia opossums were only detected during late summer (Aug–Sept; Fig. 14), at a scattering of widely disconnected sites (Fig. 13). The reason for this is unclear, but may represent seasonal movements or an extirpation.

River Otter

River Otter was the most rarely detected mammalian predator within the dataset (Fig. 16a). It appeared at only two sites, cameras #5 and #7 (Fig. 16b), which were, unsurprisingly, adjacent to Alameda Creek and Mount Eden Creek, respectively (Fig. 15). This predator therefore appears localized entirely to the creeks and the infrequent observations likely represent rare crossings of levees. Nevertheless, these could be considered “early warning signs” for a potential looming threat. River Otter are a very serious predator that to date has not yet been an issue for South San Francisco Bay Snowy Plover populations. However, they have significantly depredated both Snowy Plover and Least Tern colonies in Napa County, and were the cause of a major depredation event at a Least Tern colony on an island on nearby East Bay Regional Park District land (D. Riensche, pers. comm.).

Northern Harrier

Northern Harriers were far more common in North Eden Landing (Fig. 17), having been detected only once in South Eden Landing, by pond E2 (Fig. 18b). Camera trap detections were infrequent (Fig. 18a), but detectability by field surveyors was very high (>50%; Fig. 17, Table 7). These species were of special focus to field surveyors in both years. In regular weekly predator surveys, Northern Harriers were observed at Eden Landing at a higher frequency in 2022 compared to 2021 (Table 7). However, the majority of these observations occurred March-April, as well as in July and August when breeding activity was declining. Despite conducting focused surveys in March and April 2022 to search for harrier breeding activity, none were observed during this timeframe, and considering the relative lack of observations in May and June, it appears that they may not have nested at Eden Landing in 2022. One pair was confirmed nesting in nearby Hayward Marsh and was a frequent predator of the Least Tern and Forster's Tern colonies located at Hayward Shoreline until the harrier nest was itself depredated (D. Riensche, pers. comm.) The territory of Northern Harriers has been documented as ranging in size from 170 to 15,000 ha, with the size of the territory depending upon prey density within it (Machwhirter and Bildstein 2016). Thus it seems likely that the harriers that we believe nested at Eden Landing in 2021 instead nested at Hayward Marsh in 2022, and once their nest failed returned to hunting over a wider area, including at ponds E12, E13, and E14.

Great Blue Heron

Like Northern Harriers, Great Blue Heron were more commonly observed in North Eden Landing than South Eden Landing, and much more frequently by field surveyors (Fig. 19). Based on camera trap data, their naïve occupancy increased later in the year (Fig. 20a), though it is unclear if this is a true difference or the result of behavioral differences, given the low relative detectability of this method.

Great Egret

The Great Egret was one of the most commonly detected predators during field surveys, showing a high detection rate across nearly all sites (Fig. 21). Detectability was significantly lower for camera traps, which appeared to miss altogether several populations in the E1C–E5C complex which actually had high occupancy (Fig. 22b). Nevertheless, the camera traps did agree with the field survey data that overall naïve occupancy of Great Egrets was higher than that of Great Blue Herons (Table 5; Fig. 22a vs. Fig. 20a)

Effectiveness of Predator Management

Predator Removal

USDA personnel spent a total effort of 229.5 hours in 2021 and 242 hours in 2022 conducting predator control at Eden Landing. Itemized lists of removed animals are included in Tables 1–4. In 2022, eight different species and 70 individuals were captured and removed, with striped skunks the most commonly removed species. In 2022, four species and 36 individuals were captured and removed, with skunks again being the most common. Since Northern Harriers were not identified to breed within Eden Landing, we did not make any effort to relocate them as a potential predator control strategy.

Testing for Landscape and Removal Effects on Occupancy

Our occupancy models did not suggest any evidence that trapping impacted site-level rates of occupancy or extinction (Table 8). However, most models performed poorly, with several having large standard errors indicating models had difficulty estimating the parameters (Appendix 1). Notably, observations of many species were rather rare and, in some cases, all sites began wholly unoccupied (e.g., feral cats; Fig. 12), creating challenges for model convergence. Trapping was also relatively rare for most species during the sample period (only three had a significant number of captures, and all efforts concluded for the year on September 17, 2021), and the removal data was collected at a very coarse spatial scale (only coded to north or south of Alameda Creek). Therefore, we caution against drawing firm conclusions about the efficacy of trapping efforts for predator removal, and emphasize that this was a preliminary study to provide proof-of-concept for the utility of camera trapping. An improved research effort that better aligns camera trapping efforts both spatially and temporally with specific camera traps, over a longer time period, would likely have much better statistical power.

Other landscape-scale covariates were significant. The strongest effects were on detection probability, which was significantly higher for multiple species when the levee was bounded by water on both sides (essentially funneling animals into the camera's view; Table 8). Detection was significantly lower for multiple species when the camera was positioned on a drivable levee or a trailhead, plausibly indicating a behavioral avoidance of areas that are high-traffic, and Northern Harriers showed a weak propensity not to colonize parts of Eden Landing closer to urban areas. However, striped skunks curiously showed a significant positive relationship between detection and levee drivability, and a significantly lower risk of extinction in areas heavily used by hikers (Table 8). Coyotes and river otters also showed lower extinction rates and higher occupancy rates in high-traffic areas, respectively. Taken together, it seems reasonable that these predators may be being attracted to anthropogenic food sources. The only predator that showed a significant positive relationship with plovers (i.e., as a potential food source) was raccoons; however, this model very poorly converged and this relationship is likely spurious.

It is important to note that in the context of Eden Landing over several months, extinction could also result from an individual shifting its territory to another nearby pond. However, the small scale of the reserve and camera trap locations relative to the possible home range sizes of these animals doubtless further complicates inference.

Effectiveness of Fencing for Predator Management

The fence installation was completed over a period of two weeks in March 2022, after we stopped analyzing data from the camera traps for this study. Therefore, our analysis of the fence's success or failure is based on anecdotal evidence gathered during the 2022 and 2023 Snowy Plover breeding seasons.

During the 2022 season, we encountered several design flaws with the fence that could be impacting its efficacy. First, the fence gates could not be buried, and we encountered evidence of mammals digging underneath them. Second, fluctuating water levels in E13 and E14 impacted whether the edges of fences were covered by water or exposed. When exposed, mammals and trespassers could easily skirt around the sides of the fences (Pearl et al. 2023).

To remedy these issues, in February 2023 prior to the breeding season, SFBBO contracted ABC Fence Company to pour concrete pads and install hardware cloth under the gates to prevent digging. This solution was extremely effective and we observed no evidence of mammals digging under the fences during the 2023 season (Schwarz et al. 2024). Additionally, following the 2022 breeding season, SFBBO biologists dug trenches (4 inches wide and 1–2 inches deep) 3–4 feet into the ponds on both sides of the fence to ensure that fences were submerged in water and reduce accessibility to humans and mammals. Unfortunately, these trenches were highly susceptible to erosion and could not be sufficiently maintained to remain functional. Although water levels around E14 were closely monitored throughout the 2023 breeding season, there were short periods of time (less than a week) where enough land was exposed for predators to walk around the edge of the fence.

Effects on Snowy Plover breeding success at E14 due to the fence are difficult to quantify. In both 2022 and 2023, red fox was still observed on E14, showing that the fence did not completely exclude this species. Red fox was only detected once during the 2022 season, but five times during the 2023 season (Pearl et al. 2023, Schwarz et al. 2024). This perhaps shows that the foxes have acclimated to the fence's presence and found ways to move around it that we have not identified yet. Snowy Plover hatch rate at E14 in 2022 was much lower than the hatch rate in the South Bay overall (40% at E14 versus 56% overall; Pearl et al. 2023). In 2023, hatch rate at E14 was similar to but slightly higher than the hatch rate in the South Bay overall (67% at E14 versus 66% overall; Schwarz et al. 2024). Many variables affect Snowy Plover nest success each year, so these data points are inconclusive and cannot be used to draw any conclusions about the efficacy of the fence.

Management Recommendations for the Restoration Project Management Team

This work was only a pilot project, and has laid a foundation for improved use of camera trapping to monitor predators going forward. Both native and non-native predator species severely limit survival and reproduction of breeding Snowy Plovers and Least Terns. As breeding habitats are reduced across the region, higher densities of breeding birds will likely attract predators. While both lethal and non-lethal management may reduce depredation risk for nest and chicks, the availability of high quality breeding habitat is paramount for retaining Snowy Plover and Least Tern populations. Therefore, we urge the Restoration Project management team to continue to research predators and support their management efforts.

The large disparity between camera trap and field survey methods, and the complementary set of species detected by each, indicate that there would be value in continuing to deploy camera traps within Eden Landing and other parts of the Restoration Project in the future. The maps produced in this report can be utilized to target trapping efforts to the highest-density areas (i.e., red foxes at pond E10). However, their utility may be hampered by the fact that they are now nearly three years out-of-date. If a robust workflow for placing, retrieving data from, and analyzing data from camera traps could be created, predator monitoring efforts within Eden Landing could be greatly improved. A sizable analysis codebase was already created for this project, and automation methods for image classification are continuously improving thanks to recent breakthroughs in AI models (Vélez et al. 2023). If camera traps are placed into Eden Landing again, our results clearly show how to optimize detection rate for multiple species. Cameras should be placed on small, non-drivable levees with water on both sides, far from trailheads.

Our analysis of the effectiveness of predator trapping, removal, and fencing efforts was limited by the fact that data collection efforts around these activities was not coordinated with the activities themselves. Notably, no camera trap data was assessed during the fencing period. Furthermore, USDA trapping efforts did not record precise coordinates of removed predators, so these could only be very coarsely aligned with changes in occupancy at the scale of North versus South Eden Landing. For future data collection, it is imperative that monitoring and management actions be coordinated with precise spatial measurements so that data can be better utilized to answer management questions. To understand the effectiveness of efforts to reduce predation rates on Snowy Plover reproductive success, it is necessary to measure and quantify the causal links between predator management efforts (including removal, behavioral deterrents, or other actions), predator density, predation rates, and Snowy Plover reproductive success. Ultimately, a controlled experiment that manipulates predator management and measures the outcomes on each of these biological indicators will be necessary.

The Eden Landing management team should continue to work closely with SFBBO staff to manage water levels at E14 (and all other ponds) to maximize efficacy of fences but not flood out Snowy Plover and Least Tern nests.

We recommend that the Restoration Project management team communicate with landowners outside of the Restoration Project footprint to ensure that important Snowy Plover breeding areas are protected to supplement the decreasing breeding habitat within the Restoration Project footprint. Coordinated efforts by landowners whose properties support breeding plovers will ensure that parties can share challenges, ideas, and knowledge to best manage for Snowy Plover recovery. If Snowy Plovers have more breeding habitat, they can have more choices for breeding and may breed at lower densities. This potentially could reduce predation pressure if Snowy Plovers are not always predictably breeding in the same colonies at the same sites each year.

Least Terns currently only breed in Eden Landing within the Restoration Project footprint (Pearl et al. 2022a). Since they breed colonially, they will always be highly visible and attractive to predators. Thus, consistent funding for predator management activities, including lethal control should be available while research efforts continue to identify the impact of different management strategies.

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TABLES

Table 1. USDA predator removals during trapping in North Eden Landing Ecological Reserve, CA, 2021.

Date	Species	Quantity	Method
5/28/2021	Red Fox	1	Cage Trap
5/28/2021	Striped Skunk	2	Cage Trap
5/28/2021	Common Raven	1	Shooting
6/2/2021	Feral Cat	1	Shooting
6/3/2021	Common Raven	1	Shooting
6/9/2021	Striped Skunk	5	Cage Trap
6/10/2021	Striped Skunk	1	Cage Trap
6/16/2021	Striped Skunk	1	Cage Trap
6/17/2021	Virginia Opossum	1	Thermal Shooting
6/17/2021	Striped Skunk	1	Thermal Shooting
6/25/2021	Striped Skunk	1	Cage Trap
6/30/2021	Striped Skunk	1	Cage Trap
7/1/2021	Striped Skunk	1	Cage Trap
7/21/2021	Virginia Opossum	1	Cage Trap
7/22/2021	Raccoon	1	Cage Trap
7/23/2021	Feral Cat	1	Cage Trap
7/28/2021	Striped Skunk	1	Cage Trap
7/29/2021	Striped Skunk	1	Cage Trap
7/30/2021	Striped Skunk	1	Cage Trap
8/12/2021	Feral Cat	1	Cage Trap
8/13/2021	Striped Skunk	1	Shooting
8/18/2021	Red Fox	1	Cage Trap
8/19/2021	Virginia Opossum	1	Thermal Shooting
8/19/2021	Raccoon	2	Thermal Shooting
8/20/2021	Red Fox	1	Cage Trap
8/25/2021	Red Fox	1	Cage Trap
8/25/2021	American Crow	1	Shooting
8/27/2021	Raccoon	1	Cage Trap
8/27/2021	Striped Skunk	1	Cage Trap
8/31/2021	Raccoon	3	Cage Trap
9/1/2021	Virginia Opossum	1	Thermal Shooting
9/11/2021	Striped Skunk	2	Cage Trap

Table 2. USDA predator removals during trapping in South Eden Landing, CA, 2021.

Date	Species	Quantity	Method
6/1/2021	Feral Cat	1	Thermal Shooting
6/1/2021	Striped Skunk	1	Thermal Shooting
6/2/2021	Striped Skunk	1	Cage Trap
6/3/2021	Common Raven	1	Shooting
6/9/2021	Striped Skunk	1	Cage Trap
6/9/2021	Feral Cat	1	Shooting
6/10/2021	Striped Skunk	2	Cage Trap
6/16/2021	Virginia Opossum	1	Thermal Shooting
6/16/2021	Striped Skunk	1	Thermal Shooting
6/25/2021	Striped Skunk	1	Cage Trap
6/29/2021	Striped Skunk	1	Cage Trap
7/21/2021	Striped Skunk	1	Cage Trap
7/28/2021	Raccoon	1	Cage Trap
7/30/2021	Striped Skunk	1	Cage Trap
8/11/2021	Striped Skunk	1	Cage Trap
8/13/2021	Striped Skunk	1	Cage Trap
8/18/2021	Striped Skunk	1	Cage Trap
8/19/2021	Striped Skunk	2	Thermal Shooting
8/19/2021	Striped Skunk	2	Cage Trap
8/20/2021	Striped Skunk	1	Cage Trap
8/25/2021	Striped Skunk	1	Thermal Shooting
8/25/2021	Striped Skunk	1	Cage Trap
8/26/2021	Striped Skunk	1	Thermal Shooting
8/26/2021	Coyote	1	Thermal Shooting
9/14/2021	Striped Skunk	1	Cage Trap
9/16/2021	Raccoon	1	Cage Trap

Table 3. USDA predator removals during trapping in North Eden Landing, CA, 2022.

Date	Species	Number	Method
4/26/2022	American Crow	2	Firearm
5/3/2022	Striped Skunk	1	Cage
5/3/2022	Red Fox	1	Cage
5/3/2023	Striped Skunk	4	Cage
5/4/2023	Striped Skunk	3	Cage
5/4/2022	Red Fox	1	Cage
5/6/2022	Red Fox	1	Cage
5/6/2022	Striped Skunk	1	Cage
5/10/2022	Striped Skunk	2	Cage
5/12/2022	American Crow	1	Firearm
5/18/2022	American Crow	1	Firearm
5/31/2022	Red Fox	1	Leg Hold
6/2/2022	Red Fox	2	Firearm
6/17/2022	American Crow	2	Firearm
7/25/2022	American Crow	1	Firearm
9/20/2022	Common Raven	1	Firearm

Table 4. USDA predator removals during trapping in South Eden Landing, CA, 2022.

Date	Species	Number	Method
5/4/2022	Striped Skunk	1	Cage
5/5/2022	Striped Skunk	2	Cage
5/6/2022	Common Raven	1	Firearm
5/10/2022	Striped Skunk	2	Cage
5/12/2022	American Crow	4	Firearm
5/12/2022	Common Raven	1	Firearm

Table 5. Summary of predator detections by biologists during Snowy Plover field surveys at 22 ponds in Eden Landing Ecological Reserve, CA, 2021–2022. "CT?" indicates whether a species was also represented in the camera trap dataset.

		% of ponds detected at		Total detections	
CT?	**Species**	**2021**	**2022**	**2021**	**2022**
Yes	Coyote	0%	9%	0	4
	Feral Cat	5%	5%	1	2
	Red Fox	14%	14%	6	3
	Racoon	0%	0%	0	0
	River Otter	0%	0%	0	0
	Striped Skunk	0%	0%	0	0
	Virginia Opossum	0%	0%	0	0
	Northern Harrier	57%	64%	62	68
	Great Blue Heron	62%	55%	86	48
	Great Egret	86%	91%	572	375
No	American Kestrel	5%	5%	1	4
	Bald Eagle	19%	23%	4	9
	Osprey	0%	9%	0	3
	Merlin	5%	18%	2	8
	Peregrine Falcon	57%	50%	48	36
	Prairie Falcon	0%	5%	0	1
	Red-shouldered Hawk	0%	5%	0	1
	Red-tailed Hawk	48%	64%	30	61
	White-tailed Kite	33%	18%	16	7
	Snowy Egret	71%	68%	1098	535
	American Crow	19%	36%	14	83
	Common Raven	57%	50%	50	99
	Black-crowned Night-Heron	19%	27%	21	15
	Bonaparte's Gull	5%	5%	1	4
	California Gull	81%	77%	5366	4441
	Glacuous-winged Gull	5%	0%	2	0
	Herring Gull	29%	18%	20	5
	Iceland Gull	10%	0%	4	0
	Ring-billed Gull	33%	32%	65	123
	Short-billed Gull	5%	0%	43	0
	Western Gull	19%	14%	55	10
	Unidentified Gull	62%	55%	3560	3728

Table 6. Comparison of monthly detection rate (probability of detection per survey day) between camera trap and field surveys for six species of terrestrial mammalian predators of Snowy Plover in Eden Landing, CA. Camera traps were up from July 2021–February 2022, though some cameras were not functional for the entire period. Field surveys were conducted by biologists from March–September 2021. Months that were not sampled by a given camera are not shown.

			Coyote		**Striped Skunk**		**Feral Cat**		**Raccoon**		**Fox**		**Virginia Opossum**	
Station	**Pond(s)**	**Month**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**
3	E8	2021-07	0	0	0	0	0	0	0	0	0	0	0	0
3	E8	2021-08	0	0	0	0	0	0	0	0	0	0	0	0
3	E8	2021-09	0.067	0	0	0	0	0	0	0	0	0	0	0
3	E8	2021-10	0	-	0	-	0	-	0	-	0	-	0	-
3	E8	2021-11	0.033	-	0	-	0	-	0	-	0	-	0	-
3	E8	2021-12	0	-	0	-	0	-	0	-	0	-	0	-
3	E8	2022-01	0	-	0	-	0.032	-	0	-	0	-	0	-
3	E8	2022-02	0.042	-	0	-	0.042	-	0	-	0.083	-	0	-
4	None	2021-07	0.043	-	0	-	0	-	0	-	0.478	-	0	-
4	None	2021-08	0	-	0	-	0	-	0	-	0.419	-	0.065	-
4	None	2021-09	0.033	-	0.033	-	0	-	0.033	-	0	-	0	-
4	None	2021-10	0.065	-	0.032	-	0	-	0	-	0.065	-	0	-
4	None	2021-11	0	-	0.100	-	0.500	-	0	-	0	-	0	-
4	None	2021-12	0	-	0.097	-	0.516	-	0.097	-	0	-	0	-
4	None	2022-01	0.032	-	0.065	-	0.677	-	0.032	-	0.194	-	0	-
4	None	2022-02	0	-	0	-	0.333	-	0	-	0.667	-	0	-
5	E14, E9	2021-07	0	0	0	0	0	0	0	0	0.174	0	0	0
5	E14, E9	2021-08	0	0	0	0	0	0	0	0	0.226	0	0.032	0
5	E14, E9	2021-09	0.033	0	0.067	0	0	0	0	0	0	0	0	0
5	E14, E9	2021-10	0.032	-	0	-	0	-	0	-	0	-	0	-
5	E14, E9	2021-11	0.033	-	0.067	-	0.033	-	0	-	0.067	-	0	-
5	E14, E9	2021-12	0.065	-	0.194	-	0	-	0	-	0.032	-	0	-
5	E14, E9	2022-01	0.032	-	0.129	-	0.097	-	0	-	0.065	-	0	-
5	E14, E9	2022-02	0	-	0	-	0	-	0	-	0.333	-	0	-
6	E2	2021-07	0	-	0	-	0	-	0	-	0	-	0	-
6	E2	2021-08	0	-	0.161	-	0	-	0	-	0	-	0	-
6	E2	2021-09	0.067	-	0.500	-	0	-	0	-	0	-	0.033	-
6	E2	2021-10	0.032	-	0.290	-	0	-	0	-	0	-	0	-

