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USING BIRD ODOR TO DETER MAMMALIAN PREDATORS FROM DEPREDATING SHOREBIRD NESTS

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USING BIRD ODOR TO DETER MAMMALIAN PREDATORS FROM DEPREDATING SHOREBIRD NESTS

BY

NICOLE D, DEFELICE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE
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MASTER OF SCIENCE THESIS

OF

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APPROVED:

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ABSTRACT

Managing for populations of nesting piping plovers (*Charadruis melodus*) along the Atlantic coast has always been a challenge for state, federal, and conservation organizations. Though piping plovers face numerous threats, such as human disturbance and habitat degradation, controlling nest predators remain a challenge. In this study, we evaluated a non-lethal technique to deter mammalian predators from disturbing and predating shorebird nests by deploying chemically-extracted bird odors in areas where piping plovers historically nest, with the idea that predators will key in on the scents, realize there is no "food reward" associated with the scent, and then lose interest in the bird scent over time. We focused on two study sites along the southern coast of Rhode Island, Trustom Pond National Wildlife Refuge and Ninigret National Wildlife Refuge and Conservation Area, where the main mammalian nest predators are coyote (*Canis latrans*), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*) and Virginia opossum (*Didelphis virginianus*). From the end of March through the beginning of June (one month pre- and two months post egg-laying), we deployed bird scent every three days on a rock in view of a trail camera. Trail cameras recorded the frequency of predator visits and length of time predators spent at the scent stations over time. We found bird odors did attract mammal interest. There was interspecific and annual variation in the number of visits, and the length of time each species spent at the scents. In 2022, coyote and fox detections reduced to zero by the end of the odor deployment season, with time spent by predators at scent stations also reduced. In 2023, coyotes, opossum, and skunks spent more time investigating scents and continued to visit scents more frequently as time progressed. We found certain bird scent types were more effective.

in attracting predators, particularly a mixture of waterfowl species. In addition, the scent we derived directly from waterfowl uropygial glands was the most effective in attracting predators. This study found that coyotes and red fox, the two key plover nest predators, appeared to habituate to the scents. Further investigations should be conducted on beaches throughout New England to confirm the utility of using this non-lethal technique to deter nest predators at beaches in North America.

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PREFACE

This thesis is prepared according to the manuscript format in preparation for submission to the *Journal of Field Ornithology*. The manuscript is presented as submitted to the journal and may be subsequently amended for publication.

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CHAPTER 1

USING BIRD ODOR TO DETER MAMMALIAN PREDATORS FROM DEPREDATING SHOREBIRD NESTS

Nicole DeFelice, Maureen Durkin, Peter Paton, and Brian Gerber

This manuscript is prepared for submission to the *Journal of Field Ornithology*

INTRODUCTION

Managing populations of shorebirds nesting in coastal sandy dune systems continues to be a management concern for U.S. state and federal agencies (Stantial et al. 2020, 2021). In particular, the federally threatened piping plover (*Charadrius melodus*) is a focal species for conservation efforts along the Atlantic Coast and was listed as threatened under the protection of the Endangered Species Act (ESA) in 1986. Important goals of the Atlantic Coast population Recovery Plan are to increase and maintain at least 2,000 breeding pairs for five years, attain a five-year average productivity of 1.5 fledged chicks per pair, and ensure long-term preservation of their wintering habitat to sustain survival rates for a 2,000 pair population (Hecht et al. 1996). When the species was first federally listed in 1986, there were 184 breeding pairs in New England and only ten breeding pairs in Rhode Island. Piping plover populations declined due to habitat loss from coastline development, and human disturbance (Hecht et al. 1996). The Atlantic Coast piping plover nesting habitats include low elevation shorelines of barrier islands, mudflats, sandbars, wrack lines, coastal ponds, lakes, and saltmarshes (Zeigler et al. 2021 and Robinson et al. 2021). These dynamic landscapes are susceptible to the ebb and flow of storm events and tidal forces which allow for overwash to occur, creating open, flat areas with sparse vegetation, which is ideal nesting and foraging habitat for piping plovers (Walker et al. 2019, Robinson et al. 2021, Zeigler et al. 2021). Although, with sea level rise and warming ocean temperatures, storm events such as hurricanes are becoming stronger and more intense, increasing coastal flooding and erosion (Walker et al. 2019). As a result of stronger storms, commercial and residential development, recreational expansion along the coast, and vegetation succession, these overwash events are less likely to occur, which fragments and reduces shorebird nesting habitat (Cohen et al. 2009). While considerable achievements have been made in addressing human disturbance and habitat degradation through symbolic fencing, outreach, and regulatory mechanisms, managing nest predators remains a challenge.

The Atlantic Flyway Shorebird Initiative (AFSI) highlighted predation as one of four primary anthropogenic threats to shorebird populations in the flyway (Hunt 2019). For plovers, populations of most predators in the region are influenced by human developments that provide food subsidies, such as trash and litter, that attract predators closer to nesting habitat, so active and costly management is often necessary to prevent predation of nests and chicks (Hunt et al. 2019, Darrah et al. 2020, Stantial et al. 2021, Anteau et al. 2021, Robinson et al. 2024). Opportunistic predator species in coastal regions in New England, such as raccoons (*Procyon lotor*), striped skunks (*Mephitis mephitis*), red foxes (*Vulpes vulpes*), Virginia opossum (*Didelphis virginiana*), and fish crows (*Corvus ossifragus*), all benefit from human food supplements (Cohen et al. 2009, Deuser et al. 2013, Johnson 2016, Melvin et al. 1992). Coyotes (*Canis latrans*), which historically did not occupy New England, now occur widely throughout eastern North America and also benefit from human subsidies (Foster et al. 2002). With increased predator presence on coastal beaches, vulnerable beach-nesting birds face the impeding threat of a nest being eaten, thus there is a need manage these predators. Lethal predator control, in combination with non-lethal strategies, is an important tool for beach-nesting bird management in many areas (Robinson et al. 2024, Ryan et al. 2015, Stringham and Robinson 2015), however, lethal techniques are not feasible on many beaches (Darrah et al. 2020). Reasons include ethical concerns of some landowners, lack of funding, staff limitations, difficulty, or because the area is too small to trap safely (Perry and Perry 2008 and Gieder 2015). In addition, removing a top predator can have unintended consequences, such as creating a mesopredator release, where mid-sized predator numbers increase, and the nest success of ground-nesting birds decreases (Harrison et al. 1989, Crooks and Saule 1999, Ritchie and Johnson 2009, Hunt et al. 2019, Stantial et al. 2021).

Hunt et al. (2019) outlines the importance of non-lethal strategies in predator management regimes. Non-lethal strategies widely used by plover biologists include nest exclosures (Melvin et al. 1992), placing irritating substances in dummy eggs (Hoover and Conover 1998, 2000; Selonen et al. 2022), using odor repellents (Lehner et al. 1976, Wauson and Rogers 2021), electric fencing (Mayer and Ryan 1991, Verhoeven et al. 2022), and habitat management (Cohen et al. 2009). A piping plover nest exclosure is a cage-like structure of metal or plastic mesh, secured with stakes, that covers the nest to protect it from predators, allowing the birds access while preventing disturbance (Melvin et al. 1992, Anteau et al. 2022, Stantial et al. 2024). Though exclosures are an important non-lethal management tool in deterring predators and aiding in nest success, they can have negative consequences (Darrah et al. 2020). Coyotes and red fox can enter exclosures to capture adult plovers and consume their eggs by breaking through or digging under the walls, jumping on top of the exclosure, or encircling the exclosure, forcing the adults off the nest and capture plovers as they leave the exclosure (Doherty and Heath 2011). This can result in adult mortality (Murphy 2003), nest abandonment, or predation of eggs (Doherty and Heath 2011). In addition, nest exclosures are not suitable in many instances due to topography (Murphy et al. 2003, Darrah et al. 2020). Alternative non-lethal strategies include deceiving predators with dummy eggs, and conditioning predators to the irritating substances in dummy eggs (Norbury et al. 2005). Hoover and Conover (2000) found pulegone, which is an irritating substance, can be toxic to egg embryos, so this method is not recommended for use in actual eggs, which could limit management efforts. Electric fencing can be an effective tool in keeping predators out of a localized nesting area, however, electric fences cannot be used in high-use areas, and can be faulty, making them unreliable and difficult to maintain (Gautschi et al. 2024). With all these limitations, there is a pressing need for reliable, cost-effective, alternative non-lethal methods of predator management where lethal management is not practical or feasible.

In this study, we evaluated the efficacy of an alternative non-lethal predator deterrence method that can be used to address predator induced nest disturbance and egg loss on beach nesting birds in Rhode Island. Researchers in Australia and New Zealand developed a non-lethal scent-based method to deter mammalian predators from disturbing and predating shorebird nests (Norbury et al. 2021). They randomly placed chemically extracted bird odor in habitats used by ground-nesting birds prior to and during the nesting season to condition mammalian predators to disassociate the scent of bird from food. After predators learned that bird odors were not likely to result in a food "reward", nest survival rates increased by 70 percent for three species of shorebirds over the first month of the nesting season (Norbury et al. 2021). Norbury et al. (2021) suggested that by habituating mammalian predators to bird odor cues, nest predators will lose interest in investigating the cues, which can reduce nest depredation rates of ground nesting shorebirds in New Zealand.

Although Norbury et al.'s (2021) results are promising, the ecosystem and predator community in New Zealand differ substantially from the Atlantic Coast. The New Zealand study sites were large (over 1,000 ha), non-linear sand and gravel riverbeds where the primary mammalian predators were introduced ferrets (*Mustela putorius furo*), feral cats (*Felis catus*), and European hedgehogs (*Erinaceus europaeus occidentalis*). Atlantic Coast beaches tend to be linear, relatively narrow, and surrounded by development and upland vegetation, thus limiting the availability of suitable nesting habitat (Stantial et al 2020). The primary mammalian predators throughout the Atlantic Coast include more diverse and mostly native species, including coyote, red fox, striped skunk, and Virginia opossum (Hecht et al. 1996). Furthermore, the shorebird nesting density in the New Zealand study area was low density (20-60 nests per 1,000 ha, Norbury et al. 2021), making it challenging for mammalian predators to find a shorebird nest than a denser nesting area along the Atlantic Coast (Weithman et al. 2019). Mid-Atlantic and New England beaches, as typified by sites in Rhode Island, are narrow and birds have limited space to nest, which suggests that predators have a higher probability of finding a nest on the beach (Zeigler et al. 2021). Despite these differences, the fundamental idea of Norbury et al. (2021) in conditioning mammalian predators to disassociate the scent of bird with food remains a plausible mechanism to reduce predator activity at nests on the Atlantic Coast.

The goal of our study was to implement Norbury et al. (2021)'s non-lethal predator deterrent method on beaches in southern Rhode Island to evaluate whether mammalian predators are attracted to the scent lures and then become habituated over time to the scents, marking this as the first testing of this approach in North America. Our objectives were to: (1) create scent lures using waterbird carcasses and uropygial glands in a lab, developing an odor preparation protocol, and deploying scent lure stations on piping plover nesting beaches, (2) document mammalian predator interactions with the scent lures using trail cameras by quantifying the number of times scent stations were visited, which types of scent lures had the most interactions, and if there were interspecific differences in mammal attraction to scent lures and if interactions changed over the nesting season, and (3) determine whether interactions with scent decreased over time, indicating that predators were conditioned to ignore the scent. Evidence of conditioning would indicate that this method holds promise for changing predator behavior in response to bird odor. Management agencies such as the U.S. Fish and Wildlife Service, the National Parks Service, state agencies, non-government conservation organizations, and local land managers must decide each season if and when to implement predator management and which species to focus on. This method could have broad utility for a variety of stakeholders interested in the management of birds vulnerable to mammalian nest predation.

METHODS

Study sites

We conducted fieldwork at Trustom Pond National Wildlife Refuge (NWR) in South Kingstown, Ninigret Conservation Area, and Ninigret NWR in Charlestown, Rhode Island, USA (Figure 1). We selected these sites because over the last ten years, both had at least ten pairs of nesting piping plovers and high nest predation (at least 50% of the nests were predated annually) by mammalian predators (USFWS, unpubl. data). On the Atlantic Coast, piping plover nesting areas consist of mixed substrates, such as fine sand, shells, gravel, and cobble, with sparse vegetation on the beachfront and densely vegetated dunes on the backside of the beach (Ziegler et al. 2021). The thick vegetation of coastal dunes serves as a natural barrier, protecting inland areas by absorbing the impact of storm surges (Walker et al. 2019). However, with powerful storms and hurricane events, these ecosystems are susceptible to flooding, high winds, and ultimately, habitat changes. Sometimes these storm events create overwash fans, where seawater gets pushed over the beach and dunes, depositing a new layer of sediment, occasionally burying vegetation (Robinson et al. 2021). Benefitting piping plovers, overwash fans can create additional foraging and nesting areas (Schupp et al. 2013, Walker et al. 2019, Robinson et al. 2021, \2022). Plovers prefer to nest in higher elevations away from the threat of high tides and forage in moist, saturated areas such as the shoreline (Zeigler et al. 2021, Robinson et al. 2021). At our study sites, nesting habitat includes a mixture of substrates, which ranged from sand to cobblestones, and nests occurred from the high tide line, to near the dune crest.

Trustom Pond and Ninigret NWRs are owned and managed by the U.S. Fish and Wildlife Service's (USFWS) Rhode Island NWR Complex. Ninigret Conservation Area is owned by the Rhode Island Department of Environmental Management (RI DEM) and managed for shorebirds by the USFWS Rhode Island NWR Complex through a RI DEM-funded program. Both areas are protected barrier beaches located on the southern Rhode Island coast and are approximately 8 km away from each other. The beaches are long and narrow: Trustom Pond NWR (hereafter, Trustom) is 2 km long and 60 m wide (~12 ha), and Ninigret beach (Ninigret Conservation Area and Ninigret NWR; hereafter, Ninigret) is 4.4 km long and 130 m wide (~57.2 ha). Trustom is a mix of rocky shoreline and beach face while Ninigret is composed primarily of sand. Both sites have a vegetated dune system comprised of American beachgrass (*Ammophila breviligulata*), beach rose (*Rosa rugosa*), beach pea (*Lathyrus japonicus*), and poison ivy (*Toxicodendron radicans*). Trustom has a sandy dune system that transitions to pond shore that is dominated by invasive common reed (*Phragmites australis*). This site has one house directly on the beach and several houses on the east and west ends, just outside refuge boundaries. The beach at Trustom is closed to public access starting 1 April for the piping plover nesting season, but the public are still able to walk along the beach at or below the mean high tide line where nesting shorebirds are not disturbed. Ninigret has a sandy dune system that transitions to maritime coastal shrubland and forest on the barrier interior with stands of invasive Japanese black pine (*Pinus thunbergii*). The backshore of the Ninigret barrier is saltmarsh bordered by stands of invasive common reed. Separating the coastal shrubland and forest from the sandy dune system is an off-road beach driving sand trail situated north of the dunes that run parallel with the beach. This road allows the public access to the entire beach throughout the year. Piping plover nesting areas were fenced off by USFWS staff and volunteers on the upper beach into the dunes from early April through mid-August.

Odor deployments

In January of 2022 and 2023, we modified the "Odor Preparation" protocol from Norbury et al. (2021) to create bird odor in the Food Science and Nutrition Research lab in West Kingston, Rhode Island (Appendix 1). We extracted bird scent from carcasses of gulls (hereafter gull; *Larus* spp.) and waterfowl (hereafter waterfowl; Anseriformes) and the uropygial glands of waterfowl (hereafter glands) donated by local hunters and a wildlife rehab center. We mixed multiple bird species into each scent type based on what was available from the donations (Table 1). The extracted bird scent contained a ratio of 40% bird concentrate: 60% Vaseline to ensure the scent was strong and able to stay on surfaces amid weather events such as rain and wind.

We established a total of 33 scent stations at Trustom and 48 stations at Ninigret (Figure 2 and 3). A scent station was a trail camera set up in front of scent-marked rock. We placed scent stations 40 m apart to ensure the scent was evenly dispersed across each study site. Predators utilized both the beach face and the back of the dunes, so the scent stations were placed both on the beach face and in the dunes (Johnson 2016, Kimber et al. 2020, Stantial, et al. 2020). Due to the limited availability of trail cameras in 2022, we had cameras at 13 of the 33 scent stations at Trustom, and 19 of the

48 stations at Ninigret. To survey all scent stations in 2022, we moved cameras among scent stations every three days using a random number generator and re-applied scent after each deployment only to scent stations with cameras. In 2023, we deployed cameras at all scent stations at Trustom and Ninigret. In the second year we omitted two of the 48 existing scent stations at Ninigret due to erosion resulting in reduced plover nesting habitat.