			Coyote		Striped Skunk		Feral Cat		Raccoon		Fox		Virginia Opossum	
Station	**Pond(s)**	**Month**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**
6	E2	2021-11	0	-	0.033	-	0	-	0	-	0	-	0	-
6	E2	2021-12	0	-	0.129	-	0.065	-	0	-	0	-	0	-
6	E2	2022-01	0.065	-	0.065	-	0.097	-	0	-	0	-	0	-
6	E2	2022-02	0	-	0	-	0.042	-	0	-	0	-	0	-
7	E6	2021-07	0.304	0	0.130	0	0	0	0.087	0	0	0	0	0
7	E6	2021-08	0.387	0	0.194	0	0	0	0.032	0	0	0	0	0
7	E6	2021-09	0.367	0	0.167	0	0	0	0.100	0	0	0	0	0
7	E6	2021-10	0.290	-	0.419	-	0	-	0	-	0	-	0	-
7	E6	2021-11	0.067	-	0.033	-	0	-	0.133	-	0	-	0	-
7	E6	2021-12	0.065	-	0.161	-	0	-	0.065	-	0	-	0	-
7	E6	2022-01	0.065	-	0.516	-	0	-	0.032	-	0	-	0	-
7	E6	2022-02	0.042	-	0.240	-	0	-	0.042	-	0	-	0	-
8	E14, E13	2021-07	0	0	0	0	0	0	0	0	0.130	0	0	0
8	E14, E13	2021-08	0	0	0	0	0	0	0	0	0.200	0	0	0
9	E6B	2021-07	0.087	0	0	0	0	0	0	0	0	0	0	0
9	E6B	2021-08	0	0	0	0	0	0	0	0	0	0	0	0
9	E6B	2021-09	0.100	0	0	0	0	0	0	0	0	0	0	0
9	E6B	2021-10	0	-	0	-	0	-	0	-	0	-	0	-
9	E6B	2021-11	0	-	0	-	0	-	0	-	0	-	0	-
9	E6B	2021-12	0	-	0	-	0	-	0	-	0	-	0	-
9	E6B	2022-01	0	-	0	-	0	-	0	-	0.032	-	0	-
9	E6B	2022-02	0.042	-	0	-	0	-	0	-	0.042	-	0	-
10	E6C	2021-07	0	-	0.087	-	0	-	0	-	0	-	0	-
10	E6C	2021-08	0.400	0	0	0	0	0	0	0	0	0	0	0
13	E20B	2021-07	0	0	0	0	0	0	0	0	0	0	0	0
13	E20B	2021-08	0	0	0	0	0	0	0.032	0	0	0	0	0
13	E20B	2021-09	0	0	0	0	0.067	0	0	0	0	0	0	0
13	E20B	2021-10	0.032	-	0.032	-	0	-	0	-	0	-	0	-
13	E20B	2021-11	0	-	0	-	0.033	-	0	-	0	-	0	-
13	E20B	2021-12	0	-	0	-	0.111	-	0.222	-	0	-	0	-
14	E13	2021-07	0	0	0	0	0	0	0	0	0	0	0	0
14	E13	2021-08	0	0	0	0	0	0	0	0	0	0	0	0
14	E13	2021-09	0	0	0	0	0	0	0	0	0	0	0	0

			Coyote		Striped Skunk		Feral Cat		Raccoon		Fox		Virginia Opossum	
Station	Pond(s)	Month	Camera	Survey	Camera	Survey	Camera	Survey	Camera	Survey	Camera	Survey	Camera	Survey
14	E13	2021-10	0	-	0	-	0	-	0	-	0	-	0	-
14	E13	2021-11	0	-	0	-	0	-	0	-	0.033	-	0	-
14	E13	2021-12	0	-	0	-	0	-	0	-	0	-	0	-
14	E13	2022-01	0	-	0	-	0	-	0	-	0.032	-	0	-
14	E13	2022-02	0	-	0	-	0	-	0	-	0	-	0	-
16	E1C	2021-07	0.043	0	0.087	0	0	0	0	0	0	0	0	0
16	E1C	2021-08	0.032	0	0	0	0	0	0	0	0	0	0	0
16	E1C	2021-09	0	0	0	0	0	0	0	0	0	0	0	0
18	E10	2021-07	0	0	0	0	0	0	0.043	0	0.679	0	0	0
18	E10	2021-08	0	0	0	0	0	0	0	0	0.548	0	0	0
18	E10	2021-09	0	0	0.033	0	0	0	0	0	0.533	0	0	0
18	E10	2021-10	0	-	0	-	0	-	0.065	-	0.710	-	0	-
18	E10	2021-11	0	-	0.100	-	0	-	0	-	0.200	-	0	-
18	E10	2021-12	0	-	0.129	-	0	-	0.032	-	0.258	-	0	-
18	E10	2022-01	0	-	0.065	-	0	-	0	-	0.548	-	0	-
18	E10	2022-02	0	-	0	-	0	-	0	-	0.208	-	0	-
21	E20B	2021-07	0.043	0	0	0	0	0	0	0	0	0	0	0
21	E20B	2021-08	0	0	0	0	0	0	0	0	0	0	0	0
21	E20B	2021-09	0.100	0	0	0	0	0	0	0	0	0	0	0
21	E20B	2021-10	0.097	-	0	-	0	-	0	-	0	-	0	-
21	E20B	2021-11	0	-	0	-	0	-	0	-	0	-	0	-
21	E20B	2021-12	0	-	0	-	0	-	0	-	0	-	0	-
21	E20B	2022-01	0	-	0	-	0	-	0	-	0	-	0	-
21	E20B	2022-02	0.042	-	0	-	0	-	0	-	0.042	-	0	-
22	E10, E10X	2021-07	0	0	0	0	0	0	0.043	0	0.900	0	0	0
22	E10, E10X	2021-08	0	0	0.032	0	0	0	0	0	1.000	0	0	0
22	E10, E10X	2021-09	0.033	0	0.033	0	0	0	0	0	0.700	0	0	0
22	E10, E10X	2021-10	0	-	0	-	0	-	0	-	0.710	-	0	-
22	E10, E10X	2021-11	0	-	0.067	-	0	-	0.067	-	0.367	-	0	-
22	E10, E10X	2021-12	0	-	0.129	-	0	-	0	-	0.226	-	0	-
22	E10, E10X	2022-01	0	-	0.032	-	0	-	0.032	-	0.484	-	0	-
22	E10, E10X	2022-02	0	-	0	-	0	-	0	-	0.333	-	0	-
23	E10, E10X	2021-07	0	0	0	0	0	0	0	0	0.750	0	0	0

			Coyote		Striped Skunk		Feral Cat		Raccoon		Fox		Virginia Opossum	
Station	**Pond(s)**	**Month**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**
23	E10, E10X	2021-08	0	0	0	0	0	0	0	0	0.839	0	0	0
23	E10, E10X	2021-09	0	0	0	0	0	0	0.033	0	0.567	0	0	0
23	E10, E10X	2021-10	0	-	0	-	0	-	0.032	-	0.742	-	0	-
23	E10, E10X	2021-11	0	-	0.033	-	0	-	0	-	0.300	-	0	-
23	E10, E10X	2021-12	0	-	0.065	-	0	-	0	-	0.129	-	0	-
23	E10, E10X	2022-01	0	-	0	-	0	-	0.032	-	0.258	-	0	-
23	E10, E10X	2022-02	0	-	0	-	0	-	0	-	0.167	-	0	-
24	E6B, E8	2021-07	0	0	0	0	0	0	0	0	0	0	0	0
24	E6B, E8	2021-08	0	0	0.032	0	0	0	0	0	0	0	0	0
24	E6B, E8	2021-09	0.167	0	0	0	0	0	0	0	0	0	0	0
24	E6B, E8	2021-10	0.065	-	0	-	0	-	0	-	0	-	0	-
24	E6B, E8	2021-11	0	-	0.033	-	0.167	-	0.033	-	0	-	0	-
24	E6B, E8	2021-12	0	-	0	-	0.129	-	0	-	0	-	0	-
24	E6B, E8	2022-01	0	-	0	-	0.097	-	0	-	0	-	0	-
24	E6B, E8	2022-02	0	-	0	-	0.083	-	0	-	0.042	-	0	-
25	E8XN	2021-07	0	0	0.174	0	0	0	0	0	0.130	0	0	0
25	E8XN	2021-08	0	0	0	0	0	0	0	0	0.194	0	0.032	0
25	E8XN	2021-09	0.067	0	0	0	0	0	0	0	0	0	0	0
25	E8XN	2021-10	0.065	-	0	-	0	-	0	-	0	-	0	-
25	E8XN	2021-11	0	-	0.048	-	0.143	-	0	-	0	-	0	-

Table 7. Comparison of monthly detection rate (probability of detection per survey day) between camera trap and field surveys for four species of avian and aquatic mammalian predators of Snowy Plover in Eden Landing, CA. Camera traps were up from July 2021–February 2022, though some cameras were not functional for the entire period. Field surveys were conducted by biologists from March–September 2021. Months that were not sampled by a given camera are not shown.

			River Otter		Great Blue Heron		Great Egret		Northern Harrier	
Station	**Pond(s)**	**Month**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**
3	E8	2021-07	0	0	0	0.500	0	0.250	0	0.750
3	E8	2021-08	0	0	0	0.400	0	0.400	0	0.200
3	E8	2021-09	0	0	0	0	0	0.500	0	1.000
3	E8	2021-10	0	-	0	-	0	-	0	-
3	E8	2021-11	0	-	0	-	0.033	-	0	-
3	E8	2021-12	0	-	0	-	0	-	0	-
3	E8	2022-01	0	-	0	-	0	-	0	-
3	E8	2022-02	0	-	0	-	0	-	0	-
4	None	2021-07	0	-	0	-	0.043	-	0	-
4	None	2021-08	0	-	0	-	0	-	0	-
4	None	2021-09	0	-	0	-	0.033	-	0.033	-
4	None	2021-10	0	-	0	-	0.032	-	0	-
4	None	2021-11	0	-	0	-	0	-	0	-
4	None	2021-12	0	-	0	-	0.161	-	0	-
4	None	2022-01	0	-	0.032	-	0.032	-	0	-
4	None	2022-02	0	-	0	-	0.667	-	0.333	-
5	E14, E9	2021-07	0	0	0	0	0	0	0	1.000
5	E14, E9	2021-08	0	0	0	0.200	0	0.400	0	0.600
5	E14, E9	2021-09	0	0	0	0	0.033	0	0	0
5	E14, E9	2021-10	0	-	0	-	0	-	0	-
5	E14, E9	2021-11	0	-	0	-	0.033	-	0	-
5	E14, E9	2021-12	0	-	0	-	0	-	0	-
5	E14, E9	2022-01	0.032	-	0	-	0	-	0	-
5	E14, E9	2022-02	0	-	0	-	0	-	0	-
6	E2	2021-07	0	-	0	-	0	-	0	-
6	E2	2021-08	0	-	0	-	0	-	0.032	-

			River Otter		Great Blue Heron		Great Egret		Northern Harrier	
Station	**Pond(s)**	**Month**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**
6	E2	2021-09	0	-	0	-	0	-	0	-
6	E2	2021-10	0	-	0	-	0	-	0	-
6	E2	2021-11	0	-	0	-	0	-	0	-
6	E2	2021-12	0	-	0	-	0	-	0	-
6	E2	2022-01	0	-	0	-	0	-	0	-
6	E2	2022-02	0	-	0	-	0	-	0	-
7	E6	2021-07	0.087	0	0	0	0.043	0.750	0	0
7	E6	2021-08	0.032	0	0	0.250	0.097	0.500	0	0
7	E6	2021-09	0	0	0	0	0.100	0	0	0
7	E6	2021-10	0.032	-	0.032	-	0	-	0	-
7	E6	2021-11	0.033	-	0	-	0	-	0	-
7	E6	2021-12	0	-	0	-	0	-	0	-
7	E6	2022-01	0	-	0	-	0	-	0	-
7	E6	2022-02	0	-	0	-	0	-	0	-
8	E14, E13	2021-07	0	0	0.043	0.125	0	0.375	0	0.500
8	E14, E13	2021-08	0	0	0	0.350	0	0.575	0	0.425
9	E6B	2021-07	0	0	0	0.250	0	0.250	0	0.250
9	E6B	2021-08	0	0	0	0.200	0.032	0.400	0	0
9	E6B	2021-09	0	0	0	0	0	0	0.033	0
9	E6B	2021-10	0	-	0	-	0	-	0	-
9	E6B	2021-11	0	-	0	-	0	-	0	-
9	E6B	2021-12	0	-	0	-	0	-	0	-
9	E6B	2022-01	0	-	0	-	0	-	0	-
9	E6B	2022-02	0	-	0	-	0	-	0	-
10	E6C	2021-07	0	-	0	-	0	-	0	-
10	E6C	2021-08	0	0	0	0	0	1.000	0	0
13	E20B	2021-07	0	0	0	0	0	0	0	0
13	E20B	2021-08	0	0	0	0	0	0	0	0
13	E20B	2021-09	0	0	0	0	0	0	0	0
13	E20B	2021-10	0	-	0	-	0	-	0	-

			River Otter		Great Blue Heron		Great Egret		Northern Harrier	
Station	**Pond(s)**	**Month**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**	**Camera**	**Survey**
13	E20B	2021-11	0	-	0	-	0	-	0	-
13	E20B	2021-12	0	-	0	-	0	-	0	-
14	E13	2021-07	0	0	0	0.250	0	0.750	0	0
14	E13	2021-08	0	0	0	0.500	0	0.750	0	0.250
14	E13	2021-09	0	0	0	0	0	0.500	0	0.500
14	E13	2021-10	0	-	0	-	0	-	0	-
14	E13	2021-11	0	-	0	-	0	-	0	-
14	E13	2021-12	0	-	0	-	0	-	0	-
14	E13	2022-01	0	-	0	-	0	-	0	-
14	E13	2022-02	0	-	0	-	0	-	0	-
16	E1C	2021-07	0	0	0	0	0	0	0	0
16	E1C	2021-08	0	0	0	0	0	0.333	0	0
16	E1C	2021-09	0	0	0	0	0	0	0	0
18	E10	2021-07	0	0	0	1.000	0	1.000	0	0
18	E10	2021-08	0	0	0	0.667	0	0.667	0	0
18	E10	2021-09	0	0	0	1.000	0	0.500	0	0.500
18	E10	2021-10	0	-	0	-	0	-	0	-
18	E10	2021-11	0	-	0	-	0	-	0	-
18	E10	2021-12	0	-	0	-	0	-	0	-
18	E10	2022-01	0	-	0	-	0.032	-	0	-
18	E10	2022-02	0	-	0	-	0	-	0	-
21	E20B	2021-07	0	0	0	0	0	0	0	0
21	E20B	2021-08	0	0	0	0	0	0	0	0
21	E20B	2021-09	0	0	0	0	0	0	0	0
21	E20B	2021-10	0	-	0	-	0	-	0.032	-
21	E20B	2021-11	0	-	0	-	0	-	0	-
21	E20B	2021-12	0	-	0	-	0	-	0	-
21	E20B	2022-01	0	-	0	-	0	-	0.032	-
21	E20B	2022-02	0	-	0	-	0	-	0	-
22	E10, E10X	2021-07	0	0	0	1.000	0	1.000	0.043	0

Station	Pond(s)	Month	River Otter		Great Blue Heron		Great Egret		Northern Harrier	
			Camera	Survey	Camera	Survey	Camera	Survey	Camera	Survey
22	E10, E10X	2021-08	0	0	0	0.667	0	0.667	0	0
22	E10, E10X	2021-09	0	0	0	1.000	0	0.500	0	0.500
22	E10, E10X	2021-10	0	-	0	-	0	-	0	-
22	E10, E10X	2021-11	0	-	0	-	0	-	0	-
22	E10, E10X	2021-12	0	-	0	-	0.161	-	0	-
22	E10, E10X	2022-01	0	-	0.032	-	0	-	0	-
22	E10, E10X	2022-02	0	-	0	-	0	-	0	-
23	E10, E10X	2021-07	0	0	0	1.000	0.200	1.000	0	0
23	E10, E10X	2021-08	0	0	0.065	0.667	0.290	0.667	0	0
23	E10, E10X	2021-09	0	0	0	1.000	0.433	0.500	0	0.500
23	E10, E10X	2021-10	0	-	0.032	-	0.129	-	0	-
23	E10, E10X	2021-11	0	-	0.033	-	0.033	-	0.033	-
23	E10, E10X	2021-12	0	-	0.097	-	0.129	-	0.097	-
23	E10, E10X	2022-01	0	-	0.032	-	0.258	-	0	-
23	E10, E10X	2022-02	0	-	0	-	0.240	-	0	-
24	E6B, E8	2021-07	0	0	0	0.375	0.043	0.250	0	0.500
24	E6B, E8	2021-08	0	0	0	0.300	0	0.400	0	0.100
24	E6B, E8	2021-09	0	0	0	0	0	0.250	0	0.500
24	E6B, E8	2021-10	0	-	0.032	-	0	-	0	-
24	E6B, E8	2021-11	0	-	0	-	0	-	0	-
24	E6B, E8	2021-12	0	-	0	-	0.097	-	0	-
24	E6B, E8	2022-01	0	-	0	-	0	-	0	-
24	E6B, E8	2022-02	0	-	0	-	0	-	0	-
25	E8XN	2021-07	0	0	0	0.250	0	0.500	0	0
25	E8XN	2021-08	0	0	0	0.200	0.032	0.400	0	0
25	E8XN	2021-09	0	0	0	1.000	0	0	0	0
25	E8XN	2021-10	0	-	0	-	0	-	0	-
25	E8XN	2021-11	0	-	0	-	0	-	0	-

Table 8. Summary table of model selection results for multi-season occupancy models of ten species of predators detected by camera traps in Eden Landing Ecological Reserve, CA, July 2021–February 2022. A "+" indicates a positive relationship between the parameter and covariate, a "-" an inverse relationship, and a "++" and "--" a statistically significant positive ($p < 0.05$, respectively) in the top model. For example, "E-" indicates that as that covariate's value increases at a site, the rate of extinction at that site is predicted to decrease. Species for which trapping and removal was not conducted in significant amounts have *n/a* (not applicable) for the *Trap01* variable. Due to small sample sizes ($n = 17$ sites), some models showed unstable estimates with high standard errors that may indicate unreliable estimates. See Appendix 1 for AICc model selection tables and top models.

	Occupancy / Colonization / Extinction probability				**Detection probability**		
Species	**Trap01**	**Plovers**	**Humans**	**Urban**	**Trailhead**	**WaterBothSides**	**Drivable**
Red fox					--	++	
Coyote	*n/a*		E-			++	
Striped skunk			E--		--		++
Raccoon*	*n/a*	O+				++	--
Feral cat	*n/a*					-	--
Virginia opossum*							--
River otter*	*n/a*		O+		-		
Northern Harrier	*n/a*			C-			
Great Blue Heron	*n/a*					++	
Great Egret	*n/a*					++	--

*model showed convergence issues with high standard errors

FIGURES

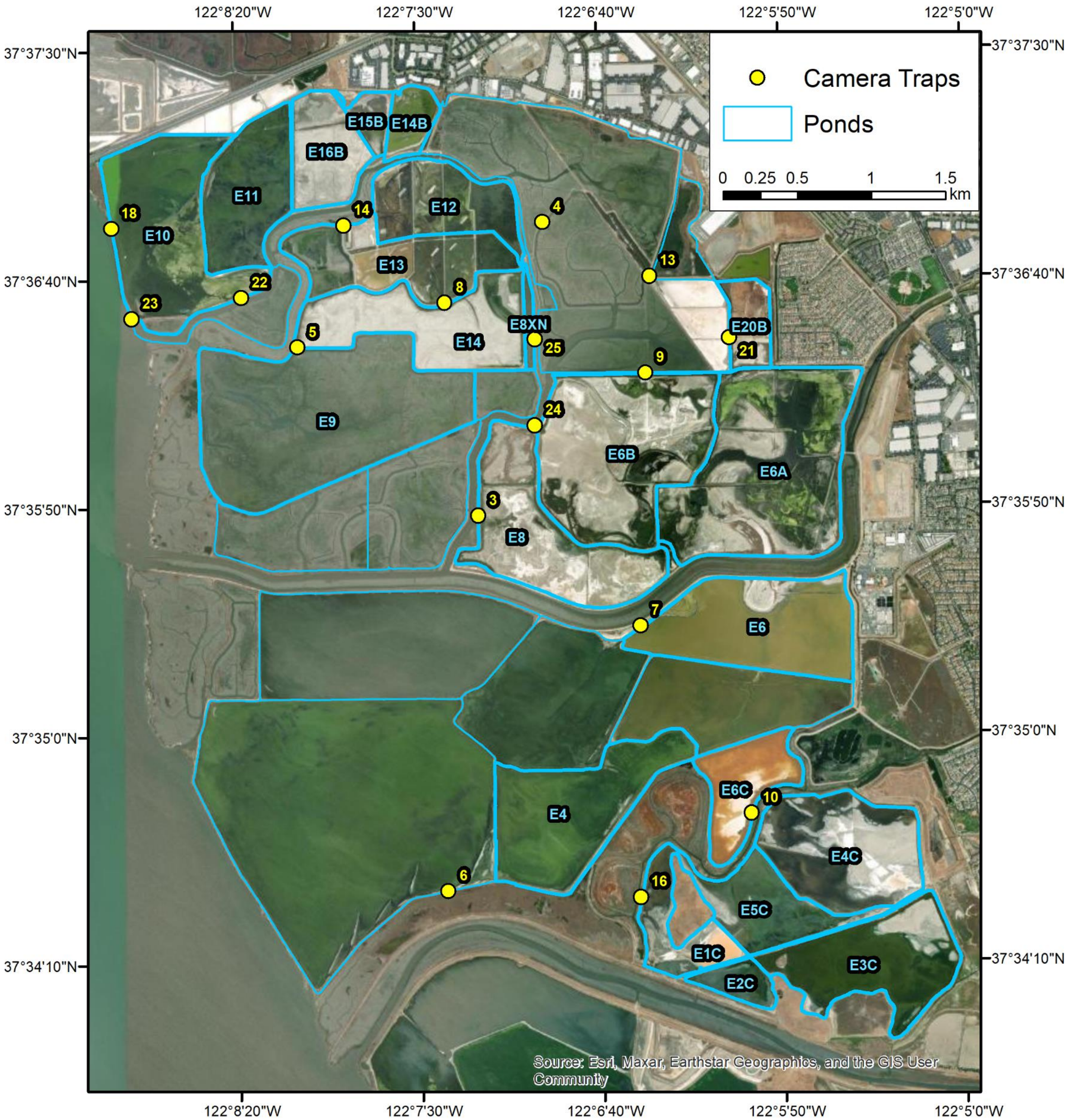

Figure 1. Locations of camera traps (yellow) relative to ponds (blue) in the CDFW's Eden Landing Ecological Reserve, Hayward, California. Ponds with Snowy Plover field monitoring conducted from 2021-2022 are bolded and labeled.