We deployed odors at three-day intervals (called deployments) starting one month before egg-laying was initiated and ceased deployments two months post piping plover egg-laying (based on the previous year's USFWS' monitoring data). We deployed controls at 25% of the stations (five to six scent stations) for the first four weeks of each study period, along with bird odors as the other 75%. At control stations, we only deployed a camera and/or Vaseline without the bird odor. At all other scent stations, we applied 0.1 ml of bird concentrate on a rock (with nitrile-gloved hands) in view of the camera, approximately 3 m away.

In 2022, scent stations were active and monitored for 76 days (25 deployments) at Trustom, and 64 days (21 deployments) at Ninigret from 27 March through 10 June (Table 2). In 2023, we lengthened the odor deployment season, with active scent stations at Trustom for 87 days (29 deployments), and Ninigret for 89 days (29 deployments) from 29 March through 26 June for 12.5 weeks (Table 3). We added 2.5 weeks of fieldwork in 2023 to give predators more time to be exposed to the scents.

We used three models of cameras (i.e., Bushnell (Core DS-4K No Glow), Reconyx (HyperFire 2 Covert IR), and Browning (Strike Force Pro XD)) to record which species of predator utilized scent stations. To reduce the chance cameras were stolen, we attached all cameras to a 0.50 m post using a Python lock with a 2-m long cable that was buried into the ground. We set cameras to photo burst mode, which took three photos per trigger to capture behavior of the predator as it interacted with the scent. To categorize and identify predators in the photos, we utilized the photo identification program, Camelot (Hendry and Mann 2018). We considered any detection as an "interaction" when a predator was within a body length of the scented rock. We also recorded behaviors including sniffing, licking, rubbing, or scent marking. Following Norbury et al. (2021), we classified animals that were detected in imagery at least five minutes apart to be a different individual detected.

Piping plover monitoring

Throughout the piping plover breeding season (March to late August), USFWS staff monitored the breeding ecology of piping plovers in southern Rhode Island. Technicians searched all potential nesting areas at both sites for evidence of possible breeding activity by surveying habitat on foot and identified any breeding behaviors such as false-sitting, figure-eight flying, broken wing displays, vocalizations, and visual evidence such as tracks or scrapes to find areas (Carins 1982). For any nests found at Trustom or at Ninigret, we installed a trail camera to accurately identify any potential nest predators. Technicians checked the nest every one to three days until it hatched or failed. Observers recorded nest locations with a tablet (accuracy ± 3m) and nest status (i.e., number of eggs, number of chicks) using the software Survey123 (https://survey123.arcgis.com) and ArcGIS' Field Maps (https://www.esri.com/en-us/arcgis/products/arcgis-field-maps/overview). Once a nest hatched, technicians monitored the number of chicks present and observed them until they fledged, which occurred approximately at 25 days. If a nest was found within 25 m of an active scent station with a deployed odor, we moved the scent station to at least 25 m away to ensure the scent station was not attracting predators to active nests.

Statistical analyses

We used R statistical software to summarize, plot, and analyze the camera data (R Core Team (2023)). The R-packages we used were ggplot2 (Wickham 2016), ggeffects (Lüdecke 2018), tidyverse (Wickham et al. 2019), dplyr (Wickham 2023), AICcmodavg (Mazerolle 2023), and mgcv (Wood 2011). We conducted two types of analyses separately for each species of predator; one considered the count, or number of instances a predator was detected at a scent station, and the other analyzed interaction time, or the amount of time a predator spent investigating the scent. Throughout, we use a Type 1 error rate of 0.05 to reject the null hypothesis and accept the alternative hypothesis to indicate a significant statistical difference.

Detection analysis

We analyzed predator detections at two scales: site and camera. The site-level pooled all scent stations at each of the two study sites, such that the focus was on summarizing how the total number of detections (across all cameras) by species varied throughout the sampling period at each beach. The objective of this analysis was simply to understand whether detections increased or decreased over the period of interest. The camera-level analysis focused on understanding more nuanced changes in predator detections by considering both spatial (across cameras) and temporal (across sampling period) covariates. For both analyses, we modeled detections by fitting Generalized Linear Models (GLM) with a Poisson distribution (Coxe et al. 2009). For the site-level analyses, we considered four competing models, in which where was no variation in detection (null model), or a linear trend in detections that varied temporally by each day (day), by each week (week), or by the interval of time between each deployment, which was every three days (deployments). To evaluate model performance, we compared models for each species using Akaike Information Criterion (AIC) and selected the model with the lowest AIC value as the model that is most supported (Aho et al. 2014). For the site-level investigation, we also fit a Generalized Additive Model (GAM) to consider non-linear changes (Guisan et al. 2002) in predator detections over time. Default thin plate spline regression smoothing (Wood 2011) was used on a variable indicating the day of each detection. These models allowed for more flexibility than a GLM framework.

For the camera-level analyses, we used additive and interaction models with one or more spatial or temporal covariates to explain the variation in predator detections. Covariates included scent types (i.e., control, gull, waterfowl, glands), the presence of active piping plover nests (active nests), and different time variables (day, week, deployment). For all models including scent types, the intercept represented was the control. When scent type was the highest ranked model, we created a bar chart to display the mean number of detections per one camera day per scent type. We did this by standardizing the number of predator detections by dividing by the total camera effort (i.e., number of cameras deployed by the number of days each camera was active).

Interaction time analysis

For our second analysis type, we assessed predator interaction time, or the amount of time a predator spent investigating a scent per detection. For a sequence of photos of a predator examining the scent, we calculated time, in seconds, from the first photo to the last photo of the same individual, given the animal was behaving continuously. We fit these data using the GLM framework with a Gamma distribution. We considered additive and interactions models with one or more covariates of scent type, site, day, week, and deployments. For the skunk interaction time analysis, we omitted the scent types, controls and glands, because there were few interactions with these scent types. The only scents considered for skunk detections were waterfowl and gull.

RESULTS

In 2022, Trustom had a total of 148 mammal predator interactions at scent stations and Ninigret had 92 interactions. In 2023, detections increased likely due to a higher sampling effort, with 484 detections at Trustom and 286 detections at Ninigret (Table 4). There were 11 mammalian species that were detected at the scent stations. Of all the predators that investigated scents, we focused the analyses on coyote, red fox, opossum, and striped skunk. We chose these species because they interacted with the scents > 20 times in one year, and because the species has been documented predating piping plover nests in New England (Melvin et al. 1992, pers. obs.).

Coyote

The most supported model, based on AIC weight (ω) for coyote detections at both Trustom and Ninigret in 2022, was day ($\omega = 0.35$; Table 5) ($\omega = 0.44$; Table 6). The linear effect of day on detections for Trustom was statistically significant (day $\beta = -0.01$, detections $\beta = 0.52$, both $P < 0.05$), showing a decline in the number of detections of coyotes through the sampling period (Figure 4). The linear effect of day on detections for Ninigret was also statistically significant, and slightly negative (day $\beta = -0.02$, detections $\beta = 0.92$, both $P < 0.05$), indicating a decline in the number of coyote detections throughout the season (Figure 5). We found no evidence of a difference between the mean predictions of both the GLM and GAM (Figure 4 and 5).

The most supported models for coyote detections at the site level in 2023 were week for Trustom, ($\omega = 0.43$; Table 7) and the null model for Ninigret ($\omega = 0.39$; Table 8). For Trustom, the linear effect of week on coyote detections was statistically significant (week $\beta = 0.05$, detections $\beta = 1.13$, both $P < 0.05$), showing a slight increase in the number of coyote detections throughout the sampling period (Figure 6). There were noticeable differences amongst the GLM and GAM prediction trends for this site, showing the variability in detections over time. With the null model as the most supported for Ninigret, this indicates there was no variation in detections over time for this species, therefore there is no slope. Although, the GAM showed a slightly declining trend early in the nesting season, there was a gradual increase in the prediction trend as the season progressed (Figure 7).