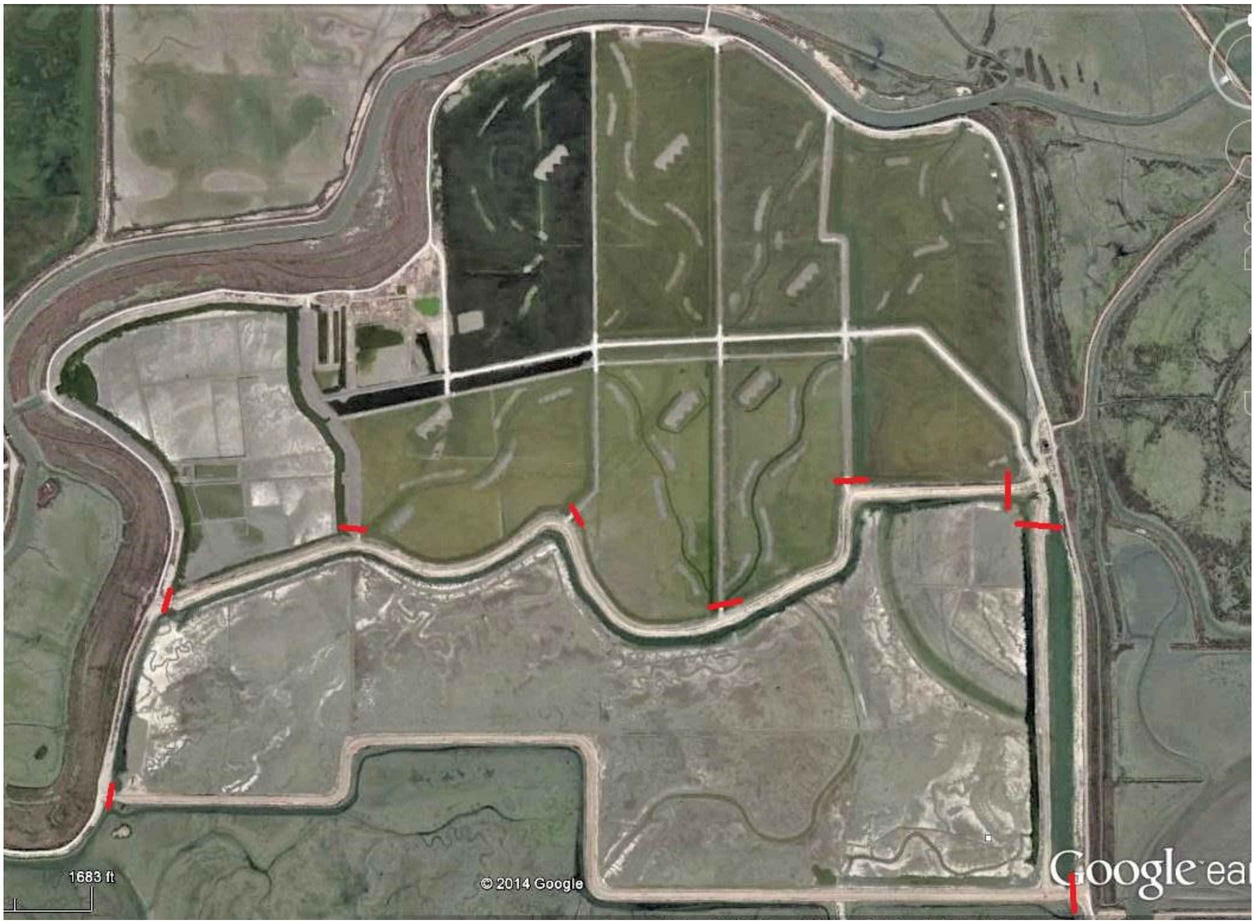

Figure 2. Map showing nine predator fencing locations erected in 2022 along E14 northern border in Eden Landing Ecological Reserve, CA.

Red Fox

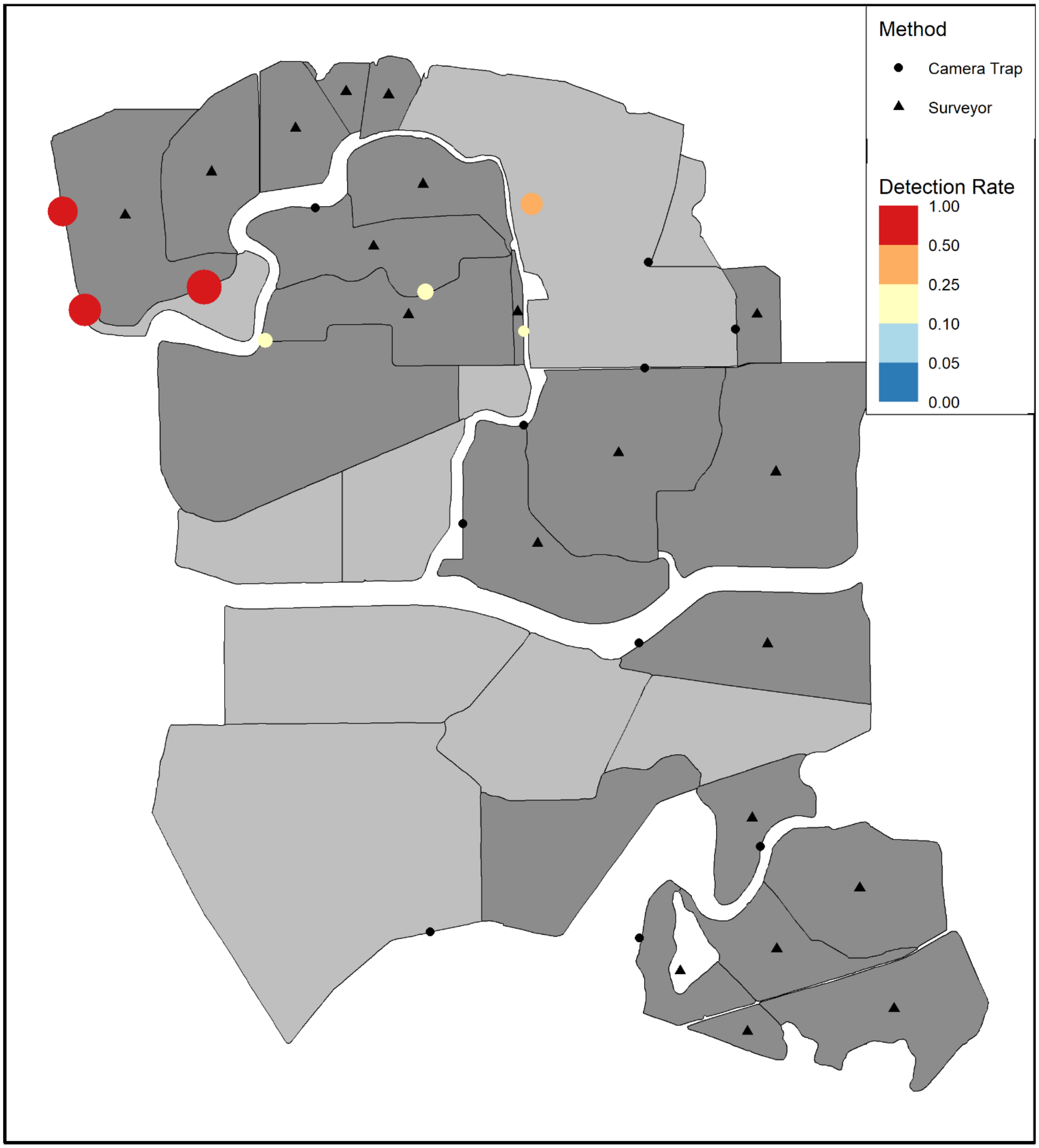

Figure 3. Map of the daily detection rate (probability of a detection per day of surveying) for red fox at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

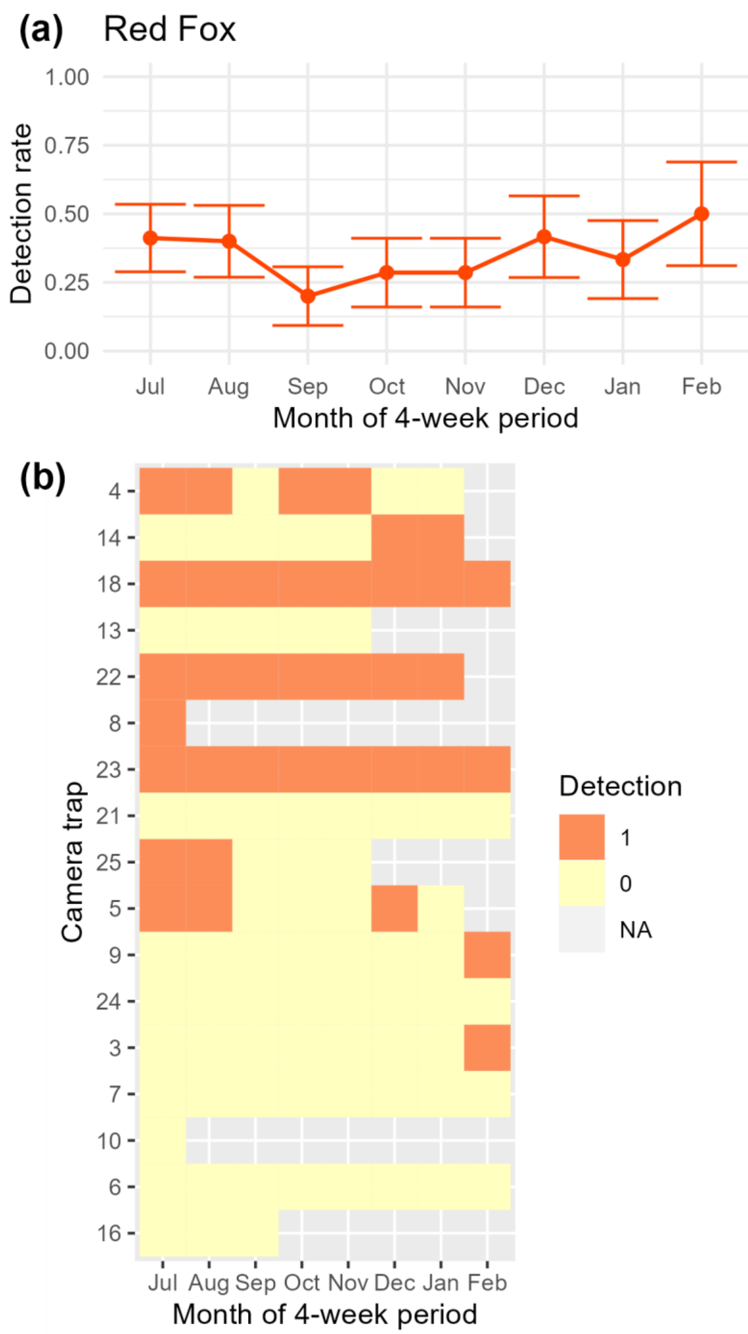

Figure 4. Red fox (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of N/A represent dates after which the camera was no longer functioning.

Coyote

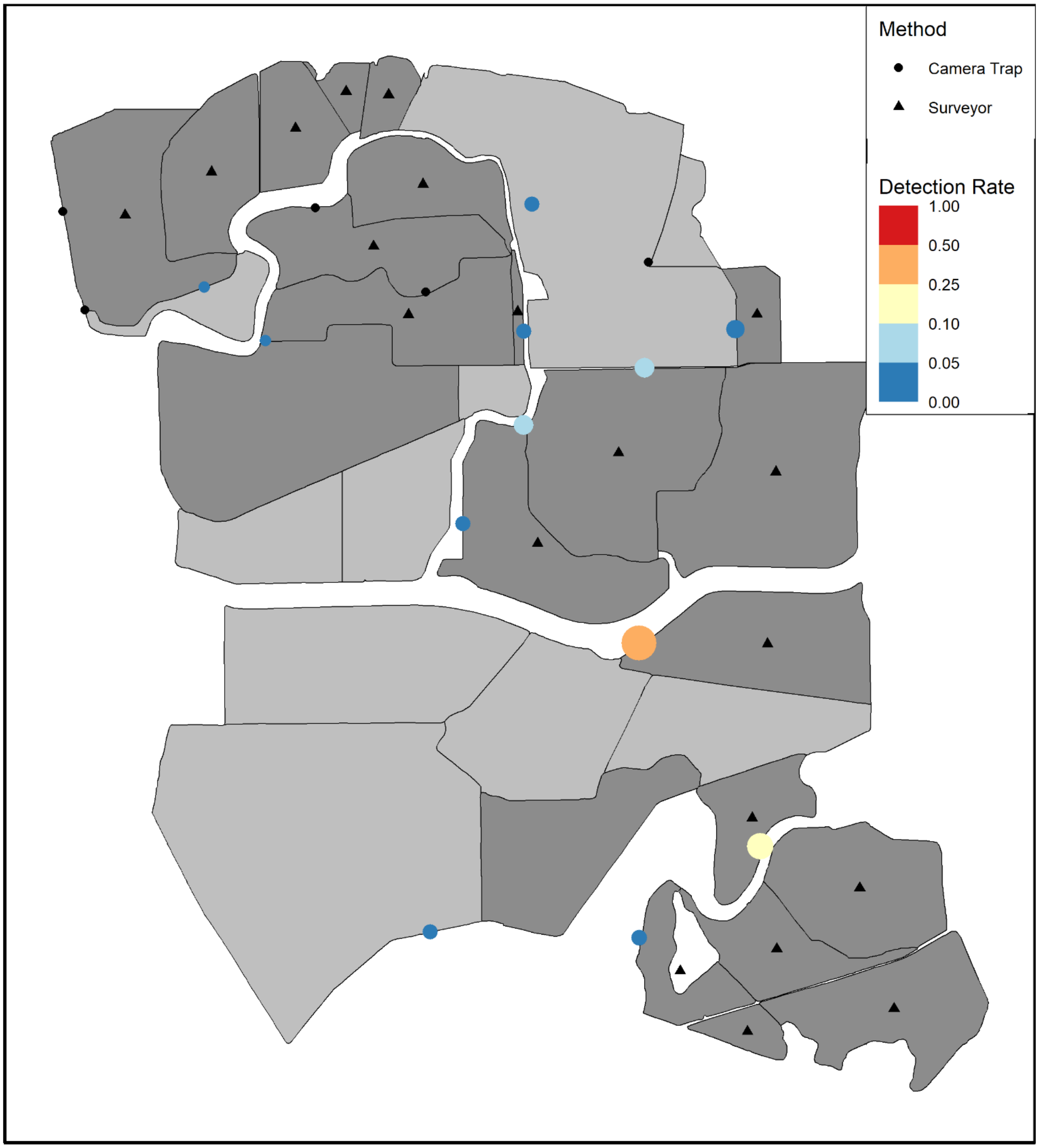

Figure 5. Map of the daily detection rate (probability of a detection per day of surveying) for coyotes at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

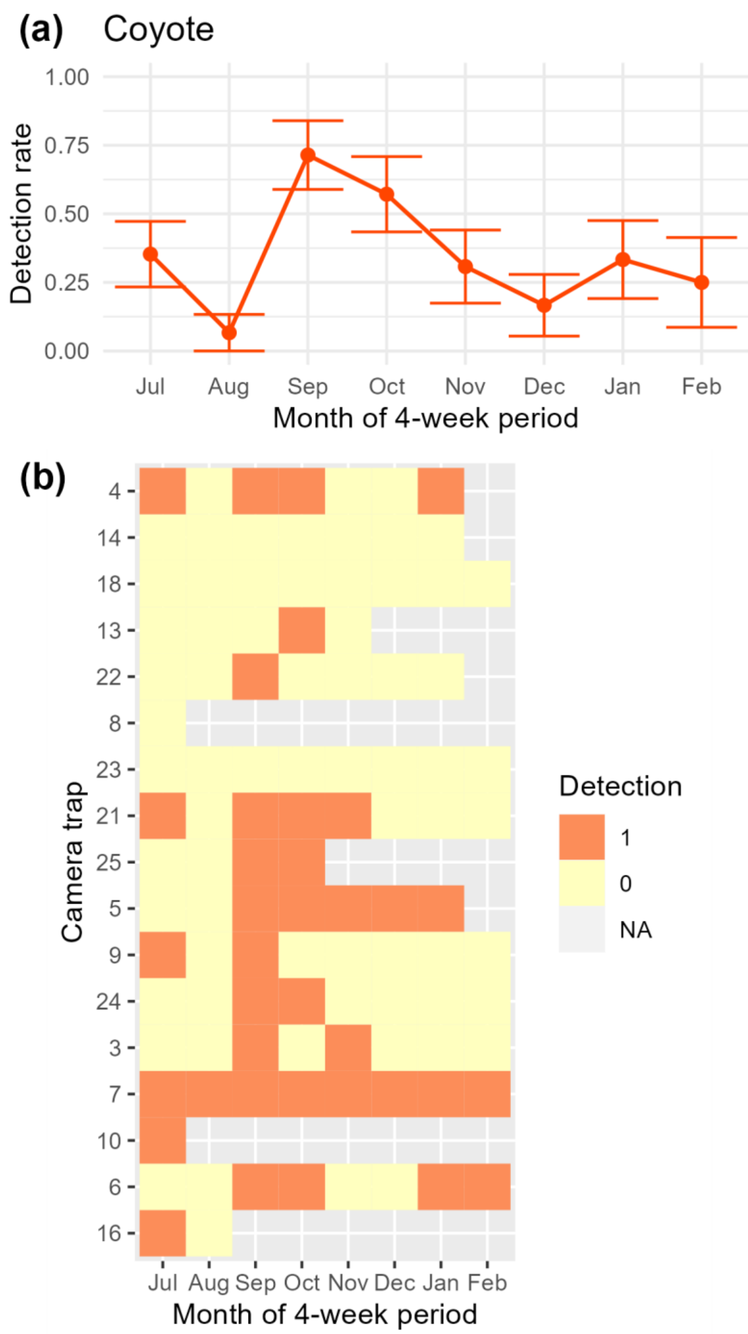

Figure 6. Coyote (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

Striped Skunk

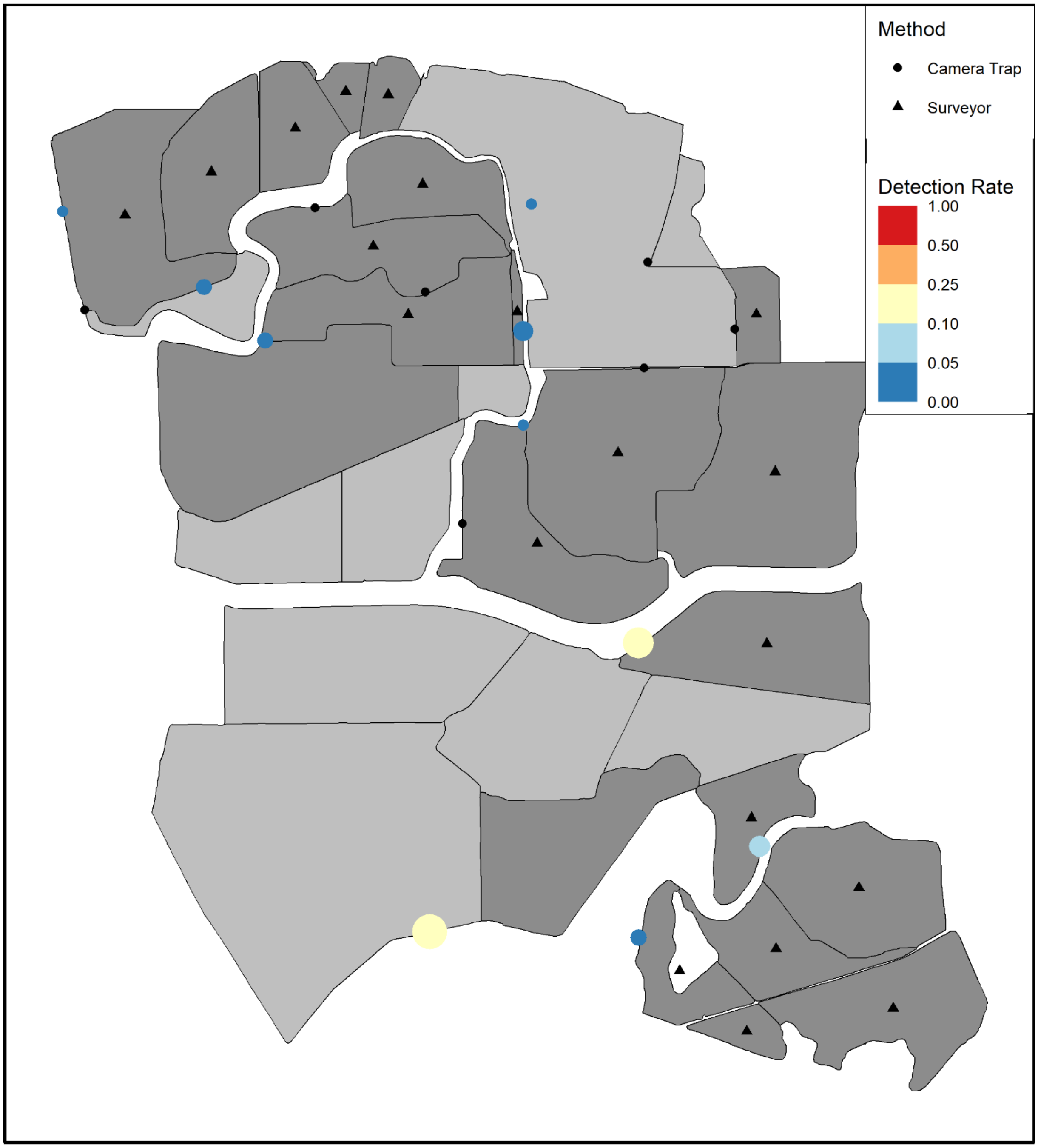

Figure 7. Map of the daily detection rate (probability of a detection per day of surveying) for striped skunk at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