The most supported models by AIC weight (ω) for coyote detections at the camera level in 2022 was active nests for Trustom ($\omega = 0.34$; Table 9), and deployments for Ninigret ($\omega = 0.47$; Table 10). The active nests model had a negative coefficient estimate ($\beta = -0.05$, $P = 0.12$), indicating a decreasing slope, however the coefficients were not statistically significant. As active nests increased in numbers on the landscape, coyote detections declined (Figure 8). The deployments model coefficients were statistically significant for detections, but not deployments ($\beta = -2.65$ $P < 0.05$ and $\beta = -0.01$, $P = 0.38$). The negative coefficient estimate generated a declining linear trend, showing detections decreased as deployment periods increased (Figure 9). This effect was greater than the Trustom slope, indicating coyotes at Ninigret lost interest in the scents more quickly than coyotes at Trustom in 2022.

The most supported model at the camera level at Trustom in 2023 was deployments interacting with scent types ($\omega = 0.23$; Table 11) and day interacting with scent type for Ninigret ($\omega = 0.41$; Table 12). For the Trustom model, controls were the only statistically significant coefficient ($\beta = -2.81$, $P < 0.05$). Since control deployments ceased by day 25 and there were zero detections by the end of the season, there was a mean difference in detections with controls with a large confidence interval. With no statistical significance across the remaining scent types interacting with deployments, the slopes were stable throughout the deployment period (Figure 10). For Ninigret's most supported model, day interacting with scent types, the only coefficient that was not significant, was the scent type, Glands (β= -0.66, P = 0.20). Therefore, the slope of day interacting with each scent type varies throughout the season, showing unique trends for each scent type (Figure 11).

The most supported model for coyote interaction time (seconds) in 2022 was scent type interacting with site with a high AIC weight (ω = 0.99; Table 13). Based on the coefficient estimates, no covariates were statistically significant, indicating interaction time with scent types at one site did not differ from another site. Comparing coyote interaction time with each scent type, coyotes at Trustom spent the most amount of time (ca. 12 sec) investigating glands (Figure 12). For coyotes at Ninigret, all scent types overlapped, indicating no statistical significance in the amount of time spent at each scent type. At both sites, coyotes spent the least amount of time inspecting the controls.

The highest ranked model for coyotes' interaction time (seconds) in 2023 was site interacting with day (ω = 0.99; Table 14). According to the coefficient estimates, interaction time, day, and Trustom interacting with day were all statistically significant (β = 1.17, β = -0.02 and β = 0.02, $P < 0.05$). There was a positive linear effect of interaction time increasing with each passing day, particularly at Trustom (Figure 13). In both years, coyote detections decreased overall at Ninigret. At this site in 2022, they spent 6 seconds investigating scents at the beginning of the season. In 2023, coyotes spent less time investigating scents, with the first few days of the deployment season averaging around 3 seconds (Figure 14). At the beginning of the season in both years at Trustom, coyotes spent around 4 seconds investigating the scents. However, later in 2023, coyotes spent more time sniffing the scents.

Red Fox

The most supported model for foxes at the site level at Trustom in 2022 was the null model (ω = 0.30; Table 15). The detection sample size was small, with most of the points as non-detections, indicating no variations in detections over time for this species, therefore there is no clear slope (Figure 15). The prediction lines for the GLM and GAM almost overlapped, suggesting no noticeable difference between the mean predictions of both models. Detections did not correlate with events such as increase bird nesting activity or the end of the controls, however, they remained constant, averaging one to two detections per day.

The most supported model at the camera level for foxes at Trustom in 2022 ranked scent types as the highest ($\omega = 0.67$; Table 16). The coefficients indicate controls, glands, gull, and waterfowl were all statistically significant with $P < 0.05$. These scent types had negative coefficient estimates, (β= -3.18, β= -0.96, β= -1.45, and β= -1.69). Foxes interacted with controls scents most frequently (Figure 15), followed by glands, gull, and then waterfowl scents.

The highest ranked model for fox interaction time (seconds) was an additive effect of scent type and day ($\omega = 0.65$; Table 17). Glands, gull, waterfowl, and day all showed statistical significance with $P < 0.05$. The day covariate showed a negative estimate ($\beta = -0.05$), indicating as days progress, interaction time spent investigating a scent decreased. Red fox spent the most amount of time investigating waterfowl ($\beta = 3.30$), and the least amount at the controls ($\beta = 0.06$) (Figure 16). Interaction times across all scent types went down to almost zero by the end of the deployment season, indicating that red fox lost interest in investigating the scents.

Opossum

The most supported model by AIC weight (ω) for possum detections at the site level at Trustom in 2023 was the null model ($\omega = 0.45$; Table 18) and the deployments model for Ninigret ($\omega = 0.88$; Table 19). The GLM and GAM prediction lines were almost overlapping, indicating no difference between the mean predictions, which supports the null model as the highest ranked model. With a small detection sample size and a nearly unchanged slope, Trustom detections of opossum were not influenced by time (day, deployment, week) (Figure 17). For Ninigret opossum detections, deployments were statistically significant ($\beta = 0.18$, $P < 0.05$). Although the GLM prediction line continuously increased near the end of the season, the GAM showed predictions beginning to level off towards the end. There were no opossum detections at Ninigret until ~day 38 of the season, and then detections started to ramp up around day 60 (Figure 18). When detections were at their highest, a piping plover nest was depredated by an opossum.

The most supported model for opossum detections at the camera level at Trustom in 2023 was the null model ($\omega = 0.34$; Table 20), and the deployments model for Ninigret ($\omega = 0.59$; Table 21). The null model was the most supported for Trustom, indicating no variation in detections over time for this species. Based on the coefficients of Ninigret's most supported model, detections and deployments were statistically significant ($\beta = -7.91$ and $\beta = 0.17$, $P < 0.05$). As the deployment season progressed, opossum detections increased, particularly around the latter half of the deployment season (Figure 20). This correlates with the site level data where observed daily detections increased around day 60 (Figure 19).

The most supported model for opossum interaction times in 2023 was an additive effect of scent type and site ($\omega = 0.81$; Table 22). Glands was the only statistically significant coefficient ($\beta = 1.78$, $P < 0.05$), showing the greatest mean difference in interaction time (Figure 21). At both sites, opossums interacted with gull for the least amount of time, and glands the most (Figure 21). Opossums at Ninigret, on average, spent slightly more time investigating scents (~ 5 seconds) than opossums at Trustom (~ 2 seconds).

Skunk

The highest ranked model for skunk detections at the site level at Trustom in 2023 was day ($\omega = 0.42$; Table 23). The coefficient estimates show detections and days were statistically significant ($\beta = -7.12$ and $\beta = 0.09$, $P < 0.05$), indicating a positive linear trend (Figure 22). Besides one skunk scent detection at the very beginning of the odor deployment season around day 5 (Figure 22), skunks did not interact with scents until the last ten days of the odor deployments. Both GLM and GAM prediction lines increased considerably towards the end of the odor deployment period. There were no detections during significant events such as increased bird nesting activity on the beach, or the end of the control period.

The most supported model by AIC weight (ω) for skunk detections at Trustom in 2023 at the camera level was day ($\omega = 0.40$; Table 24). The coefficient estimates indicated a statistical significance for detections and day ($\beta = -10.6$ and $\beta = 0.09$, $P < 0.05$), showing an increasing slope. The marginal effects plot (Figure 23) reflects the number of skunk detections at Trustom and how they greatly increase at the tail end of the odor deployment season.

The highest ranked model for skunk interaction time (seconds) was an additive effect of scent and week ($\omega = 0.40$; Table 25). There was no statistical significance amongst the coefficients, meaning scent type and time (week) had no effect on the amount of time a skunk spent at a scent. The interaction time for both waterfowl and gull scent types increased as the season progressed, with skunks spending time investigating waterfowl the most (Figure 24).

Predations on piping plover nests

Concurrent monitoring recorded mammalian predations of piping plover nests with camera photos during the odor deployment period. We documented one coyote predation at Trustom in 2022, five coyote nest depredations at Trustom in 2023, and one at Ninigret in 2023, and one opossum nest predation at Ninigret in 2023. Nests were also predated by fish crow (*Corvus ossifragus*) throughout the odor deployment season. We exclosed second-attempt nests where possible to improve hatching success after an initial failure.

DISCUSSION

Predator detections

We found that the bird odors attracted interest from all four focal predator species (coyote, red fox, opossum, skunk) during this study in coastal Rhode Island. However, there was clear interspecific variation in the number of predator detections at the scent stations across both years and sites. Coyotes tended to interact more with scent stations than the other three mammalian species in both years. Coyotes are more likely to have more extensive home ranges than other mammals (Trewhella et al. 1988, Weissinger et al. 2009, Mitchell et al. 2015, Ward et al. 2018, Pearman-Gillman et al. 2020), and they are generalists, with a wider range of food sources, which could explain the high number of encounters with the bird odors (Latham et al. 2019). Piping plover eggs are an incidental prey item for coyote, which primarily prey on small mammals (Jensen et al. 2022). In 2022 at both sites, the number of coyote detections at scent stations was relatively high, and then reduced to zero detections by the end of the odor deployment season. This could indicate a decline in interest, or a possible habituation to the bird odors and the novel objects (trail cameras) on the beach, which concurs with the trends that Norbury et al. (2021) documented in New Zealand. We had many photos of coyotes passing by scent stations (outside their body length), but not approaching them, which could indicate a habituation to the scents as well. In 2023, however, coyote interest fluctuated frequently throughout the season, especially at Trustom. The higher number of detections throughout the season could have been influenced by other events occurring on the beach, such as bird nesting activity, or heightened levels of human recreation, creating food subsidies for coyotes (Murray and St. Clair 2017). In the second year of this study, coyote detections were never reduced to zero by the end of the season, suggesting they were not habituated to the bird scents.

We found red fox, opossum, and skunk did not interact with scents as consistently as coyotes during this study. Red fox detections were relatively constant throughout the deployment season at Trustom in 2022, yet in 2023, they only interacted with scents on three occasions. An increase in coyotes in 2023 could explain the paucity of red fox detections, as coyotes and red fox are interference competitors with non-overlapping territories (Major and Sherburne 1987), and coyotes are predators of red foxes (Masters and Maher 2022). Red foxes often spatially separate themselves to avoid encounters with an apex predator such as the coyote (Harrison et al. 1989). Red fox at Trustom could be avoiding coyotes because they were detecting their scents (Banks et al. 2016). Yet, in 2022, we saw camera images of red fox investigating the same scent station one hour after a coyote visited the same scent station and vice versa. At Trustom, red fox did not avoid the areas used by coyotes; rather, they utilized the same spaces but during alternate time periods.

The inconsistency in detections between years and sites was similar for opossums, with the species only detected once at Trustom and Ninigret in 2022, and more frequent in 2023. Opossum are potential prey for coyotes, so they also could be avoiding sites used by coyotes (Shedden et al. 2020). Opossum were not present at sites until early June at the end of the odor deployment season. This species exhibits strong seasonal variation in their spatial distribution and activity patterns, which is driven by their foraging and nesting behaviors (O'Connell et al. 2006). Kanda (2005) found female opossums in Massachusetts spend the winter and spring raising litters in a more urban area where they rely heavily on anthropogenic resources to survive. Once offspring are reared and temperatures warm, females will relocate to a more natural habitat which offers better foraging opportunities and fewer human interactions such as car collisions. This could be why we were seeing more opossum on the beaches where there are less roads and large swathes of natural areas.

Of all species of mammals detected at scent stations during this study, skunk detections were the most irregular. Skunk were not detected at either site in 2022, and in 2023 were only detected at Trustom starting early June. Johnson (2016) found coastal striped skunks tend to be more active foraging on the backside of dunes with increased human activity during the busy beach season on Martha's Vineyard because human food subsidies apparently attract them. Human recreational activity increased from late May into early June in Rhode Island, which coincided with the later emergence of skunks on the sites. Johnson (2016) also documented that beach houses and/or large human objects washed up by storms provide high quality den sites for skunks. Trustom had one resident house on site, with private neighborhoods on either side of the beach entrances, as well as marine debris from intense winter storms (e.g., crab/lobster pots, bundles of rope, and unidentifiable plastic bins) in the dunes. Besides food, these structures and novel objects could have attracted skunks for denning.

Interaction Time

To determine whether predators were exhibiting conditioning to scents, we analyzed the amount of time they spent investigating scents. Based on results from Norbury et al. (2021), we anticipated that interaction times at scent station would decline as the season progressed. Both coyotes at Ninigret (in both years) and red fox at Trustom spent less time at scent stations as the season progressed, from a mean of 3.5 seconds per interaction early in the nesting season, to 1-2 second interactions by the end of the odor deployment season. The quick 1-2 second sniffing of the bird scent could signify the coyote or red fox's routine exploratory behavior to receive information about its territory and/or the possibility of food (Wells 1978, Major and Sherburne 1987). The longer time spent sniffing the scent earlier in the season could be due to the novelty of the trail camera and scent on the landscape, and the reduction in time spent could be an indication of being habituated to the scent and the scent station.

At Trustom, we had photo evidence of coyotes and red fox scent-marking some of the deployed bird odors. Typically, scent-marking is used to mark territories (Allen et al. 1999), signal alarm, announce reproductive condition (Gese and Ruff, 1997), or to indicate the presence or absence of food. Harrington (1982) explained the term “book-keeping”, which is a method coyote, red fox, and wolves (*Canis lupus*) use to tell others that there’s no food left in the area, possibly to “enhance foraging efficiency”. Therefore, learning there was no food reward associated with scents, predators could be scent-marking to reduce the time and energy spent foraging, which could indicate habituation to lose interest in the scent stations (Henry, 1977, Harrington 1981, Allen et al. 1999).

In contrast to other mammalian predators, coyotes at Trustom exhibited an increased interest over the field season. This prolonged curiosity could have been because they were investigating scent marks from individuals that visited the scent station prior, or because of the possibility of a food source (Gese and Ruff 1997). Opossums and skunk also showed a slight increase in time spent at the scent stations. Since both species were not detected on site until much later in the season, it is possible the initial interest was high because they were encountering something new on site, similar to what Norbury et al. (2021) observed with the later emergence of hibernating hedgehogs in their study.

Scent types

There was considerable variation among predators’ interest in scent types across years and sites during this study. Selonen et al. (2022) also documented interspecific variation in predators’ reactions to different scent types. The waterfowl and uropygial gland scent attracted three of the four predators the most during this study. Glands and waterfowl were a mix of different waterfowl species, which could have perplexed predators, drawing in further investigative interest. Since glands were derived directly from the preening gland itself, rather than from the full carcass of the animal, this scent could have been a more potent odor as well. Waterfowl species, or birds that inhabit an aquatic environment, tend to have larger uropygial glands for waterproofing plumage (Moreno-Rueda, 2017), therefore we could have yielded more bird odor in the extraction process than from a gull.

The bird odor that attracted the lowest interaction times across all mammalian predators was gull. Coyotes rarely feed on sick or dead adult gulls, as well as gull eggs (Jehl and Chase 1987), which may explain why coyotes were not attracted to gull odors. It was common for gulls (e.g., great black-backed gull (*Larus marinus*), ring-billed gull (*Larus delawarensis*), and herring gull (*Larus argentatus*) to stage and preen near some scent station areas, which also might explain why there was little interest in the gull scent.

Initially, controls did attract coyotes and foxes during this study, however, interactions with the controls quickly declined, indicating the apparent visual novelty of trail cameras on the beach could have been the alluring factor (Sergeyev et al. 2020). Skunks and in some cases, opossums, did not interact with the controls at all. This may be because skunks and opossums were rarely detected on the landscape during the control deployment period.

Bird arrivals and nesting activity

Throughout the season, the number of detections for each predator varied. These waves in detections might be explained by other events such as the nesting chronology of least terns (*Sternula antillarum*). Least terns are a colonial ground-nesting seabird that nest at Trustom and Ninigret and are also susceptible to egg predation by mammals (Hecker and Hecker 1988). Unlike a piping plover nest that is usually solitary and more difficult to locate, least terns can be more susceptible to predation because colonies are loud and active which could draw in curious predators (Varela et al. 2007). Least terns also rely on defensive behaviors such as mobbing and dive bombing to deter predators away from nests (Brunton 1997). Although this can be very effective, this strategy risks leaving eggs unprotected and vulnerable to heat exposure, and creates opportunities for secondary predators to sneak in (Byerly et al. 2021). Typically, least terns arrived at Trustom about a week earlier than Ninigret (personal observation). Arrival dates averaged 10 May and ranged from 3 to 17 May (Fink et al. 2023). Yet, the number of detections at scent stations was quite low during early to mid-May, which suggests that the arrival of least terns did not affect mammalian predator occurrence at either site.