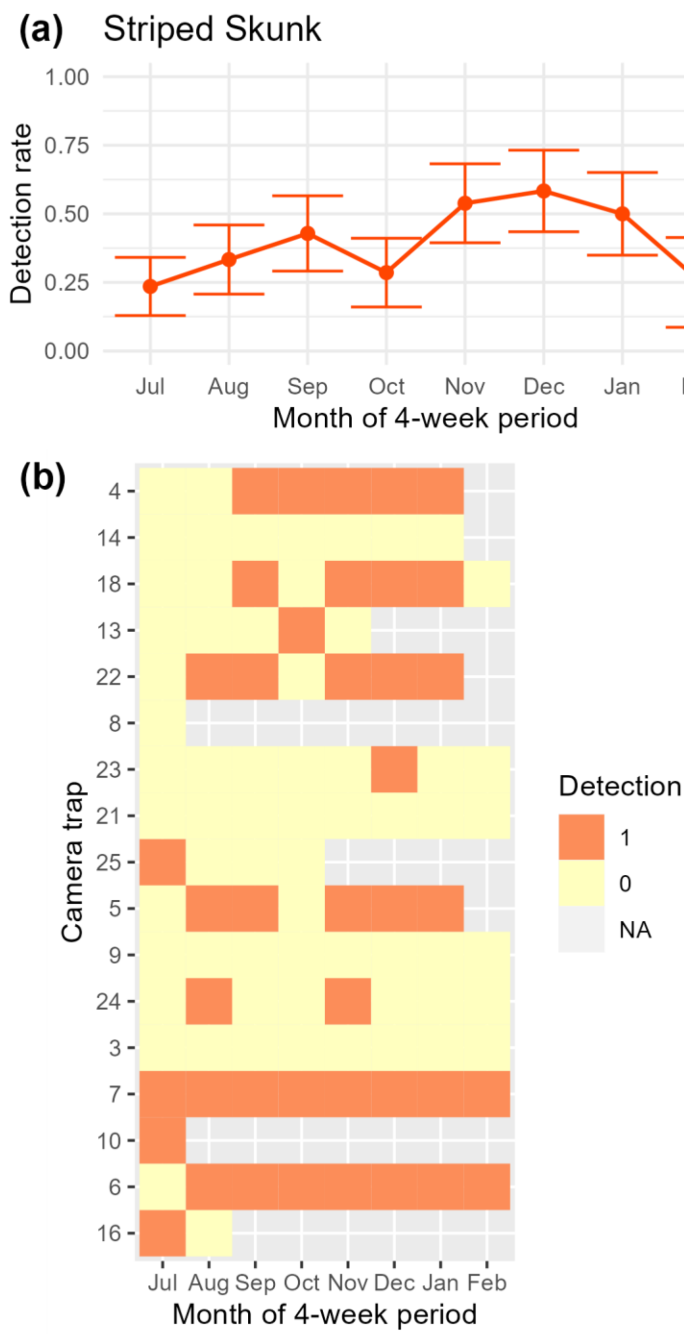

Figure 8. Striped skunk (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

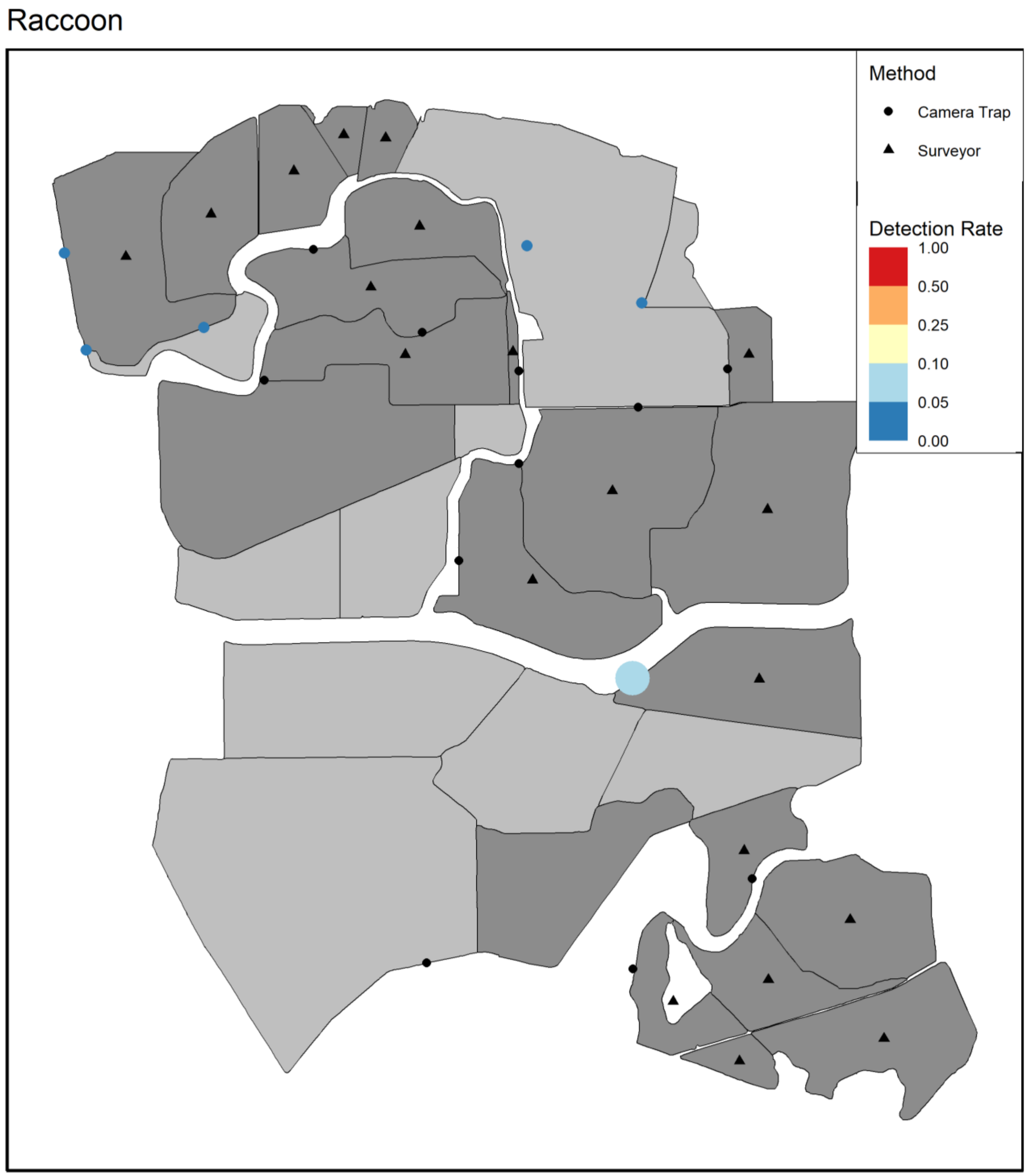

Figure 9. Map of the daily detection rate (probability of a detection per day of surveying) for raccoon at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

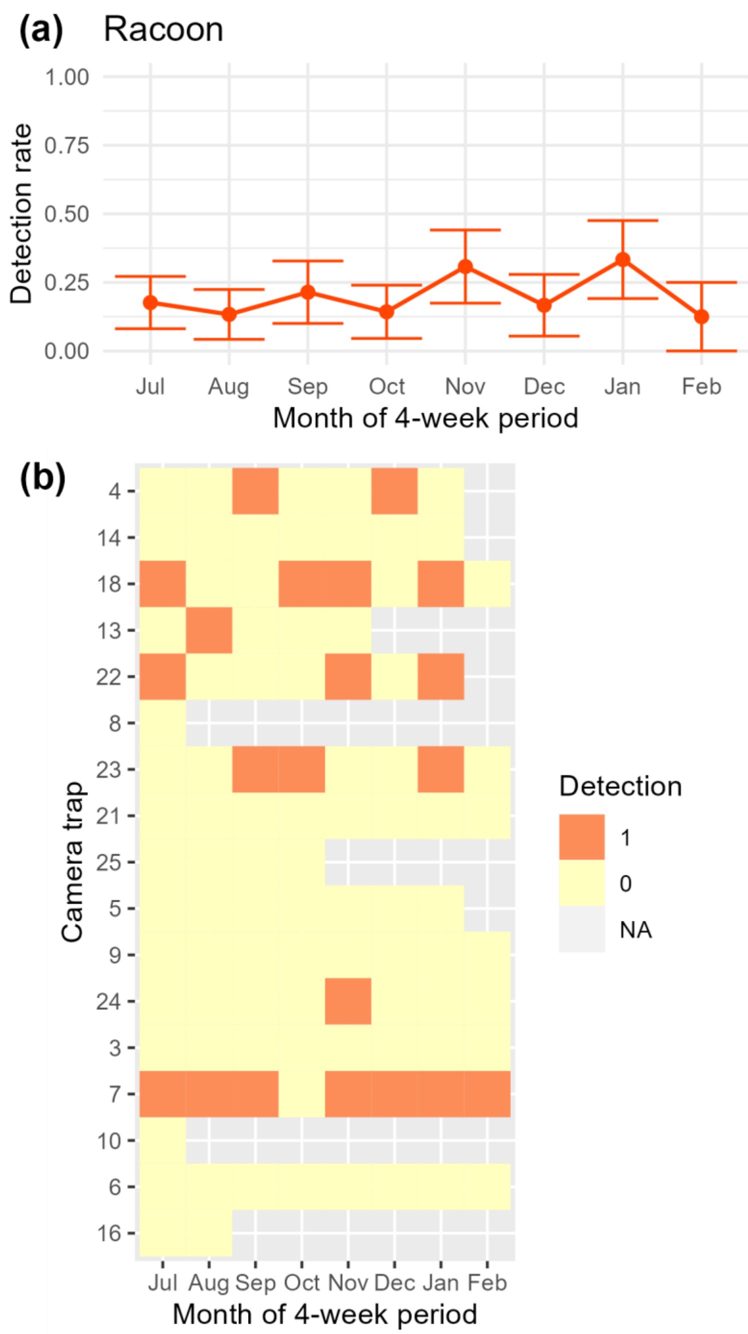

Figure 10. Raccoon (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

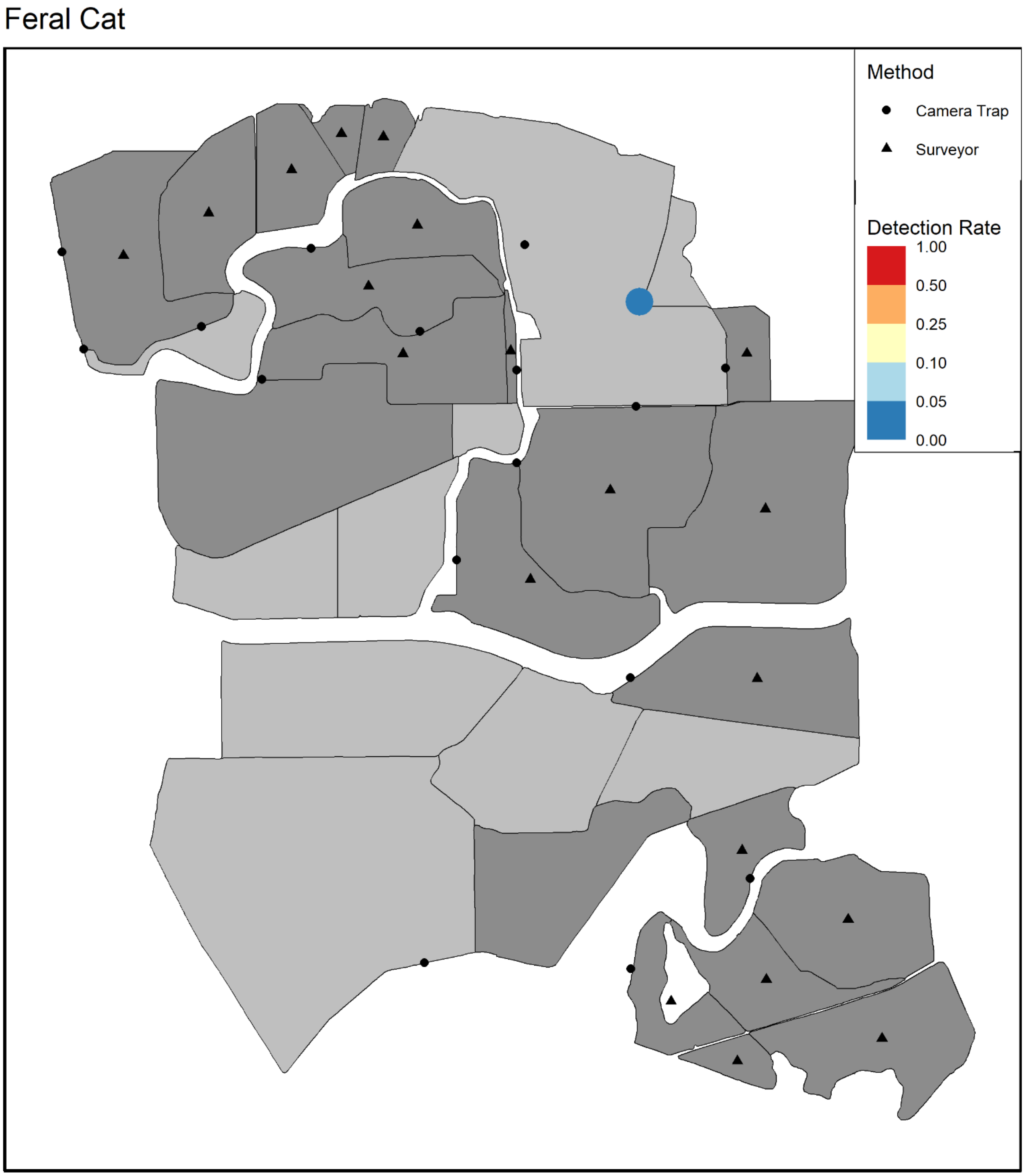

Figure 11. Map of the daily detection rate (probability of a detection per day of surveying) for feral cat at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections. Note that this map does not show the spread of this colonization in later months (see Fig. 12).

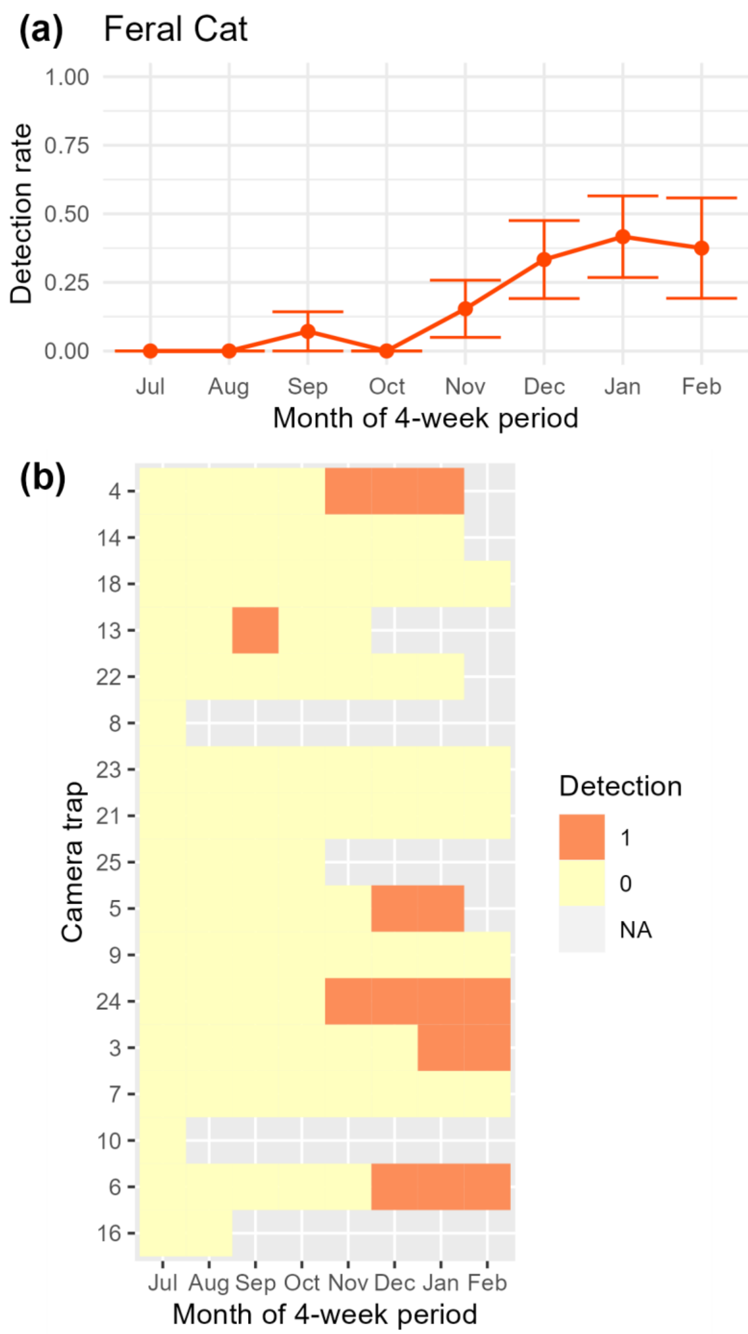

Figure 12. Feral cat (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

Virginia Opossum

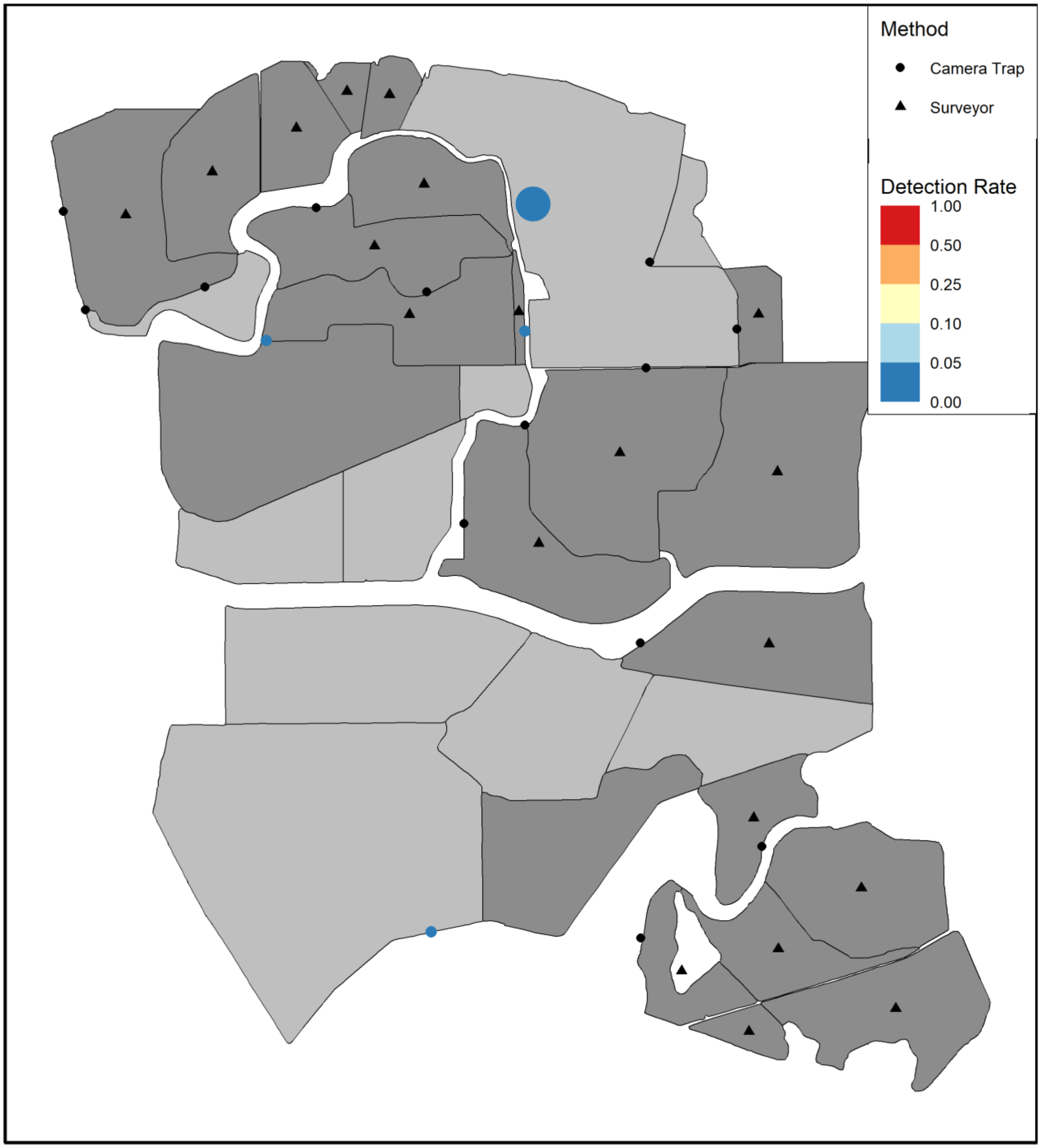

Figure 13. Map of the daily detection rate (probability of a detection per day of surveying) for Virginia opossum at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

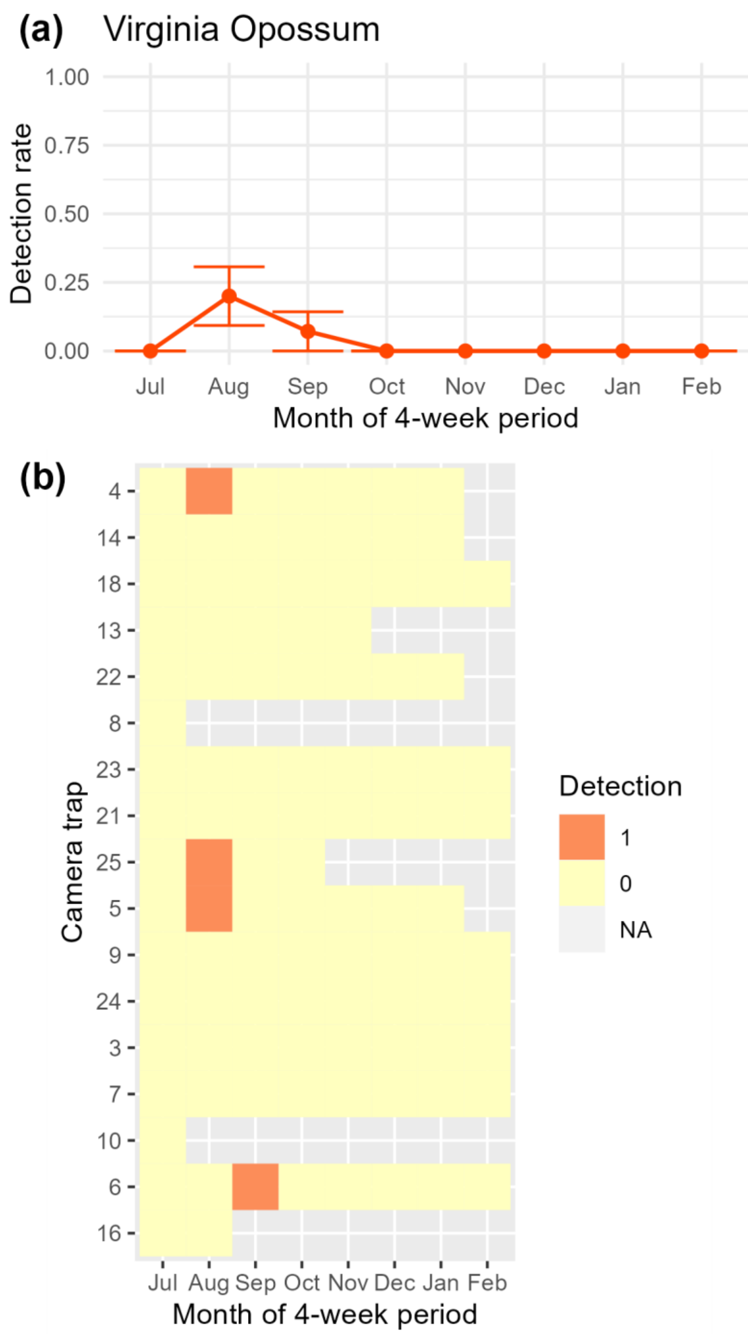

Figure 14. Virginia opossum (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

River Otter

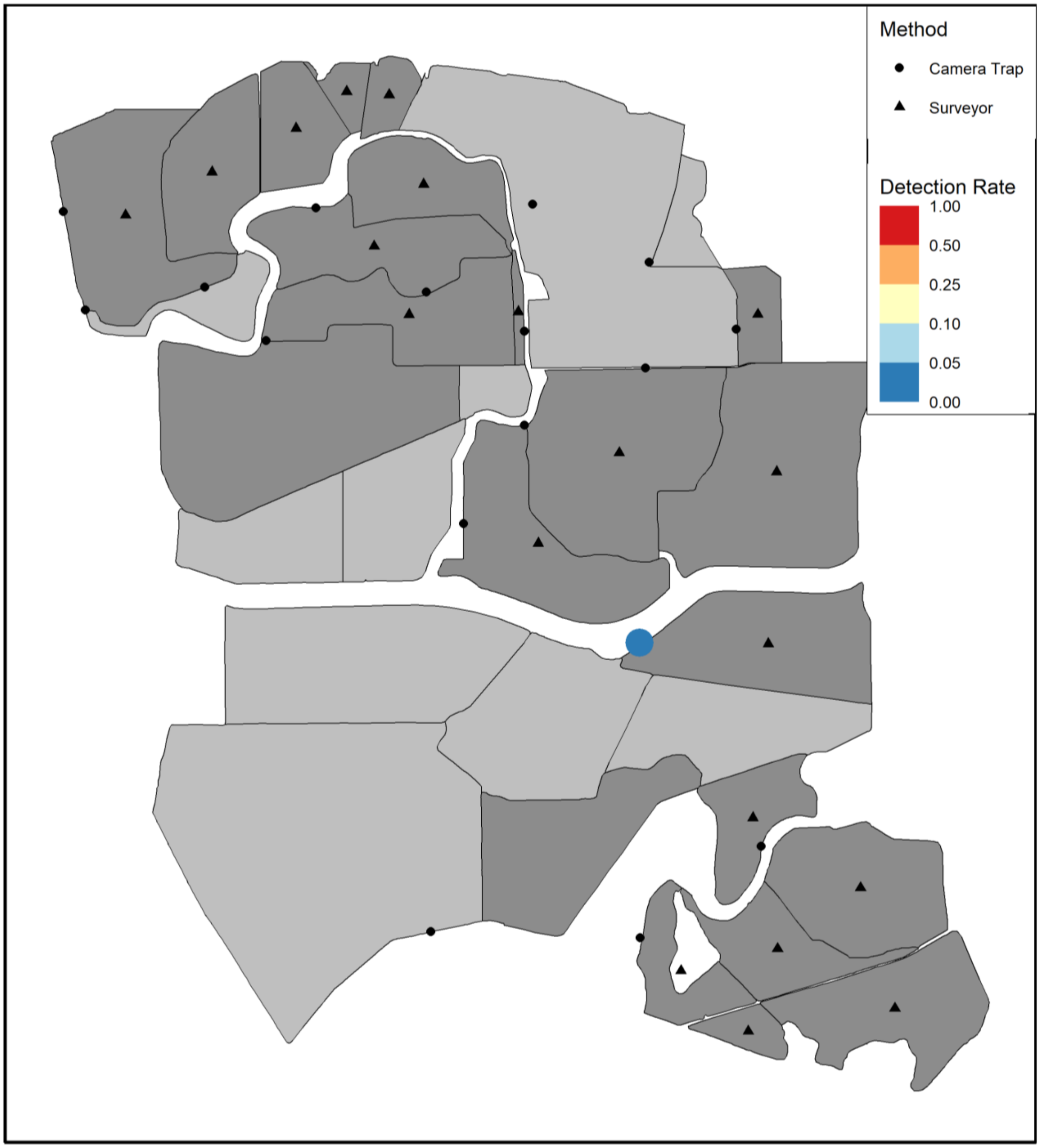

Figure 15. Map of the daily detection rate (probability of a detection per day of surveying) for river otter at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

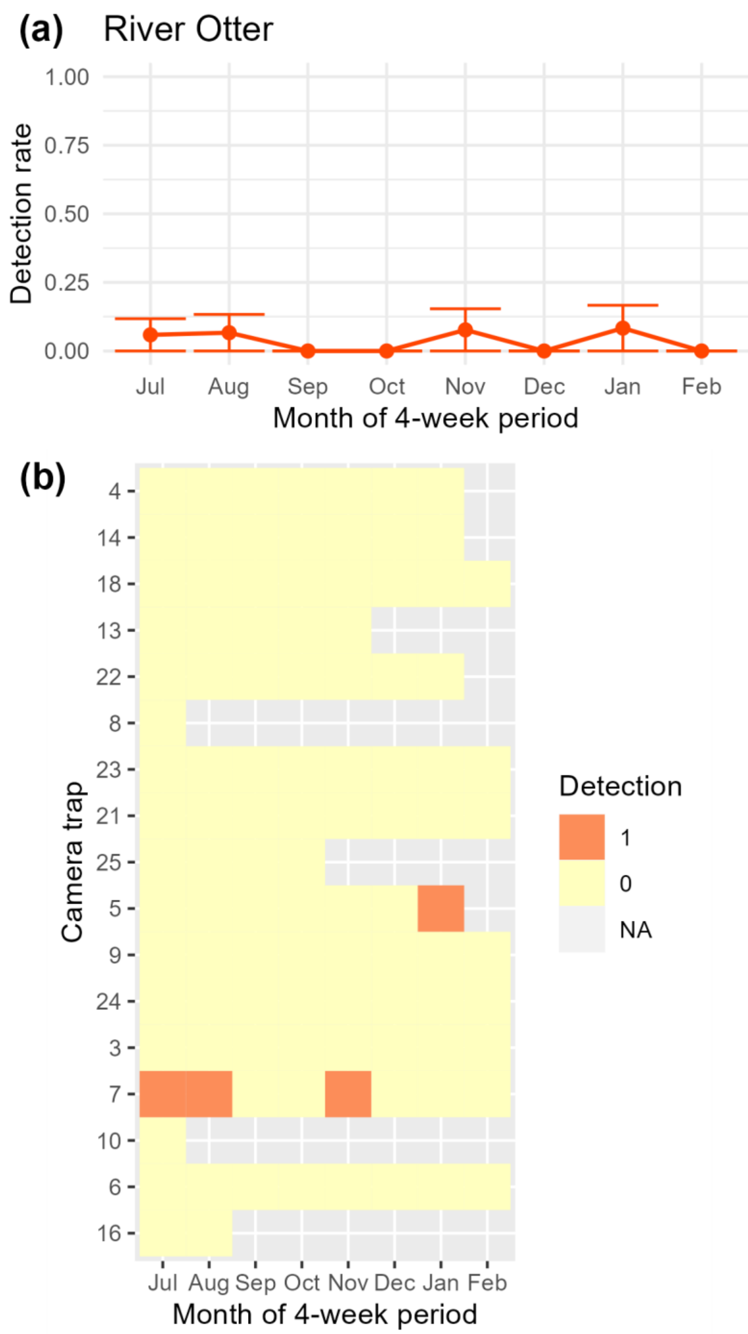

Figure 16. River otter (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

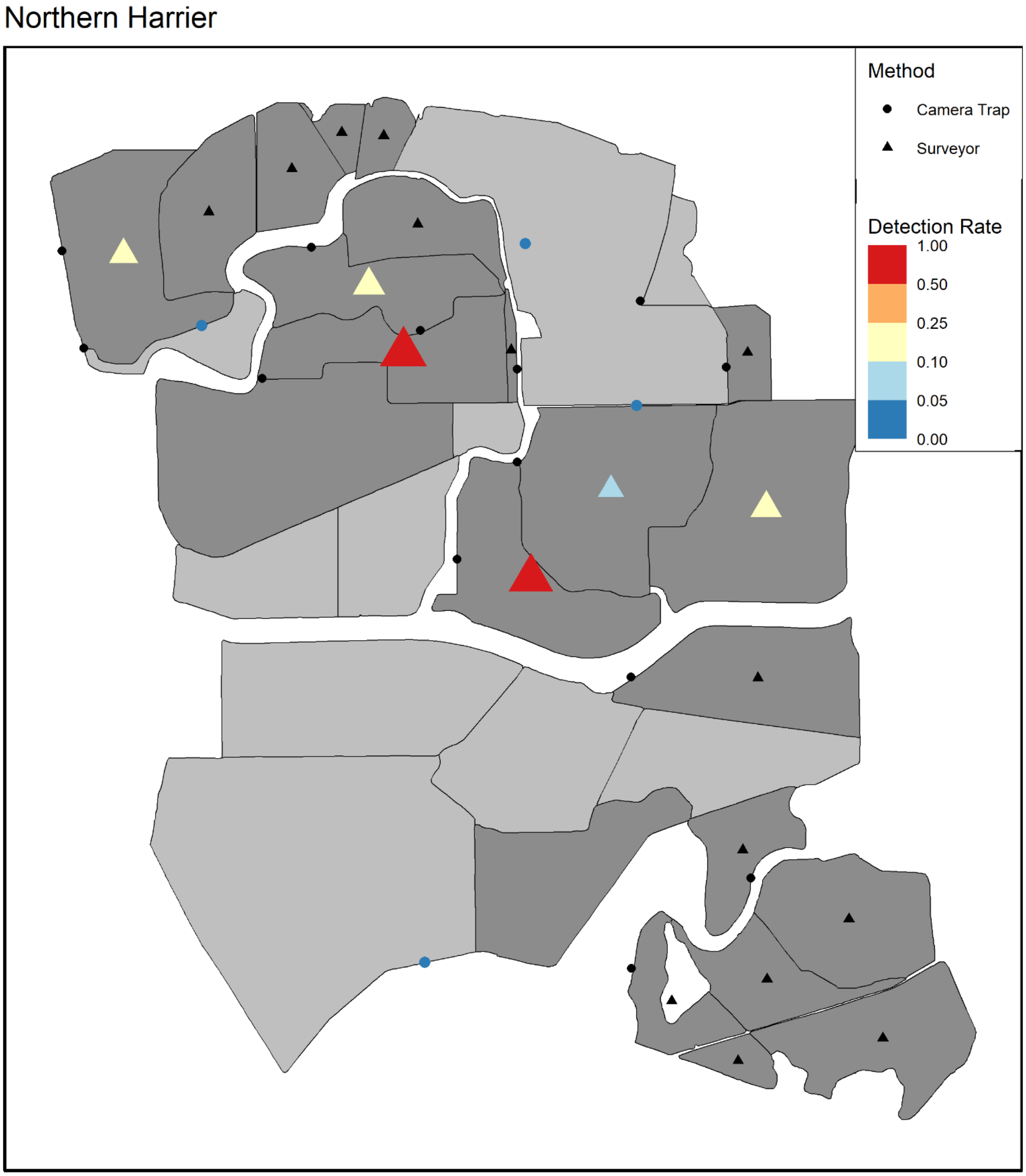

Figure 17. Map of the daily detection rate (probability of a detection per day of surveying) for Northern Harrier at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

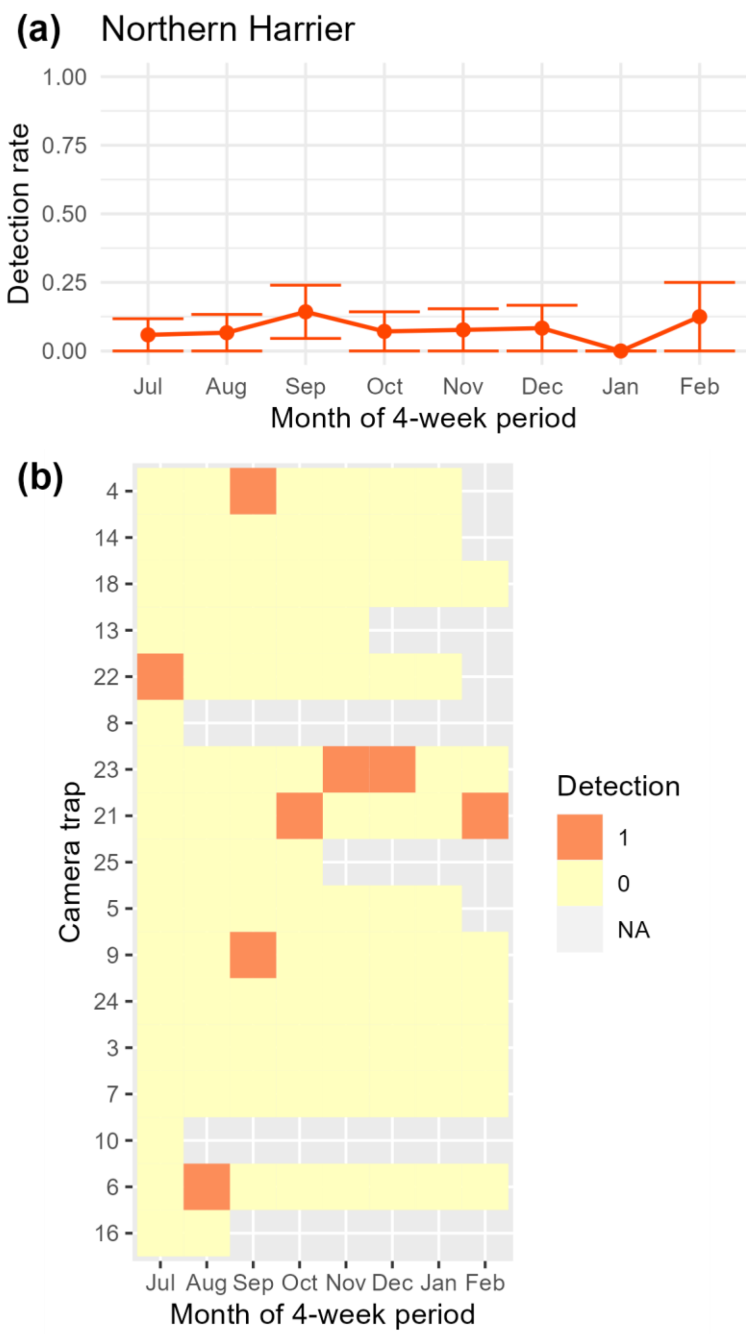

Figure 18. Northern Harrier (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

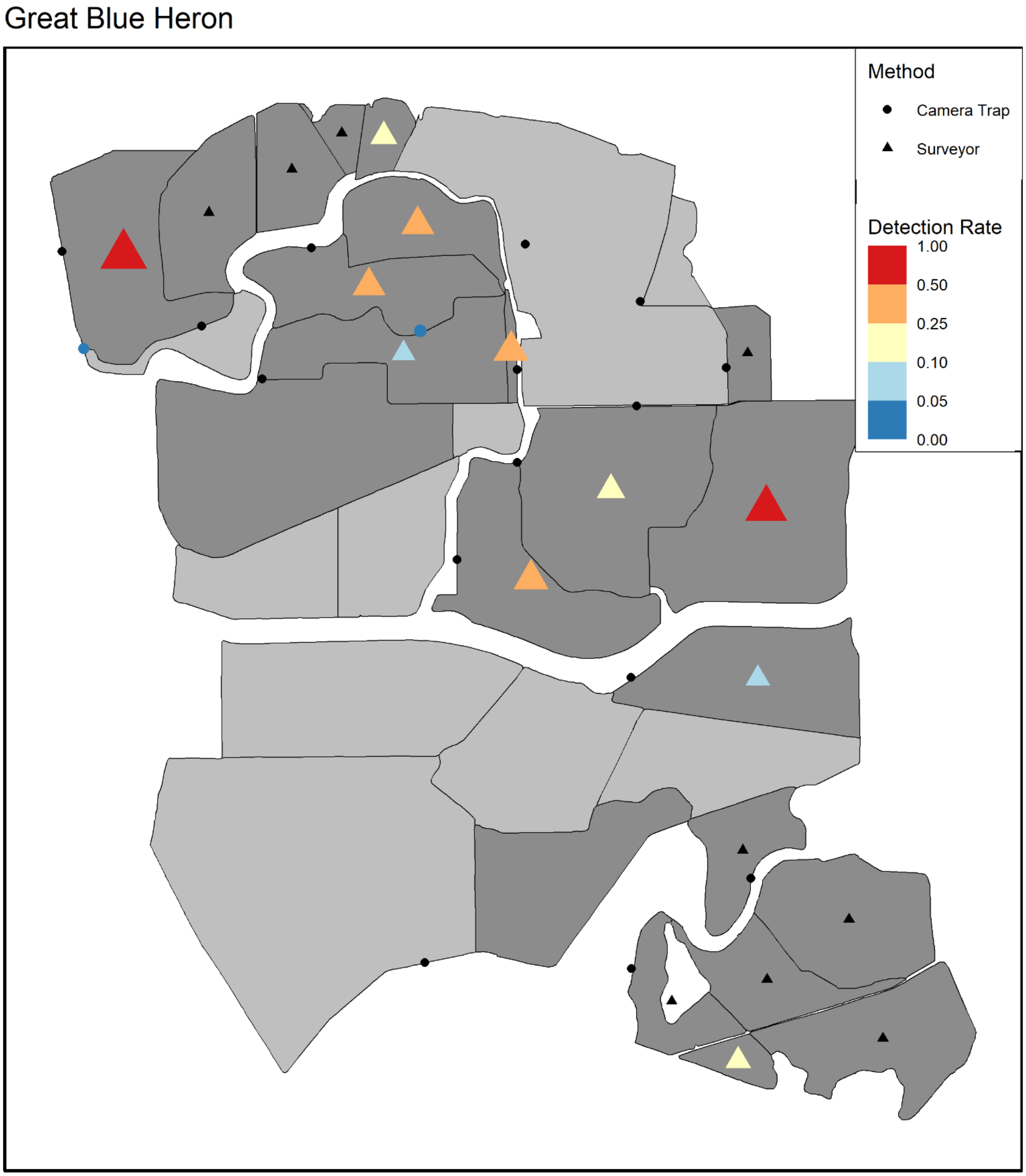

Figure 19. Map of the daily detection rate (probability of a detection per day of surveying) for Great Blue Heron at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

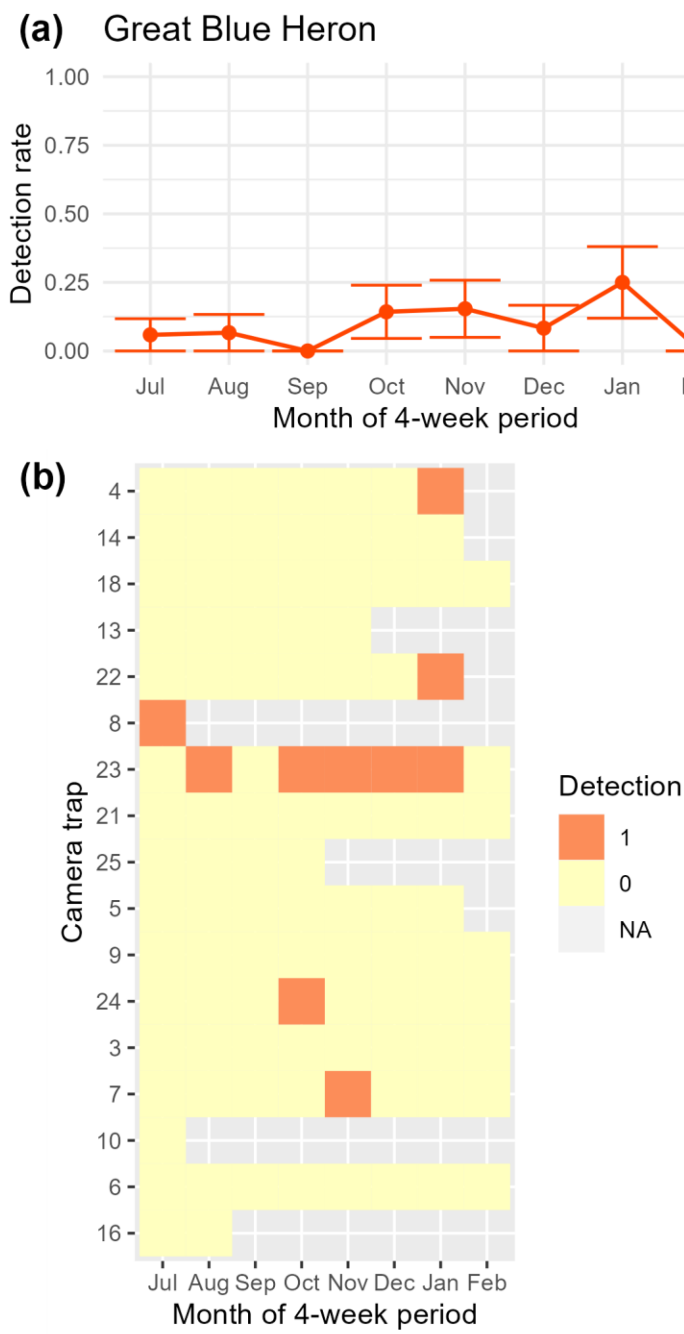

Figure 20. Great Blue Heron (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