In southern Rhode Island, piping plovers initiate egg laying at Trustom one week earlier than Ninigret (personal observation). The earliest clutches were deposited on 25 April 2022 (Trustom) and 1 May 2023 (Trustom), and continued into mid-June (USFWS, unpubl. data). Similar to least tern arrivals, the number of predator detections at scent stations was not correlated with the start of piping plover nesting season. Early June was when piping plover chicks were hatching and were more active on the landscape and when human recreation started to increase on Rhode Island beaches (DeRose-Wilson et al. 2018). This is also when opossum began being detected which are potential prey to coyotes (Shedden et al. 2020 and McClennen et al. 2001). Therefore, the combination of increased plover chick activity patterns, human food subsidies, and the seasonal emergence of prey could have increased mammalian predator activity levels at the scent stations, specifically for coyotes, skunks, and opossums at Trustom in 2023.

Comparisons with Norbury study

Our results indicate that Rhode Island predators showed no consistent habituation to the bird odors. Compared to the Norbury et al. (2021) study, we did not detect a steady decline in the number of predator detections at active scent stations across all predator species in this study, nor did detections cease by the end of the odor deployments. Instead, we saw considerable variation in mammalian predator interest throughout the odor deployment period. We did, however, document a decline in the length of time predators investigated the scents for coyotes at Ninigret in both years and for red fox.

Some piping plover nests continued to be predated by mammals during the odor deployment period during this study. Latham et al. (2019) found that while shorebird mammalian predators in New Zealand can habituate to the scents, dishabituation may occur, leading them to locate nests. This dishabituation could have been possible amongst coyotes on Trustom, in particular.

New Zealand's predators were less likely to encounter a shorebird nest because their study areas were much larger. For instance, one of NZ's four study sites was around 1,000 ha, while our largest site, Ninigret, was only 57 ha (Norbury et al. 2021). The dune systems on the southern Rhode Island coast were long, and linear, and as Stantial et al. (2020) suggested, the linear nature of these narrow barrier beaches could encourage pursuant mammals to search for prey in a similar, straight route. Piping plovers prefer to nest in open, flat areas with sparse vegetation (Zeigler et al. 2021), however, with a tight, constricted beach face, plovers are sometimes limited to nesting at the base of dunes to avoid overwash from high tides. For a predator such as a coyote or fox utilizing the foot of the dunes, it is highly likely that they would come across a piping plover nest, regardless of odor cues. Being within proximity to nests allows predators to use visual cues such as seeing a disturbed piping plover run off their nest which could help predators locate nests more efficiently. Since New Zealand's habitat was widespread and non-linear, their predators could have relied more on odor cues to locate nests, rather than visual cues. New Zealand's study areas were isolated from human development and activity, with only an occasional vehicle passing by along the edges of the study sites (Grant Norbury, personal communication). Our beaches were less than one km from occupied homes and had constant human activity with people recreating and walking on both sites throughout the odor deployment season. As a result of human development and recreation, food subsidies and trash could have attracted predators to the sites. Even adjacent developments and towns could have attracted mammalian predators to the coastal region, inflating predator populations where they historically did not inhabit (Way et al. 2004, Newsome et al. 2015).

The predator community in Rhode Island differed substantially from the introduced mammals in New Zealand. In Rhode Island, predators were physically larger, and had larger home ranges. Coyotes inhabiting a coastal, suburban environment in Cape Cod can cover up to 75-100 km per night (Jehl and Chase 1987) and have home ranges averaging 50 - 70 km^2 (Hinton et al. 2015 and Chamberlain et al. 2021). In comparison, feral cats, the largest shorebird nest predator examined in the Norbury et al. (2021) study, only had an average home range up to 10 km^2 (Recio et al. 2010). The combination of a tighter nesting area inhabited by predators with larger home ranges made it more likely for a predator to come across deployed scents, and unfortunately, shorebird nests.

MANAGEMENT IMPLICATIONS

These findings suggest that this novel technique does have an effect on mammalian predators of ground-nesting shorebirds on Atlantic Coast beaches. Chemically-extracted bird odors did attract mammalian predators' interest; however, there was considerable interspecific variation in detection and interaction rates at scent stations. Our results found that mixing multiple bird species in one scent type attracted predators more often than a familiar smell such as gull. Therefore, we recommend mixing multiple bird species in the extraction process to create scent lures, both from carcasses and uropygial glands. Additionally, deploying different types of bird scents on the landscape attracted the greatest predator interest. We recommend using uropygial glands for extraction as they require less solvents and are equally effective in attracting predators compared to the carcass-derived scents. We found using a 40:60 ratio of bird concentrate to Vaseline achieved an adequately strong enough smell to lure in predator interest. Like Norbury et al. (2021), we suggest deploying odors at least one month prior to shorebird nesting to ensure predators are keying in on the scents prior to bird arrival. To assure scents are potent on the landscape, we propose to continue to reapply odors every three days. Continuing to use additional piping plover non-lethal predator management practices such as exclosing nests is recommended. Although some predator species indicated evidence of habitation to the scents, further investigations should be conducted on other types of mammalian predators, larger study areas, and different types of ecosystems.

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TABLE 1 Bird species used in the bird odor extraction process and the method in which they were made. Carcass is the full body of the bird, and glands are the uropygial gland that was extracted and used.

Common Name	**Scientific Name**	**Method**	**Year Used**
American Black Duck	*Anas rubripes*	Carcass & Glands	2022, 2023
American Wigeon	*Mareca americana*	Glands	2022, 2023
Atlantic Brant	*Branta bernicla*	Carcass & Glands	2023
Bufflehead	*Bucephala albeola*	Carcass	2022
Cackling Goose	*Branta hutchinsii*	Glands	2023
Canada Goose	*Branta canadensis*	Glands	2022, 2023
Canvasback	*Aythya valisineria*	Glands	2023
Cinnamon Teal	*Anas cyanoptera*	Glands	2023
Common Eider	*Somateria mollissima*	Glands	2022
Gadwall	*Mareca strepera*	Glands	2023
Great Black-backed Gull	*Larius marinus*	Carcass	2022
Greater Scaup	*Anas marila*	Glands	2022, 2023
Green-winged Teal	*Anas carolinensis*	Carcass & Glands	2023
Herring Gull	*Larus argentatus*	Carcass & Glands	2022, 2023
Hooded Merganser	*Lophodytes cucullatus*	Carcass & Glands	2022, 2023
Lesser Scaup	*Aythya affinis*	Carcass & Glands	2022, 2023
Long-tailed Duck	*Clangula hyemalis*	Carcass & Glands	2022, 2023
Mallard	*Anas platyrhynchos*	Carcass & Glands	2022, 2023
Northern Pintail	*Anas acuta*	Glands	2023
Redhead	*Aythya americana*	Glands	2023
Ring-billed Gull	*Larus delawarensis*	Carcass	2022, 2023
Ring-necked Duck	*Aythya collaris*	Glands	2022, 2023
Surf Scoter	*Melanitta perspicillata*	Glands	2022
Wood Duck	*Aix sponsa*	Glands	2022

TABLE 2 Summary of scent odor deployments to deter mammalian predators at two sites (Trustom and Ninigret) in southern Rhode Island in 2022.

Parameter	Trustom	Ninigret
Start Date	27 March	8 April
End Date	10 June	10 June
# of days in deployment season	76	64
# of scent stations	33	46
# of active scent stations on any given day	13	19
# of days between moving scent station	3	3
# of scent applications	25	21

TABLE 3 Summary of scent odor deployments to deter mammalian predators at two sites (Trustom and Ninigret) in southern Rhode Island in 2023.

Parameter	Trustom	Ninigret
Start Date	29 March	29 March
End Date	24 June	26 June
# of days in deployment season	87	89
# of scent stations	33	46
# of active scent stations on any given day	33	46
# of days between applying scent	3	3
# of scent applications	29	29

TABLE 4 Total number of detections at scent stations by mammals at two sites (Trustom and Ninigret) in southern Rhode Island in 2022 and 2023. Six species were potential predators of piping plover (PIPL) nests, and were included in species-specific analyses.