Great Egret

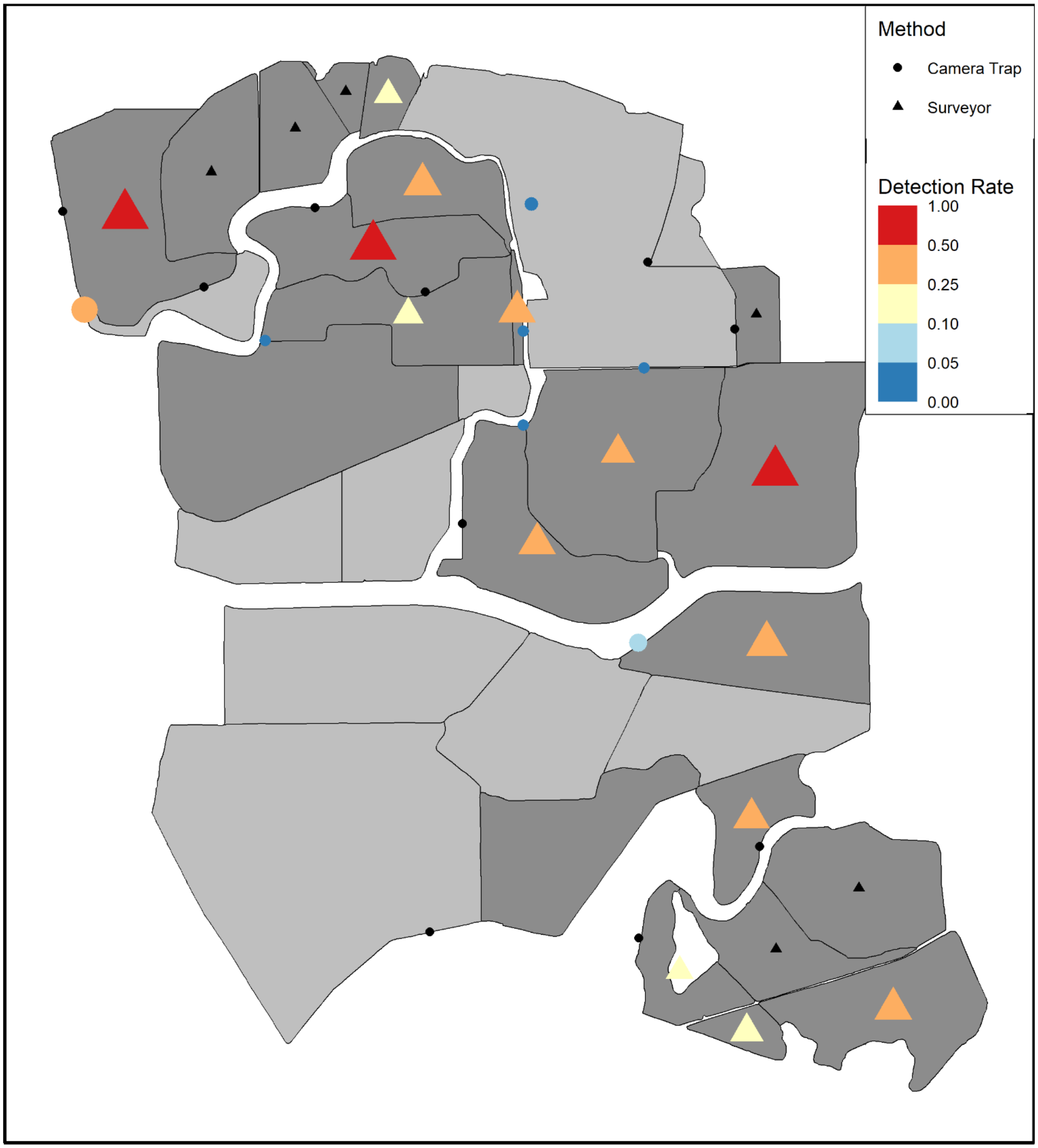

Figure 21. Map of the daily detection rate (probability of a detection per day of surveying) for Great Egret at camera traps placed along berms (circles) or during field surveys around the perimeter of ponds (triangles) from July 9th through September 30th, 2021. Black sites indicate no detections.

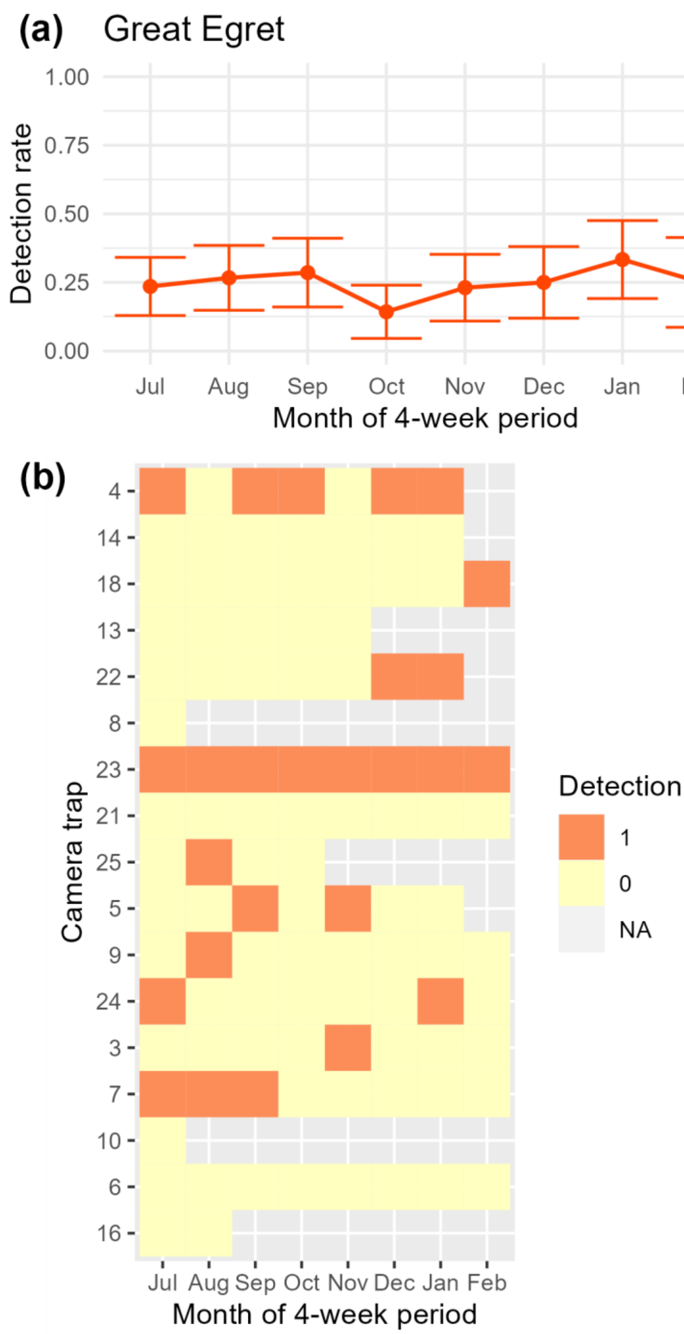

Figure 22. Great Egret (a) overall detection rate across camera traps (naïve regional occupancy) and (b) detections by camera trap (naïve occupancy), over 4-week periods used in occupancy models, within Eden Landing Ecological Reserve, CA. In panel (b), sites are sorted by UTM *y* coordinate (northern at the top, southern at the bottom), and values of NA represent dates after which the camera was no longer functioning.

APPENDIX 1

Model selections results (AICc summary tables and top models) for multi-season occupancy models of ten species of predator in Eden Landing Ecological Reserve, CA, July 2021–February 2022; only the top 20 models are shown in each table.

Table A1.1. AICc model selection table results for red fox occupancy (including trapping) in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
O ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	6	1414.69	0.00	-697.14	0.44
O ~ 1 | C ~ 1 | E ~ Plovers | D ~ Trailhead + WaterBothSides	7	1417.03	2.34	-695.29	0.58
O ~ 1 | C ~ 1 | E ~ Humans | D ~ Trailhead + WaterBothSides	7	1419.48	4.79	-696.52	0.62
O ~ Urban | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	7	1419.60	4.91	-696.58	0.66
O ~ 1 | C ~ Plovers | E ~ 1 | D ~ Trailhead + WaterBothSides	7	1419.69	5.00	-696.62	0.70
O ~ 1 | C ~ 1 | E ~ Trap01 | D ~ Trailhead + WaterBothSides	7	1419.98	5.30	-696.77	0.73
O ~ 1 | C ~ Humans | E ~ 1 | D ~ Trailhead + WaterBothSides	7	1420.18	5.49	-696.87	0.76
O ~ 1 | C ~ Urban | E ~ 1 | D ~ Trailhead + WaterBothSides	7	1420.24	5.55	-696.90	0.78
O ~ Humans | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	7	1420.30	5.61	-696.93	0.81
O ~ 1 | C ~ 1 | E ~ Urban | D ~ Trailhead + WaterBothSides	7	1420.57	5.89	-697.07	0.83
O ~ Plovers | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	7	1420.65	5.96	-697.10	0.86
O ~ Trap01 | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	7	1420.73	6.04	-697.14	0.88
O ~ 1 | C ~ 1 | E ~ Plovers + Trap01 | D ~ Trailhead + WaterBothSides	8	1420.83	6.14	-693.42	0.90
O ~ 1 | C ~ 1 | E ~ Plovers + Urban | D ~ Trailhead + WaterBothSides	8	1421.89	7.20	-693.95	0.91
O ~ 1 | C ~ 1 | E ~ Humans + Trap01 | D ~ Trailhead + WaterBothSides	8	1422.54	7.85	-694.27	0.92
O ~ 1 | C ~ Plovers | E ~ Plovers | D ~ Trailhead + WaterBothSides	8	1423.21	8.52	-694.60	0.93
O ~ Urban | C ~ 1 | E ~ Plovers | D ~ Trailhead + WaterBothSides	8	1423.44	8.75	-694.72	0.93
O ~ Humans | C ~ 1 | E ~ Plovers | D ~ Trailhead + WaterBothSides	8	1424.12	9.43	-695.06	0.94
O ~ 1 | C ~ Urban | E ~ Plovers | D ~ Trailhead + WaterBothSides	8	1424.18	9.49	-695.09	0.94
O ~ 1 | C ~ Humans | E ~ Plovers | D ~ Trailhead + WaterBothSides	8	1424.23	9.54	-695.12	0.94

Top model

```
Initial:
 Estimate    SE     z P(>|z|)
   -0.333 0.498 -0.67   0.503

Colonization:
 Estimate    SE     z  P(>|z|)
    -2.24 0.447 -5.01 5.52e-07

Extinction:
 Estimate    SE     z  P(>|z|)
    -1.96 0.586 -3.34 0.000836
```

```
Detection:
                Estimate    SE     z  P(>|z|)
(Intercept)        -1.29 0.162 -7.94 1.95e-15
Trailhead          -1.42 0.277 -5.14 2.68e-07
WaterBothSides      1.38 0.176  7.79 6.62e-15
```

Table A1.2. AICc model selection results for coyote multi-season occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ WaterBothSides	6	751.52	0.00	-365.56	0.18
OP ~ 1 | C ~ Urban | E ~ Humans | D ~ WaterBothSides	7	752.01	0.49	-362.78	0.32
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ WaterBothSides	6	752.42	0.90	-366.01	0.44
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ WaterBothSides	5	752.45	0.93	-368.50	0.55
OP ~ 1 | C ~ Humans + Urban | E ~ 1 | D ~ WaterBothSides	7	755.18	3.67	-364.37	0.58
OP ~ 1 | C ~ Plovers | E ~ Humans | D ~ WaterBothSides	7	755.66	4.14	-364.61	0.60
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ Drivable + WaterBothSides	7	755.78	4.26	-364.67	0.62
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	6	755.83	4.32	-367.72	0.64
OP ~ 1 | C ~ Humans | E ~ 1 | D ~ WaterBothSides	6	756.00	4.49	-367.80	0.66
OP ~ 1 | C ~ Humans + Urban | E ~ Humans | D ~ WaterBothSides	8	756.53	5.01	-361.27	0.68
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	756.65	5.13	-368.12	0.69
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ Drivable + WaterBothSides	7	756.67	5.15	-365.11	0.70
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ WaterBothSides	6	756.75	5.23	-368.17	0.72
OP ~ Plovers | C ~ 1 | E ~ Humans | D ~ WaterBothSides	7	756.79	5.28	-365.17	0.73
OP ~ 1 | C ~ 1 | E ~ Humans + Plovers | D ~ WaterBothSides	7	756.81	5.29	-365.18	0.74
OP ~ 1 | C ~ Plovers | E ~ 1 | D ~ WaterBothSides	6	756.96	5.45	-368.28	0.75
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	6	757.10	5.58	-368.35	0.77
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	757.24	5.72	-368.42	0.78
OP ~ 1 | C ~ Humans | E ~ Humans | D ~ WaterBothSides	7	757.26	5.74	-365.41	0.79
OP ~ Urban | C ~ 1 | E ~ Humans | D ~ WaterBothSides	7	757.32	5.80	-365.44	0.80

Top model

```
Initial:
 Estimate    SE      z P(>|z|)
   -0.337 0.574 -0.587   0.557

Colonization:
 Estimate    SE     z P(>|z|)
    -1.37 0.499 -2.75 0.00603

Extinction:
            Estimate   SE      z P(>|z|)
(Intercept)     1.06 1.36  0.776   0.438
Humans         -8.77 6.75 -1.299   0.194
```

```
Detection:
                Estimate    SE      z  P(>|z|)
(Intercept)        -3.07 0.237 -12.97 1.88e-38
WaterBothSides      1.59 0.289   5.52 3.30e-08
```

Table A1.3. AICc model selection results for striped skunk (including trapping) multi-season occupancy in Eden Landing Ecological Reserve, CA.O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection prob. (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
O ~ 1 | C ~ 1 | E ~ Humans | D ~ Drivable + Trailhead	7	1007.94	0.00	-490.75	0.20
O ~ 1 | C ~ 1 | E ~ Humans | D ~ Trailhead	6	1009.39	1.45	-494.50	0.29
O ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + Trailhead	6	1009.84	1.90	-494.72	0.37
O ~ 1 | C ~ Plovers | E ~ Humans | D ~ Trailhead	7	1010.89	2.95	-492.22	0.41
O ~ 1 | C ~ Plovers | E ~ Humans | D ~ Drivable + Trailhead	8	1010.94	3.00	-488.47	0.46
O ~ 1 | C ~ Plovers | E ~ 1 | D ~ Drivable + Trailhead	7	1011.06	3.12	-492.31	0.50
O ~ 1 | C ~ 1 | E ~ Urban | D ~ Drivable + Trailhead	7	1011.34	3.40	-492.45	0.53
O ~ 1 | C ~ 1 | E ~ Humans + Plovers | D ~ Trailhead	7	1011.72	3.78	-492.64	0.56
O ~ 1 | C ~ 1 | E ~ Humans + Plovers | D ~ Drivable + Trailhead	8	1011.90	3.96	-488.95	0.59
O ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead	5	1012.16	4.22	-498.35	0.61
O ~ 1 | C ~ 1 | E ~ Urban | D ~ Trailhead	6	1012.32	4.38	-495.96	0.64
O ~ 1 | C ~ Plovers | E ~ 1 | D ~ Trailhead	6	1012.32	4.38	-495.96	0.66
O ~ Humans | C ~ 1 | E ~ Humans | D ~ Trailhead	7	1013.14	5.20	-493.35	0.67
O ~ 1 | C ~ Plovers | E ~ Urban | D ~ Trailhead	7	1013.55	5.61	-493.55	0.69
O ~ Plovers | C ~ 1 | E ~ Humans | D ~ Trailhead	7	1013.66	5.72	-493.61	0.70
O ~ Plovers | C ~ 1 | E ~ Humans | D ~ Drivable + Trailhead	8	1013.72	5.78	-489.86	0.71
O ~ 1 | C ~ Plovers | E ~ Urban | D ~ Drivable + Trailhead	8	1014.09	6.15	-490.04	0.72
O ~ 1 | C ~ 1 | E ~ Humans | D ~ Trailhead + WaterBothSides	7	1014.11	6.17	-493.83	0.73
O ~ 1 | C ~ 1 | E ~ Humans + Urban | D ~ Trailhead	7	1014.18	6.24	-493.87	0.73
O ~ Plovers | C ~ 1 | E ~ 1 | D ~ Drivable + Trailhead	7	1014.41	6.47	-493.98	0.74

Top model

```
Initial:
 Estimate    SE     z P(>|z|)
   -0.871 0.619 -1.41   0.159

Colonization:
 Estimate    SE     z P(>|z|)
    -1.07 0.385 -2.79 0.00528

Extinction:
            Estimate   SE     z P(>|z|)
(Intercept)    0.768 0.80  0.96  0.3369
Humans        -7.063 3.55 -1.99  0.0465
```

```
Detection:
            Estimate    SE     z  P(>|z|)
(Intercept)   -2.665 0.345 -7.73 1.06e-14
Drivable       0.888 0.359  2.47 1.34e-02
Trailhead     -1.394 0.333 -4.18 2.88e-05
```

Table A1.4. AICc model selection results for raccoon multi-season occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	353.95	0.00	-163.75	0.12
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	6	354.49	0.53	-167.04	0.22
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	354.49	0.54	-167.05	0.31
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead	5	355.22	1.26	-169.88	0.37
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ 1	4	356.11	2.15	-172.39	0.41
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ Trailhead	6	356.12	2.16	-167.86	0.46
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ WaterBothSides	5	356.61	2.65	-170.58	0.49
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ Drivable + WaterBothSides	7	356.99	3.03	-165.27	0.52
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ WaterBothSides	6	357.32	3.36	-168.46	0.54
OP ~ Plovers | C ~ 1 | E ~ Urban | D ~ WaterBothSides	7	357.41	3.45	-165.48	0.56
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ 1	5	357.75	3.79	-171.15	0.58
OP ~ 1 | C ~ Humans | E ~ 1 | D ~ 1	5	357.84	3.89	-171.19	0.60
OP ~ 1 | C ~ Humans | E ~ 1 | D ~ Trailhead	6	358.42	4.46	-169.01	0.61
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ 1	5	358.50	4.54	-171.52	0.62
OP ~ 1 | C ~ Plovers | E ~ 1 | D ~ Drivable + WaterBothSides	7	358.68	4.72	-166.12	0.63
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ 1	5	358.84	4.89	-171.69	0.64
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ Trailhead	6	358.99	5.04	-169.30	0.65
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ Trailhead	6	359.13	5.17	-169.36	0.66
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	359.38	5.43	-169.49	0.67
OP ~ Humans + Plovers | C ~ 1 | E ~ 1 | D ~ WaterBothSides	7	359.41	5.46	-166.48	0.68

Top model

```
Initial:
              Estimate    SE      z P(>|z|)
(Intercept)     -52.7  92.1 -0.572   0.567
Plovers         194.4 335.1  0.580   0.562

Colonization:
 Estimate   SE      z P(>|z|)
      -11 75.4 -0.146   0.884

Extinction:
 Estimate   SE      z P(>|z|)
    -11.9 72.2 -0.165   0.869
```

```
Detection:
                Estimate    SE     z  P(>|z|)
(Intercept)        -3.71 0.452 -8.21 2.29e-16
Drivable           -1.78 0.687 -2.58 9.74e-03
WaterBothSides      1.95 0.556  3.52 4.37e-04
```

Table A1.5. AICc model selection results for feral cat multi-season occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	6	424.85	0.00	-202.23	0.22
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable	5	426.24	1.39	-205.39	0.33
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ Drivable + WaterBothSides	7	426.82	1.97	-200.19	0.41
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ Drivable + WaterBothSides	7	427.02	2.17	-200.29	0.48
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ Drivable	6	427.78	2.92	-203.69	0.53
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ Drivable	6	428.01	3.16	-203.81	0.58
OP ~ 1 | C ~ Humans | E ~ 1 | D ~ Drivable	6	428.36	3.50	-203.98	0.61
OP ~ 1 | C ~ Humans | E ~ 1 | D ~ Drivable + WaterBothSides	7	428.57	3.71	-201.06	0.65
OP ~ 1 | C ~ Humans | E ~ Urban | D ~ Drivable	7	429.28	4.42	-201.42	0.67
OP ~ 1 | C ~ Humans | E ~ Humans | D ~ Drivable	7	429.42	4.56	-201.49	0.69
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ Drivable	6	429.70	4.85	-204.65	0.71
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + Trailhead	6	430.26	5.40	-204.93	0.73
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ Drivable + WaterBothSides	7	430.28	5.43	-201.92	0.74
OP ~ 1 | C ~ Plovers | E ~ 1 | D ~ Drivable + WaterBothSides	7	430.40	5.55	-201.98	0.76
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ Drivable + WaterBothSides	7	430.90	6.04	-202.23	0.77
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	430.90	6.04	-202.23	0.78
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	430.91	6.05	-202.23	0.79
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	430.91	6.06	-202.23	0.80
OP ~ 1 | C ~ Humans | E ~ Urban | D ~ Drivable + WaterBothSides	8	431.04	6.19	-198.52	0.81
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ Drivable + Trailhead	7	431.09	6.24	-202.32	0.82

Top model

```
Initial:
 Estimate SE      z P(>|z|)
    -10.7 57 -0.187   0.851

Colonization:
 Estimate    SE    z  P(>|z|)
    -1.84 0.409 -4.5 6.93e-06

Extinction:
 Estimate   SE      z P(>|z|)
       -9 33.8 -0.266    0.79
```

```
Detection:
                Estimate     SE      z  P(>|z|)
(Intercept)        0.164  0.203  0.807 4.20e-01
Drivable          -2.805  0.286 -9.812 1.00e-22
WaterBothSides    -9.697 26.297 -0.369 7.12e-01
```