				2022		2023	
Common Name	Scientific Name	PIPL Predator?	Conducted Species Specific Analysis	Trustom detections	Ninigret detections	Trustom detections	Ninigret detections
Bobcat	*Lynx rufus*	No	No	1	0	8	17
Domestic Dog	*Canis lupus*	Yes	No	3	1	15	30
Eastern Coyote	*Canis latrans*	Yes	Yes	85	73	376	145
Gray Fox	*Urocyon cinereoargenteus*	Yes	No	0	0	0	1
House Mouse	*Mus musculus*	No	No	1	0	0	10
North American River Otter	*Lontra candadensis*	Yes	No	1	0	0	1
Raccoon	*Procyon lotor*	Yes	No	5	2	12	9
Red Fox	*Vulpes vulpes*	Yes	Yes (2022)	38	0	3	1
Striped Skunk	*Mephitis mephitis*	Yes	Yes (Trustom, 2023 only)	0	0	32	0
Virginia Opossum	*Didelphis virginiana*	Yes	Yes (2023)	1	1	17	51
White-tailed Deer	*Odocoileus virginianus*	No	No	13	15	21	21
Total	-	-	-	2156	76	2469	214

TABLE 5 Assessing coyote use of Trustom Pond National Wildlife Refuge, RI at the site level in 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	**Δ**AIC_c	**ω**
Day	2	234.69	0.00	0.35
Deployments	2	234.94	0.25	0.31
Week	2	235.28	0.59	0.26
Null	1	237.73	3.04	0.08

TABLE 6 Assessing coyote use of Ninigret at the site level in 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	**Δ**AIC_c	**ω**
Day	2	206.88	0.00	0.4436
Deployments	2	206.99	0.12	0.4184
Week	2	209.22	2.34	0.1379
Null	1	223.15	16.27	0.0001

TABLE 7 Assessing coyote use of Trustom Pond National Wildlife Refuge, RI at the site level in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	**Δ**AIC_c	**ω**
Week	2	588.08	0.00	0.43
Day	2	588.74	0.66	0.31
Deployments	2	589.03	0.95	0.27
Null	1	596.75	8.67	0.01

TABLE 8 Assessing coyote use of Ninigret at the site level in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Null	1	460.67	0.00	0.39
Day	2	461.08	0.41	0.31
Week	2	462.51	1.85	0.15
Deployments	2	462.64	1.97	0.14

TABLE 9 Assessing coyote use of different scent stations at Trustom Pond National Wildlife Refuge, RI in 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Active Nests	2	682.81	0.00	0.336
Null	1	683.40	0.58	0.251
Deployments	2	684.61	1.80	0.137
Day	2	684.67	1.86	0.133
Week	2	684.89	2.08	0.119
Scent type	4	689.26	6.44	0.013
Week * Scent type	8	691.60	8.78	0.004
Day * Scent type	8	691.68	8.86	0.004
Deployments * Scent type	8	691.90	9.08	0.004

TABLE 10 Assessing coyote use of different scent stations at Ninigret in 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Deployments	2	598.75	0.00	0.4719
Day	2	599.43	0.68	0.3357
Week	2	601.39	2.64	0.1261
Active Nests	2	603.38	4.63	0.0467
Deployments * Scent type	8	605.92	7.17	0.0131
Day * Scent type	8	607.73	8.98	0.0053
Week * Scent type	8	611.29	12.54	0.0009
Null	1	614.28	15.53	0.0001

TABLE 11 Assessing coyote use of different scent stations at Trustom Pond National Wildlife Refuge, RI in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Deployments * Scent type	8	2422.99	0.00	0.230
Day * Scent type	8	2423.20	0.20	0.208
Week * Scent type	8	2423.45	0.46	0.183
Week	2	2423.91	0.91	0.146
Day	2	2424.56	1.57	0.105
Deployments	2	2424.85	1.85	0.091
Scent type	4	2426.82	3.83	0.034
Active Nests	2	2429.04	6.05	0.011
Null	1	2432.62	9.62	0.002

TABLE 12 Assessing coyote use of different scent stations at Ninigret in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Day * Scent type	8	1280.21	0.00	0.4145
Deployments * Scent type	8	1280.31	0.10	0.3944
Week * Scent type	8	1281.85	1.64	0.1825
Active Nests	2	1288.70	8.49	0.0059
Null	1	1289.57	9.36	0.0038
Week	2	1291.33	11.12	0.0016
Deployments	2	1291.48	11.27	0.0015
Day	2	1291.50	11.29	0.0015
Scent type	4	1294.80	14.58	0.0003

TABLE 13 Assessing coyote interaction times at two sites in southern Rhode Island 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Scent type * Site	9	682.72	0.00	0.9960
Site * Day	5	693.99	11.27	0.0036
Scent type * Site	6	698.86	16.14	0.0003
Site	3	702.96	20.24	4.01E-05
Scent type * Day	9	703.15	20.43	3.65E-05
Site + Day	4	704.94	22.22	1.49E-05
Scent type * Week	9	705.58	22.86	1.08E-05
Scent type	5	707.65	24.93	3.85E-06
Null	2	719.85	37.12	8.64E-09
Day	3	720.14	37.42	7.45E-09

TABLE 14 Assessing coyote interaction times at two sites in southern Rhode Island 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	**ΔAIC_c**	**ω**
Site * Day	5	2126.92	0.00	0.99
Site + Day	4	2146.92	19.99	4.54E-05
Site	3	2147.67	20.74	3.13E-05
Scent type * Site	9	2147.97	21.05	2.68E-05
Scent type + Site	6	2149.21	22.29	1.44E-05
Scent type * Day	9	2190.15	63.23	1.86E-14
Scent type * Week	9	2191.47	64.55	9.60E-15
Scent type	5	2199.54	72.62	1.70E-16
Null	2	2201.22	74.30	7.34E-17
Day	3	2203.08	76.16	2.90E-17

TABLE 15 Assessing red fox use of Trustom Pond National Wildlife Refuge, RI at the site level in 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	**ΔAIC_c**	**ω**
Null	1	200.91	0.00	0.30
Deployments	2	201.18	0.27	0.26
Week	2	201.38	0.47	0.23
Day	2	201.58	0.67	0.21

TABLE 16 Assessing red fox use of different scent stations at Trustom Pond National Wildlife Refuge, RI in 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Scent type	4	409.73	0.00	0.67
Day * Scent type	8	413.59	3.85	0.10
Deployments * Scent type	8	413.61	3.88	0.10
Week * Scent type	8	414.09	4.36	0.08
Active Nests	2	415.74	6.00	0.03
Null	1	416.41	6.69	0.02
Week	2	417.77	8.04	0.01
Day	2	417.80	8.07	0.01
Deployments	2	417.82	8.08	0.01

TABLE 17 Assessing red fox interaction times at Trustom Pond National Wildlife Refuge, RI in 2022. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Scent type + Day	6	113.19	0.00	0.65
Scent type + Week	6	114.42	1.24	0.35
Scent type	5	134.21	21.02	1.77E-05
Day	3	140.58	27.39	7.33E-07
Null	2	156.74	43.56	2.26E-10

TABLE 18 Assessing opossum use of Trustom Pond National Wildlife Refuge, RI at the site level in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Null	1	95.72	0.00	0.45
Day	2	97.14	1.41	0.22
Week	2	97.73	2.01	0.17
Deployments	2	97.79	2.08	0.16

TABLE 19 Assessing opossum use of Ninigret at the site level in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Deployments	2	152.73	0.00	0.88
Week	2	157.72	4.99	0.07
Day	2	158.82	6.09	0.04
Null	1	218.94	66.21	3.71E-15

TABLE 20 Assessing opossum use of different scent stations at Trustom Pond National Wildlife Refuge, RI in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Null	1	211.73	0.00	0.343
Scent type	4	213.65	1.91	0.132
Week	2	213.65	1.92	0.131
Day	2	213.70	1.97	0.128
Deployments	2	213.72	1.98	0.127
Active Nests	2	213.72	1.99	0.127
Day * Scent type	8	220.64	8.90	0.004
Week * Scent type	8	220.66	8.92	0.004
Deployments * Scent type	8	220.72	8.98	0.004

TABLE 21 Assessing opossum use of different scent stations at Ninigret in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Deployments	2	496.33	0.00	0.590
Day	2	497.42	1.09	0.343
Week	2	500.98	4.65	0.058
Deployments * Scent type	8	505.47	9.14	0.006
Day * Scent type	8	506.54	10.21	0.004
Week * Scent type	8	510.44	14.11	0.001
Active Nests	2	527.38	31.05	0.00
Scent type	4	552.82	56.48	3.20E-13
Null	1	561.69	65.36	3.79E-15

TABLE 22 Assessing opossum interaction times at two sites in southern Rhode Island in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Scent type + Site	6	274.99	0.00	0.8100
Scent type + Day	6	279.61	4.62	0.0803
Scent type + Week	6	279.72	4.73	0.0760
Scent type	5	281.43	6.44	0.0324
Site	3	288.55	13.56	0.0009
Site + day	4	290.59	15.60	0.0003
Day	3	294.98	19.99	3.69E-05
Null	2	295.30	20.31	3.15E-05

TABLE 23 Assessing skunk use of Trustom Pond National Wildlife Refuge, RI at the site level in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC$_c$) and include the number of parameters (K), difference in AIC$_c$ from the best model (ΔAIC$_c$), and model weight (ω).