Table A1.6. AICc model selection results (including trapping) for Virginia opossum occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
O ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable	5	80.34	0.00	-32.44	0.11
O ~ 1 | C ~ 1 | E ~ 1 | D ~ 1	4	80.73	0.39	-34.70	0.19
O ~ 1 | C ~ 1 | E ~ 1 | D ~ WaterBothSides	5	81.78	1.44	-33.16	0.25
O ~ Trap01 | C ~ 1 | E ~ 1 | D ~ 1	5	82.32	1.98	-33.43	0.29
O ~ Urban | C ~ 1 | E ~ 1 | D ~ 1	5	82.99	2.65	-33.77	0.31
O ~ Humans | C ~ 1 | E ~ 1 | D ~ 1	5	83.15	2.81	-33.85	0.34
O ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	6	83.26	2.92	-31.43	0.36
O ~ Trap01 | C ~ 1 | E ~ 1 | D ~ Drivable	6	83.63	3.29	-31.62	0.38
O ~ 1 | C ~ 1 | E ~ Urban | D ~ 1	5	83.83	3.49	-34.19	0.40
O ~ 1 | C ~ 1 | E ~ Urban | D ~ Drivable	6	83.92	3.57	-31.76	0.42
O ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead	5	83.99	3.64	-34.27	0.44
O ~ Urban | C ~ 1 | E ~ 1 | D ~ Drivable	6	84.08	3.73	-31.84	0.45
O ~ 1 | C ~ 1 | E ~ Trap01 | D ~ 1	5	84.22	3.87	-34.38	0.47
O ~ 1 | C ~ 1 | E ~ Plovers | D ~ 1	5	84.47	4.13	-34.51	0.48
O ~ 1 | C ~ 1 | E ~ Humans | D ~ 1	5	84.83	4.48	-34.69	0.50
O ~ Plovers | C ~ 1 | E ~ 1 | D ~ 1	5	84.83	4.48	-34.69	0.51
O ~ 1 | C ~ Urban | E ~ 1 | D ~ 1	5	84.85	4.51	-34.70	0.52
O ~ 1 | C ~ Plovers | E ~ 1 | D ~ 1	5	84.85	4.51	-34.70	0.53
O ~ 1 | C ~ Humans | E ~ 1 | D ~ 1	5	84.85	4.51	-34.70	0.54
O ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	6	84.87	4.53	-32.24	0.55

Top model

```
Initial:
 Estimate   SE    z P(>|z|)
     8.29 48.7 0.17   0.865

Colonization:
 Estimate   SE      z P(>|z|)
    -10.5 60.9 -0.172   0.864

Extinction:
 Estimate    SE      z P(>|z|)
    -0.58 0.797 -0.727   0.467
```

```
Detection:
            Estimate    SE     z  P(>|z|)
(Intercept)    -3.48 0.805 -4.32 1.56e-05
Drivable       -2.43 1.032 -2.36 1.84e-02
```

Table A1.7. AICc model selection results for river otter multi-season occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ Trailhead	6	82.23	0.00	-30.92	0.14
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	82.25	0.02	-30.92	0.28
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	84.18	1.94	-31.89	0.33
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ 1	4	84.45	2.22	-36.56	0.38
OP ~ Humans | C ~ 1 | E ~ Urban | D ~ 1	6	84.60	2.36	-32.10	0.42
OP ~ 1 | C ~ Plovers | E ~ 1 | D ~ 1	5	85.26	3.03	-34.90	0.45
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	85.71	3.48	-32.66	0.48
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ WaterBothSides	5	85.75	3.52	-35.15	0.50
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ 1	5	86.75	4.51	-35.65	0.52
OP ~ Urban | C ~ 1 | E ~ Humans | D ~ 1	6	86.82	4.59	-33.21	0.53
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ WaterBothSides	6	86.93	4.70	-33.27	0.54
OP ~ Humans | C ~ 1 | E ~ Urban | D ~ Trailhead	7	86.97	4.74	-30.26	0.56
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ 1	5	87.13	4.90	-35.84	0.57
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead	5	87.21	4.98	-35.88	0.58
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ 1	5	87.22	4.99	-35.88	0.59
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ 1	5	87.41	5.18	-35.98	0.60
OP ~ Urban | C ~ 1 | E ~ Humans | D ~ WaterBothSides	7	87.42	5.19	-30.49	0.61
OP ~ Plovers | C ~ 1 | E ~ Humans | D ~ 1	6	87.42	5.19	-33.51	0.62
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ Drivable	6	87.50	5.27	-33.55	0.63
OP ~ Humans | C ~ 1 | E ~ Humans | D ~ Trailhead	7	87.60	5.37	-30.58	0.64

Top model

```
Initial:                                        Detection:
             Estimate   SE      z P(>|z|)                    Estimate    SE     z  P(>|z|)
(Intercept)     -23.1 39.6 -0.583   0.560      (Intercept)     -3.76 0.728 -5.16 2.44e-07
Humans           41.9 70.2  0.596   0.551      Trailhead       -2.13 1.163 -1.83 6.68e-02

Colonization:
 Estimate  SE      z P(>|z|)
    -13.3 105 -0.127   0.899

Extinction:
 Estimate   SE      z P(>|z|)
    -5.14 26.9 -0.191   0.848
```

Table A1.8. AICc model selection results for Northern Harrier multi-season occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ 1	5	152.75	0.00	-68.65	0.08
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ 1	4	153.45	0.69	-71.06	0.14
OP ~ Plovers | C ~ Urban | E ~ 1 | D ~ 1	6	153.73	0.98	-66.67	0.19
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ 1	5	153.84	1.09	-69.19	0.24
OP ~ 1 | C ~ 1 | E ~ Plovers + Urban | D ~ 1	6	154.44	1.69	-67.02	0.27
OP ~ 1 | C ~ Plovers | E ~ 1 | D ~ 1	5	154.53	1.78	-69.54	0.30
OP ~ Humans | C ~ Urban | E ~ 1 | D ~ 1	6	154.75	1.99	-67.17	0.33
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ Trailhead	6	155.38	2.62	-67.49	0.36
OP ~ 1 | C ~ Urban | E ~ Plovers | D ~ 1	6	155.48	2.73	-67.54	0.38
OP ~ 1 | C ~ Plovers + Urban | E ~ 1 | D ~ 1	6	155.73	2.98	-67.67	0.40
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ WaterBothSides	6	155.81	3.05	-67.70	0.41
OP ~ Plovers | C ~ Plovers + Urban | E ~ 1 | D ~ 1	7	155.97	3.22	-64.76	0.43
OP ~ Humans | C ~ 1 | E ~ Humans | D ~ Drivable	7	156.08	3.32	-64.82	0.45
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ WaterBothSides	6	156.13	3.38	-67.87	0.46
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ WaterBothSides	5	156.14	3.39	-70.34	0.48
OP ~ Urban | C ~ Plovers | E ~ 1 | D ~ 1	6	156.17	3.42	-67.88	0.49
OP ~ 1 | C ~ Plovers | E ~ Urban | D ~ 1	6	156.21	3.46	-67.91	0.50
OP ~ Urban | C ~ Urban | E ~ 1 | D ~ 1	6	156.26	3.50	-67.93	0.52
OP ~ Humans | C ~ 1 | E ~ Plovers + Urban | D ~ 1	7	156.29	3.54	-64.92	0.53
OP ~ Humans | C ~ Plovers | E ~ 1 | D ~ 1	6	156.39	3.64	-68.00	0.55

Top model

```
Initial:
 Estimate   SE      z P(>|z|)
   -0.445 1.32 -0.338   0.736

Colonization:
            Estimate   SE      z P(>|z|)
(Intercept)     7.58 8.15  0.931   0.352
Urban          -8.02 7.11 -1.128   0.259

Extinction:
 Estimate   SE     z P(>|z|)
    0.133 1.22 0.109   0.913
```

```
Detection:
 Estimate    SE     z  P(>|z|)
    -4.52 0.488 -9.28 1.76e-20
```

Table A1.9. AICc model selection results for Great Blue Heron multi-season occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	K	AICc	ΔAICc	LL	Cum.Wt
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ WaterBothSides	5	162.56	0.00	-73.55	0.17
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ WaterBothSides	6	162.76	0.20	-71.18	0.33
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	164.58	2.01	-72.09	0.39
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	165.03	2.47	-72.32	0.44
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	6	165.43	2.86	-72.51	0.48
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ 1	5	165.56	2.99	-75.05	0.52
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ WaterBothSides	6	165.59	3.03	-72.59	0.56
OP ~ 1 | C ~ Plovers | E ~ 1 | D ~ WaterBothSides	6	165.87	3.31	-72.73	0.59
OP ~ 1 | C ~ Humans | E ~ 1 | D ~ WaterBothSides	6	166.77	4.21	-73.19	0.61
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ 1	5	167.04	4.48	-75.79	0.63
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	6	167.23	4.67	-73.42	0.65
OP ~ 1 | C ~ Plovers | E ~ Plovers | D ~ WaterBothSides	7	167.31	4.75	-70.43	0.66
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ WaterBothSides	6	167.50	4.94	-73.55	0.68
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ 1	4	167.56	5.00	-78.11	0.69
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ WaterBothSides	6	167.61	5.05	-73.60	0.71
OP ~ 1 | C ~ 1 | E ~ Humans + Plovers | D ~ WaterBothSides	7	167.96	5.40	-70.76	0.72
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	168.15	5.58	-70.85	0.73
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ Drivable + WaterBothSides	7	168.16	5.60	-70.86	0.74
OP ~ Urban | C ~ 1 | E ~ Plovers | D ~ WaterBothSides	7	168.27	5.71	-70.91	0.75
OP ~ 1 | C ~ Humans | E ~ Plovers | D ~ WaterBothSides	7	168.27	5.71	-70.91	0.76

Top model

```
Initial:
 Estimate  SE      z P(>|z|)
   -0.653 1.3 -0.502   0.616

Colonization:
 Estimate    SE     z P(>|z|)
    -1.45 0.834 -1.73  0.0828

Extinction:
 Estimate  SE       z P(>|z|)
    -13.2 310 -0.0425   0.966
```

```
Detection:
                Estimate    SE     z  P(>|z|)
(Intercept)        -6.51 0.786 -8.28 1.24e-16
WaterBothSides      2.68 0.834  3.22 1.29e-03
```

Table A1.10. AICc model selection table for Great Egret multi-season occupancy in Eden Landing Ecological Reserve, CA. O = occupancy probability (ψ), C = colonization probability (γ), E = extinction probability (ε), D = detection probability (p).

Model formulas	**K**	**AICc**	**ΔAICc**	**LL**	**Cum.Wt**
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	6	592.28	0.0	-285.94	0.43
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ WaterBothSides	6	595.41	3.13	-287.50	0.52
OP ~ 1 | C ~ 1 | E ~ Humans + Plovers | D ~ WaterBothSides	7	596.38	4.10	-284.97	0.58
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ Drivable + WaterBothSides	7	596.91	4.63	-285.23	0.62
OP ~ 1 | C ~ Humans | E ~ 1 | D ~ Drivable + WaterBothSides	7	597.26	4.98	-285.41	0.65
OP ~ Urban | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	597.51	5.23	-285.53	0.69
OP ~ Plovers | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	597.52	5.24	-285.54	0.72
OP ~ 1 | C ~ 1 | E ~ Humans | D ~ Drivable + WaterBothSides	7	597.62	5.34	-285.59	0.75
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ Drivable + WaterBothSides	7	597.85	5.58	-285.70	0.77
OP ~ Humans | C ~ 1 | E ~ 1 | D ~ Drivable + WaterBothSides	7	598.15	5.87	-285.85	0.80
OP ~ 1 | C ~ Plovers | E ~ 1 | D ~ Drivable + WaterBothSides	7	598.20	5.92	-285.88	0.82
OP ~ 1 | C ~ Urban | E ~ 1 | D ~ Drivable + WaterBothSides	7	598.31	6.03	-285.93	0.84
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ WaterBothSides	5	599.08	6.80	-291.81	0.85
OP ~ 1 | C ~ Plovers | E ~ Plovers | D ~ WaterBothSides	7	599.22	6.94	-286.39	0.87
OP ~ 1 | C ~ 1 | E ~ Urban | D ~ WaterBothSides	6	599.65	7.37	-289.62	0.88
OP ~ 1 | C ~ 1 | E ~ Plovers | D ~ Trailhead + WaterBothSides	7	600.61	8.33	-287.08	0.88
OP ~ 1 | C ~ 1 | E ~ 1 | D ~ Trailhead + WaterBothSides	6	601.06	8.78	-290.33	0.89
OP ~ 1 | C ~ Humans | E ~ Plovers | D ~ WaterBothSides	7	601.09	8.81	-287.32	0.89
OP ~ Humans | C ~ 1 | E ~ Plovers | D ~ WaterBothSides	7	601.11	8.83	-287.33	0.90
OP ~ 1 | C ~ Plovers | E ~ Humans + Plovers | D ~ WaterBothSides	8	601.31	9.03	-283.65	0.90

Top model

```
Initial:
 Estimate    SE    z P(>|z|)
    0.231 0.721 0.32   0.749

Colonization:
 Estimate    SE     z P(>|z|)
    -1.93 0.738 -2.61 0.00894

Extinction:
 Estimate    SE     z P(>|z|)
    -2.15 0.885 -2.43  0.0153
```

```
Detection:
                Estimate    SE     z  P(>|z|)
(Intercept)        -2.89 0.315 -9.16 5.32e-20
Drivable           -1.94 0.532 -3.65 2.64e-04
WaterBothSides      3.11 0.453  6.87 6.27e-12
```

APPENDIX 2

Preliminary study by Benjamin Levin on single-season occupancy modeling of red fox detections in Eden Landing Ecological Reserve, California.

Factors influencing the occupancy of red foxes (*Vulpes vulpes*) in a Restored San Francisco Bay Wetland

Benjamin Levin
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Honors Thesis

Abstract

Mammalian predators are major limiting factors on snowy plover abundance. With usable breeding habitat becoming more scarce, conservationists are searching for ways to mitigate mammalian predation on the endangered snowy plover (*Charadrius nivosus*). This samples the mammalian community at the largest snowy plover breeding colony in Alameda County, California - the Eden Landing Ecological Reserve (ELER). By setting up a camera trap array at the ELER I obtained summary statistics on 20 species and assembled a dataset of 90,000 photos which will be used as a baseline dataset to evaluate further research. I also set out to study red foxes and their associations across the landscape that influenced occupancy. During the non-breeding season I found that red foxes were more likely to occupy areas closer to urban areas. During the breeding season, the null model was the best performing model, as I did not find a significant effect of plover nests, urban areas, sympatric carnivores, or human activity on fox occupancy. I recommend the community continue to be studied in order to further our understanding of the factors influencing fox occupancy and recommend management strategies that can conserve endangered snowy plovers.

Keywords

Red foxes, occupancy modeling, camera traps, snowy plovers, conservation

Introduction

Predators limit population abundance among bird species (Newton 2007), and ground nesting birds are particularly susceptible to mammalian predation (Fletcher et al. 2010). Frequent depredation of nests may increase risk of extinction (Peery & Henry 2010), particularly when a prey species is already threatened or endangered and limited by other factors such as habitat fragmentation or human encroachment. Due to the effects of predators on ground nesting bird populations, management actions are often taken to increase the nest success rates of these birds. While indirect predator management (management not focused on direct removal of predators) has been successful at increasing nest success rates for some species (Fletcher et al. 2010), there are situations in which this management can have negative effects on some species at other life stages, making their overall success questionable (Murphy et al. 2003; Neuman et al. 2004). Direct predator management, such as lethal and nonlethal removal, is also commonly employed. However, these methods of predator control are often expensive, time consuming, and controversial (Bolton et al. 2007; Laidlaw et al. 2015). Moreover, in some situations, reducing the abundance of a predator species does not guarantee a reduction in nest predation, as the removal of certain predators can have unintended consequences for other animals in the system (Cote & Sutherland 1997; Crooks & Soule 1999; Brook et al. 2012; Ellis-Felege et al. 2012).

Successful management actions are needed to increase the abundance of ground nesting bird populations; however, before management strategies are implemented, it is advised that the predator community should be studied (Bolton et al. 2007; Kämmerle et al. 2019). Estimating species distribution across landscapes may reveal critical information that can lead to better managed wildlife populations (Noon et al. 2012). For example, a variety of environmental variables influence predator occupancy patterns (Schuette et al. 2013), suggesting that different predators will have unique associations within ecosystems. Additionally, studying predation patterns is crucial as they influence and are influenced by ecosystem structure. A better understanding of predation patterns can lead to the implementation of more effective management strategies (Ellis et al. 2020).

In this study, the population of interest is the west coast population of snowy plovers (*Charadrius nivosus nivosus*) at the Eden Landing Ecological Reserve (ELER) (Figure 1) in Alameda County, California, which was listed as threatened by the U.S. Fish and Wildlife in

1993 (Cowell et al. 2005). Nest failure, coupled with increased habitat loss, are the primary factors leading to the decline of the pacific coast population (USFWS 2007). Unfragmented, flat swaths of dried up land are crucial to the nesting success of these birds (Ellis et al. 2020). However, regional land use change has reduced suitable nesting habitat, driving higher breeding densities causing snowy plovers to be forced into higher density breeding environments. Reduction in the hatching and fledging success of snowy plover chicks can be linked to the increase in nest density due to density dependent nest predation among the coastal population (Page et al. 1983). Management of this threatened species has often sought to maximize nest success rates as snowy plovers are a species at high risk of nest predation (Neuman et al. 2004; Ellis et al. 2015; Ellis et a., 2019).

At the Eden Landing Ecological Reserve (ELER), the salt flats comprising the prime habitat for snowy plovers are being converted into restored wetland. This pressure from humans will continue to increase the density of snowy plover nesting, leading to heavier predation rates and an overall decline in population. Since the breath of the predator community at the ELER has not been studied yet, camera traps serve as a more efficient sampling method than traditional sampling methods because of their ability to capture simultaneous data of multiple species (O'Brien & Kinnaird 2010). At the most elementary level, data from camera traps can provide an index of relative activity (Comer et al. 2018) without the need for invasive capture events (Long et al. 2010). When occupancy models are applied to the data, the imperfect detection of species can be taken into account to estimate species occurrence (Sollmann et al. 2018). Importantly, ecosystem covariates are easily included in occupancy models (MacKenzie et al. 2002).

Based on previous observations by the San Francisco Bay Bird Observatory and research (i.e., Neuman et al. 2004; Ellis et al. 2015), red foxes (*Vulpes vulpes*) depredate the nests of snowy plovers and may be a limiting factor in snowy plover nest success. Since red foxes are such a common mammalian predator, there have been many studies on their occupancy. These studies have shown that red fox space use has changed drastically as urbanization has increased worldwide (Scott et a. 2014) and urban areas have proved to be high quality habitats for the species (Handler et al. 2020). On the other hand, some research suggests that red fox activity increases the farther away from human settlement they are (Dìaz-Ruiz et al. 2015). Other occupancy studies have demonstrated that fox populations show strong declines as coyote populations increase, implying a cascading effect when coyotes are present/not present on the landscape (Levi & Wilmers 2012). Moreover, the two species are known to partition space use and resources within urban landscapes (Muller et al. 2018).

Overall, red foxes are a very well studied species whose natural history fits perfectly into the nest predator guild and are confirmed to be present on the landscape. Because of this, red foxes are the focal animal in the occupancy portion of this study and I have developed a series of hypotheses and models in order to study their occupancy whilst obtaining baseline data for future studies (Table 1).

Objectives

The objective of this study is to better understand the space use of red foxes at the Eden Landing Ecological Reserve and obtain information on the predator community as a whole so predator management can more effectively protect the west coast population of snowy plovers. This study will (1) investigate the drivers of red fox occupancy and (2) establish baseline data to evaluate future predator management outcomes. I hypothesize that red fox occupancy will be negatively associated with (a) human presence because in some situations are known to avoid human activity (Dìaz-Ruiz et al. 2015) and (b) coyote presence because red foxes are shown to spatial partition land with coyotes (Levi & Wilmers 2012); that red fox occupancy will be positively associated with (c) urban areas because they are known to use these areas as habitat (Handler et al. 2020); and that (d) snowy plover nest locations will have no significant effect on red fox occupancy because red foxes are opportunistic predators that are potentially just happening upon snowy plover nests.

Table 1. Each hypothesis above corresponds to a variable at the ELER. Each model included unique and appropriate covariates that potentially impacted occupancy probability (symbol) at the given site.

Model	Description	Variables	Predicted influence on occupancy probability	Supporting literature
PLOVER	Occupancy was influenced by the distance to a plover nest.	Dist. to plover nests (m)	No effect	Neuman et al. 2004; Ellis et al. 2015
URBAN	Occupancy was influenced by the distance to urban areas characterized by paved roads and/or cement buildings.	Dist. to urban area (m)	Positive	Scott et al. 2014; Handler et al. 2020
COYOTE	occupancy was influenced by coyote space use at the ELER	Photographic rate of coyotes	Negative	Levi & Wilmers 2012
HUMAN	Occupancy was influenced by human space use in ELER	Photographic rate of humans	Negative	Díaz-Ruiz et al. 2016
NULL	Occupancy was not influenced by any factors	-	-	-

Materials and methods

Study area

The Eden Landing Ecological Reserve covers 6,400 acres of land divided by a matrix of levees and berms which create areas that are managed for endangered bird breeding habitat and waterfowl game management (Figure 1). Through most of the 19th century the land was used as pasture for farm animals, until the late 19th century when it was converted into a solar salt production facility. The area remained this way until 2003 when the land was bought from Cargill Salt CO by California Department of Fish and Wildlife and the U.S Fish and Wildlife Service. As of 2021, 630 acres have been restored to full tidal marshes. Some of these areas are seasonally flooded using water control structures. The ELER borders the San Francisco Bay on its west side, Coyotes Hills Regional Park on its south side, and is enclosed by urban areas on its

North and East sides. There are currently plans to restore 2,200 more acres of the ELER to tidal salt marsh and wetlands (CDFW 2021). The habitat in the system varies between large restored salt flats upon which little to no vegetation grows, dense restored tidal marshes, and large open salt water areas. At the ELER there has been ongoing predator management since 2009. This management is opportunistic and involves lethal removal of red foxes and coyotes.

Data collection and processing

In order to collect data on mammalian predator activity at the ELER an array of 25 camera traps were implemented, although by the time the data was processed only 17 were used because of errors with the cameras and physical damage making data unusable. The camera's locations were determined by overlaying a 1x1 kilometer honeycomb grid onto the landscape. We placed cameras at the centroid of each grid cell. However, in areas where the center of the gridcell landed on a surface that made the camera impossible to set up, the camera was moved to the closest usable substrate within each respective gridcell. Therefore, all cameras were placed on either internal roads or berms throughout the reserve.

Each camera (Browning Spec Ops Elite HP4) was set to take a burst of 3 photos at 8 megapixels with a recapture delay of 30 seconds. The camera's sensitivity was set to moderate. During the physical set up of the cameras they were placed facing north to south in order to avoid glare at sunrise and sunset. Cameras were placed on T-posts and positioned about 2-3 feet above the ground. In two instances the cameras were drilled into an existing structure.

Cameras were checked 5 times throughout the study. The SD cards and batteries were replaced as needed and photos downloaded so they could be tagged in the metadata. All mammals were tagged to the species level (Figure 2). The amount of individuals per photo was recorded as well.

Modeling approach

I used a single-season, single-species occupancy modeling approach in order to model red fox occupancy (MacKenzie et al. 2006). Occupancy modeling allows estimates of occurrence probability (Ψ) using simple detection/non-detection data. These models account for imperfect detection (species occurring in the study area undetected during surveying) by including detection probability (p) in the models while estimating the probability of a site being occupied (MacKenzie et al. 2002). I used the R package “camptrapR” (Niedballa et al. 2022) to organize the data into detection histories which were used as objects in the R package "unmarked" (Chandler et al. 2022) where I ran the single-season, single species occupancy models.

I ran occupancy models for both the breeding season of snowy plovers and winter period when snowy plovers have migrated away. One season was made up of 6 weeks of data during the snowy plover breeding season, specifically from July 16th, 2021 through August 27th, 2021. The second season was 6 weeks worth of data during the nonbreeding season, specifically November 5th, 2021 through December 17th, 2021. The reasoning behind this was to compare whether drivers of fox occupancy were consistent between seasons.

Within these models there are two parameters. One for detection which states the likelihood that a camera will take a photo based on a variable and the second for occupancy. In order to determine the best detection model, I ran the models using three different detection variables while keeping occupancy at ~1 (the state of the null models). The detection covariates tested were (1) Trailhead, which hypothesized that animals are more or less likely to be photographed at trailheads because they act as areas where animal may converge on established paths, (2) WaterOnBothSides, which hypothesize that if there is water on both sides of a camera it may cause animals to funnel in front of the camera or deter them because there is less open space to move around and (3) the global detection model which was simply a combination of both of the previously mentioned covariates. I then ranked the models based on the lowest AIC scores and included the top detection covariate in the occupancy models.

For this study I developed a series of single-season, single-species occupancy models in order to investigate the probability of a red fox occupancy throughout the landscape. Each model characterized a different hypothesized correlation between red fox occupancy and landscape covariates (Table 1). The first model, PLOVER, investigated the correlation between red fox occurrence and snowy plover nest occurrence. This model was developed in order to see whether or not snowy plovers as prey were a driver of red fox occupancy. In order to quantify this I measured the distance to the closest plover nest from each camera and assigned that value to the camera. The second model, URBAN, stated that red fox occupancy was influenced by the distance to an urban area bordering the ELER. Examples include freeways, driveways, and backyards outside the reserve. The third model, COYOTE, stated that red fox occupancy is influenced by the presence of coyotes on the landscape. The quantitative variable used in the model to determine coyote space use was the photographic rate which is calculated by dividing the number of records by the sampling effort (i.e., the number of trap nights each camera was in operation).The fourth model, HUMAN, explored red fox occupancy in relation to human space use at the reserve. To quantify human space use I also used the photographic rate. This model did not account for the difference in the number of humans per photo (i.e., 4 vs 1, just the fact that humans were present). It is worth noting that since the cameras took photos in bursts of 3 photos I calculated the photographic rate by dividing the total number of photos taken by three in situations where there were more than 100 records. In situations where there were less I counted the photos exactly.

Once these covariates were quantified I ran every combination of the 4 variables within the occupancy portion of the model while including the covariates from the top detection model. Once all the models were run, I conducted model selection by selecting the model with the lowest AIC score and ran Mackenzie and Bailey goodness of fit tests to see how well the covariates explained the data.

Results

Over the 36 weeks that cameras were active, approximately 90,000 photos were taken. Of the 90,000 photos 20 species were identified to species level, including 12 species of mammal of which 7 were predators including striped skunks (*Mephitis mephitis*), racoons (*Procyon lotor*), river otters (*Lontra canadensis*), virginia opossums (*Didelphis viginiana*), house cats (*Felis catus*), coyotes (*Canis latrans*), and red foxes (*Vulpes vulpes*). The species most frequently photographed was the black-tailed jackrabbit (*Lepus californicus*) which was photographed 15,350 times across 16 of the 17 cameras. The most commonly photographed mammalian predator was the red fox (*Vulpes vulpes*) which was photographed 2,305 times across 13 cameras. Humans were captured 10,143 times across all 17 cameras used during data analysis (Table 2).

Table 2. Summary statistics of detections for predators at the ELER along with humans and black-tailed jackrabbits. N here represents the number of cameras which captured the respective species.

Summary Stats ELER Species

Statistic	N	Mean	St. Dev.	Min	Max
Red Fox Detections	13	177.462	292.070	3	853
Coyote Detections	13	27.538	46.816	1	181
Black-tailed Jackrabbit Detections	16	959.375	1,173.155	8	3,157
Human Detections	17	2,503.118	3,111.261	44	8,789
Racoon Detections	7	17.571	20.379	3	63
Striped Skunk Detections	12	55.750	86.814	3	304
House Cat Detections	7	65.143	117.998	6	329

Season 1 Occupancy Results

The results of the detection models run for the first season of data returned the variable WaterOnBothSides as the best detection covariate with the lowest AIC score, 57.76 (Table 3).

Table 3. AIC scores for the breeding season detection models

	Number of parameters	AIC	ΔAIC
WaterBothSides	3	57.76	0
Trailhead + WaterBothSides	4	59.41	1.96
Null	2	66.41	8.64
Trailhead	3	68.22	10.46

The occupancy models for the breeding season resulted in HUMANS being the top model with an AIC score of 58.77 (Table 4). However, there were 7 models that scored within 2 AIC of the top model.

Table 4. AIC scores for the models from the breeding season.

	Number of parameters	AIC	ΔAIC
HUMAN	4	58.77	0
URBAN	4	59.14	0.38
URBAN+HUMAN	5	59.32	0.55
COYOTE	4	59.44	0.67
PLOVER	4	59.68	0.91
COYOTE+HUMAN	5	60.41	1.65
HUMAN+PLOVER+URBAN	6	60.65	1.88
PLOVER+HUMAN	5	60.67	1.90
Global Model	8	64.85	6.08
Null Model	2	66.41	7.64

A summary of the model that includes the detection covariate WaterBothSides and all of the occupancy covariates reveals that the models HUMANS, URBAN, and COYOTE have negative impacts of red fox occupancy whereas PLOVER has a slightly positive effect. However, the standard errors for all of these estimates all overlap 0. This pattern remains consistent for all the breeding season models.

When running a Mackenzie and Bailey Goodness of Fit Test the global model returns a P-value of 0.001 and a c-hat value of 5.67. Similarly the model HUMANS returns a P-value of 0.011 with a c-hat of 4. The URBAN model returns a P-value of 0.012 and a c-hat of 4.09 and the URBAN+HUMAN model returns a P-value of 0.013 with a C-hat of 3.8. Finally, the coyote model returns a P-value of 0.001 and a c-hat of 5.84.

Season 2 (Non-breeding season) Occupancy Results

The results of the detection model remained the same as the breeding season's data with WaterBothSides being the top model for detection, this time with an AIC score of 72.88 (Table 5).

Table 5. AIC scores for the non-breeding season detection models

	Number of parameters	AIC	ΔAIC
WaterBothSides	3	72.88	0
Trailhead + WaterBothSides	4	74.12	1.24
Trailhead	3	79.54	6.66
Null	2	80.53	7.65

The results of the occupancy models from the non-breeding season resulted in the model URBAN having the lowest AIC Score of 70.78 (Table 6). However, there were also 7 other models within a ΔAIC of 2.

Table 6. AIC scores for the models from season two.

	Number of parameters	AIC	ΔAIC
URBAN	4	70.78	0
URBAN+HUMAN+COYOTE+PLOVER	7	71.20	0.42
COYOTE	4	71.27	0.50
URBAN+COYOTE+PLOVER	6	71.36	0.58
URBAN+HUMAN	5	71.79	1.01
URBAN+COYOTE	5	72.00	1.22
COYOTE+HUMAN	5	72.25	1.47
URBAN+PLOVER	5	72.67	1.89
Global Model	8	75.68	4.9
Null Model	2	80.53	9.75

For this season's top model, the variable URBAN had an influence on occupancy of -0.00548 with a standard error of 0.00276 and a P value of 0.0471 stating that these results were significant. The second highest ranking model, URBAN+HUMAN+COYOTE+PLOVER showed results with P-values over 0.05 signifying a lack of significance. The third highest ranking model, COYOTE had a P-value over 0.05; the fourth highest scoring model, URBAN+COYOTE+PLOVER also had P-values over 0.05. The 5th highest scoring, URBAN+HUMAN both had P-values over 0.05, however the URBAN variable in this model had a P-value less than 0.1. In the 6th highest scoring model, COYOTE+URBAN, the URBAN variable had a negative influence on occupancy of -0.00853 with a P-value of 0.04 indicating a significant result however the COYOTE variable was insignificant. The final model within 2 AIC of the top model was URBAN+PLOVER and in this model the variable URBAN again had a significantly negative effect on red fox occupancy (-0.01123) whereas PLOVER's effect was insignificant.

When running the Mackenzie and Bailey Goodness of Fit Test all of the non-breeding season models mentioned above are deemed to for the data based on the fact that their c-hat values are near 1 and the P-values are greater than 0.05.

Discussion

Mammalian predators are a major limiting factor of ground nesting bird nest success (Fletcher et al. 2010; Peery & Henry 2010). Since the pacific coast population of snowy plovers are endangered, it is especially pressing that we study the mammalian predator community in order to better understand its dynamics so we are able to implement successful management strategies. At the Eden Landing Ecological Reserve the Brashares Group and I set up a camera trap array in July of 2021 with the intention of surveying the landscape and obtaining a baseline dataset to evaluate the effects of future predator management outcomes. We set out to find what was present on the landscape, what the most commonly detected animals were, and obtain summary statistics on these animals. Moreover, we focused more thoroughly on the common nest predator, the red fox (*Vulpes vulpes*), and studied its occupancy in relation to different variables across the landscape.

Setting up the camera traps and establishing a baseline dataset was extremely successful. We were able to determine which animals were most active on the landscape and obtain presence absence data along with detection histories for every species. Figure 3 shows some potential applications of this data; two maps that include red fox detection histories throughout this survey overlaid by snowy plover nest location and coyote detection histories.

With respect to the occupancy models for the breeding season, none of my specified covariates had a significant impact on red fox occupancy. This result supported my hypothesis that snowy plover nest locations would have an insignificant effect on red fox space use. Paton (1994) showed that while red foxes may depredate snowy plover nests, they also are active nest predators other birds in the system, reinforcing the idea that the foxes are opportunistic hunters. Since no significant association was found between red fox occupancy and snowy plover nests, this study also supports the idea that red foxes are preying opportunistically on snowy plovers and not actively seeking them out. I found the same result for nonbreeding season data which further encourages the conclusion that snowy plovers do not influence fox occupancy. The other variables I tested in the first season (HUMAN, URBAN, and COYOTE) also did not have significant effects on red fox occupancy. This was interesting because previous occupancy studies have suggested that these factors do influence red fox space use. I was most surprised that coyotes had no effect on red fox occupancy during this season. Figure 3 shows such a striking contrast between the detection histories of the two species that I posited that they were competitively excluding each other from the landscape. Mueller et al. (2018) found that coyotes and red foxes show a degree of spatial overlap, but in general partition their space use; similarly Gosselnik et al. (2003) suggested some red foxes may avoid habitats that are used by coyotes. However, my hypothesis that red fox occupancy would be significantly affected by coyote space use was incorrect. Both the aforementioned studies included different habitat types in their studies and noticed that foxes and coyotes partitioned habitats as a way of avoiding each other. A potential explanation for coyotes having a lack of significant effect on occupancy is that the ELER is generally one kind of habitat and the two species may just share it because there is not a ton of green space in the surrounding urban area. Humans not influencing red fox occupancy is an interesting result because there have been conflicting results on the effect of humans on red foxes. Red foxes are known to use urban habitats successfully (Handler et al. 2020) suggesting that these species do not shy away from interactions with humans. However, Dìaz-Ruiz et al. (2015) demonstrated that red fox activity increased the farther away from human settlements the foxes were. These results suggest no clear picture of red foxes' relationship to humans. My study supports the studies that show red foxes are comfortable in human environments.

The most interesting results that came from this study was that red fox occupancy was not significantly affected by the distance from an urban area during the breeding season, but was influenced during the non-breeding season. I believe that a potential driver of this difference is the fact that the ELER is flooded during the non-breeding season for waterfowl management and hunting. Because of this there is less area to forage for terrestrial predators like red foxes. This may have driven the animal to rely more on urban environments for food and shelter during the non-breeding season whereas during the breeding season there was more space to be used in the ELER. The other variables studied during the non-breeding season had no significant effect on red fox occupancy, the same as the breeding season.

Limitations

The occupancy portion of this study was limited in a number of ways. Foremost was the sampling effort. The 6 week period was appropriate because of the limited timing (having to turn in my thesis), however without this time constraint the seasons analyzed could have been extended, potentially making the occupancy models more effective. A further limitation was the number of cameras. We lost 8 out of the 25 cameras that began the study due to malfunction which limited my ability to create flawless models. Without both of these limitations I would have been able to make more data and a more consistent detection history at the ELER. The final limitation was the covariates. With more time to analyze the data and describe my covariates, I would have been able to quantify more detection and occupancy covariates which may have had more significant influence on the study. Future research should examine more complex covariates including NDWI incorporating technologies such as ArcGIS Pro in order to derive more accurate spatial information than I was able to in this amount of time. Moving forward I will also requntify my covariates more accurately.

Recommendations

The data collected from the general survey can be used to further the conservation efforts that are currently taking place at the ELER. While it can certainly be useful right now, I recommend that the sampling efforts be continued and increased in order to continue to develop a stronger understanding of the landscape and its animal community. Moreover, I recommend that the community be studied in different ways too, ones that are more direct in relation to snowy plovers and ones that could be beneficial today. To do this I suggest incorporating nest monitoring using cameras into the data collection process. Studies have shown that nest monitoring does not negatively affect nesting success in some shorebird species (McKinnon & Bêty 2009) and that the field based methods of assigning nest fates are not 100% accurate (Ellis et al. 2018). Currently there is some snowy plover nest monitoring going on at the ELER; if this monitoring is integrated with my study the San Francisco Bay Bird Observatory and land managers at the ELER should be able to make informed decisions regarding snowy plover conservation. For example, since we have a general idea of where red foxes are going to be detected on the landscape, we could then compare that to the nest monitoring data. If data from the nest monitoring shows that there is more red fox nest predation in the areas where they are more prominent (ie., the northwest corner of ELER) but less prominent in the southeast corner, then they will be able to make general decisions such as to improve predator removal efforts in the northwest corner of the ELER but save the money on management in the southeast corner.

There was lower red fox occupancy farther from urban areas. While I would be extremely hesitant to use these results to invest any money into management actions such as setting up fencing around major urban entry points to Eden Landing, I believe these results are encouraging and a step in the right direction. As mentioned above, red foxes are common inhabitants of urban areas. I recommend that this association be studied more closely in order to inform management actions at the ELER. If this association is continually found to be significant, managers could then explore the idea of putting up fences, motion activated spotlights, or other fox deterring techniques at major entry points to the ELER to see if they could keep them out of the ecosystem. Importantly however, this is contingent on there being proof that red foxes are a major limiting factor of snowy plover nest failures.

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Figures

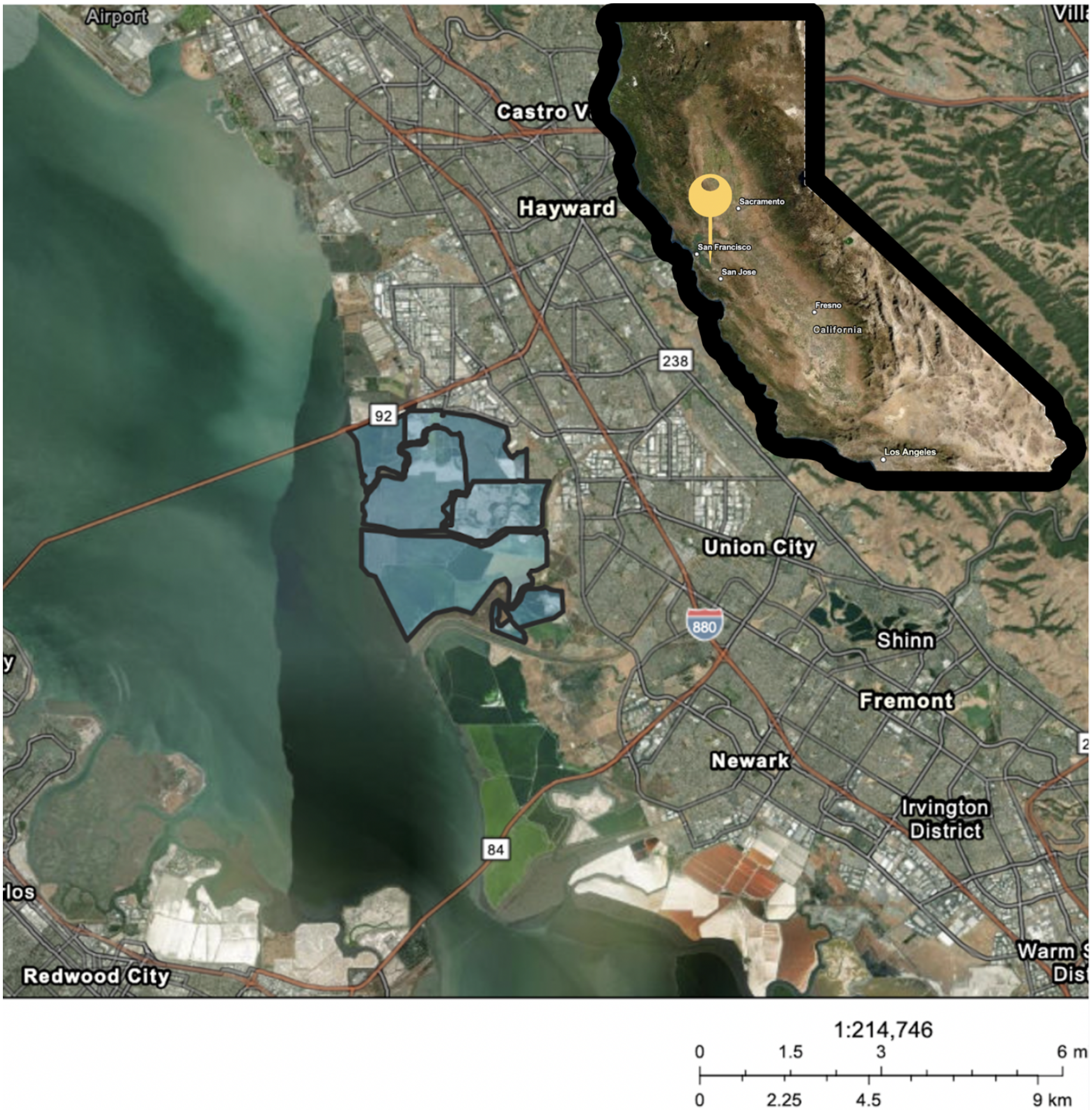

Figure 1. Maps of the Eden Landing Ecological Reserve and its location in California.

Figure 2: Example camera trap photos from the camera traps at the Eden Landing Ecological Reserve; clockwise from the top left: Bald eagle (*Haliaeetus leucocephalus*), coyote (*Canis latrans*), human, and red fox (*Vulpes vulpes*).

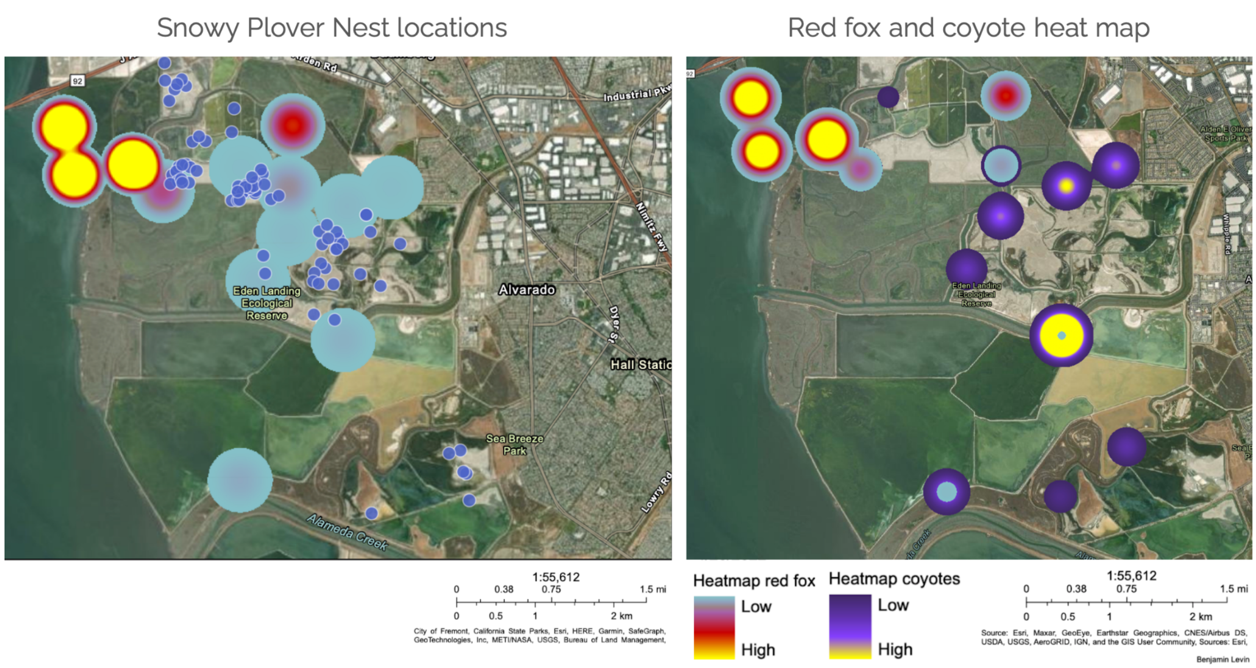

Figure 3. The map on the left shows a heat map of red fox detections with snowy plover nest locations from the previous year overlaid. The map on the right shows a heat map of red fox detections with a heat map of coyote detections overlaid.

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