Model	K	AIC$_c$	**Δ**AIC$_c$	$\boldsymbol{\omega}$
Day	2	87.99	0.00	0.42
Week	2	88.36	0.38	0.35
Deployments	2	89.26	1.28	0.22
Null	1	156.50	68.52	5.61E-16

TABLE 24 Assessing skunk use of different scent stations at Trustom Pond National Wildlife Refuge, RI in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC$_c$) and include the number of parameters (K), difference in AIC$_c$ from the best model (ΔAIC$_c$), and model weight (ω).

Model	K	AIC$_c$	**Δ**AIC$_c$	$\boldsymbol{\omega}$
Day	2	287.94	0.00	0.40
Week	2	288.31	0.37	0.33
Deployments	2	289.21	1.28	0.21
Day * Scent type	8	293.64	5.70	0.02
Week * Scent type	8	293.97	6.03	0.02
Deployments * Scent type	8	296.03	8.09	0.01
Scent type	4	346.96	59.03	6.14E-14
Null	1	356.47	68.54	5.28E-16
Active Nests	2	358.22	70.29	0.00

TABLE 25 Assessing skunk interaction times at Trustom Pond National Wildlife Refuge, RI in 2023. Candidate generalized linear models (Poisson) ranked by Akaike's Information Criterion corrected for small sample sizes (AIC_c) and include the number of parameters (K), difference in AIC_c from the best model (ΔAIC_c), and model weight (ω).

Model	K	AIC_c	ΔAIC_c	ω
Scent type + Week	4	174.75	0.00	0.40
Scent type + Day	4	175.07	0.32	0.34
Scent type	3	176.01	1.25	0.21
Null	2	178.84	4.09	0.05

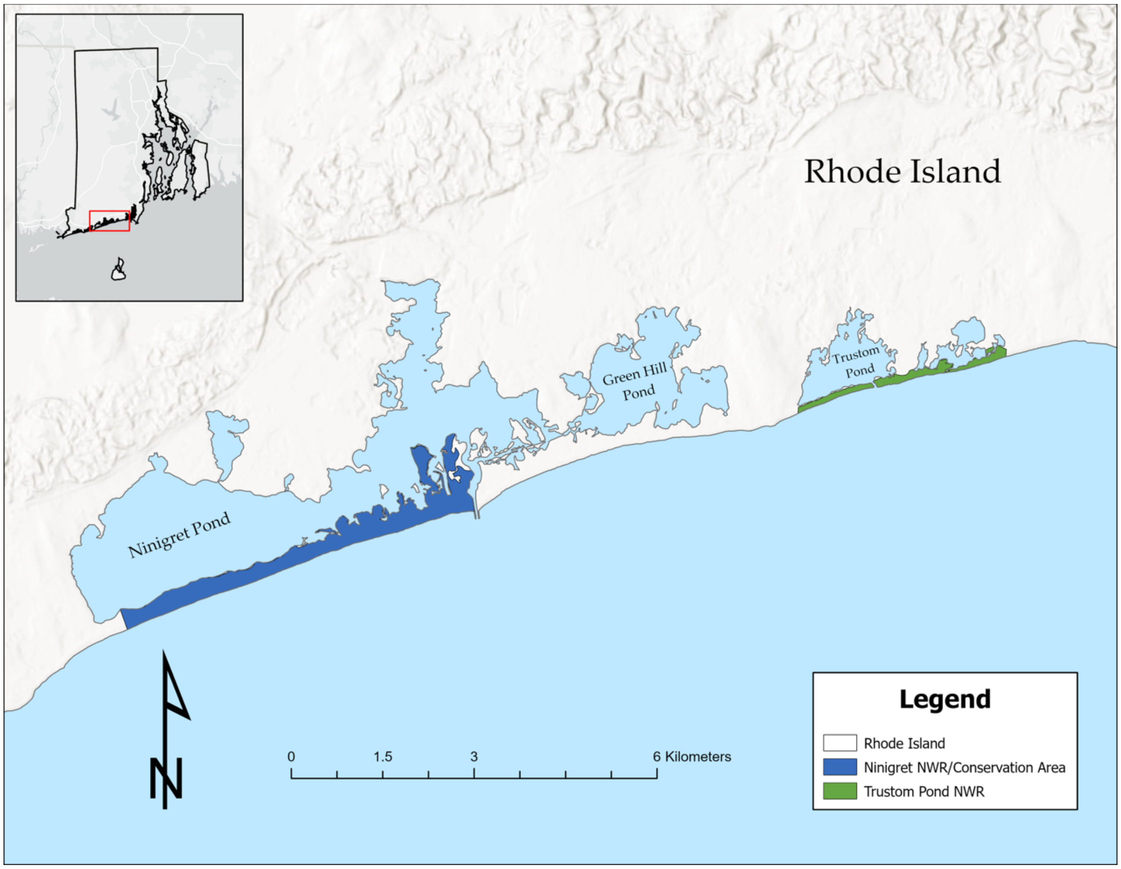

FIGURE 1 Study area map indicating the two study sites, Trustom Pond National Wildlife Refuge (green) and Ninigret National Wildlife Refuge/ Conservation Area (blue) located in Rhode Island.

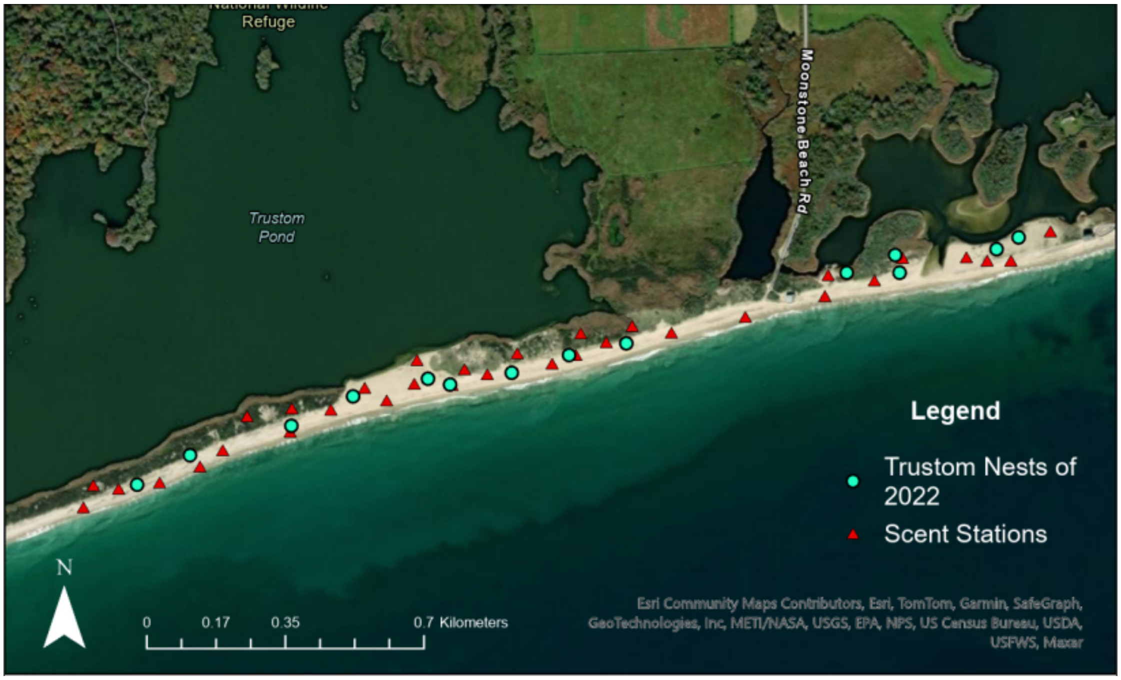

FIGURE 2 Study area map of Trustom Pond National Wildlife Refuge, Charlestown, Rhode Island. Map shows piping plover nests in 2022 (aqua dots) and scent stations (red triangles) evenly dispersed across piping plover nesting area.

FIGURE 3 Study area map of Ninigret National Wildlife Refuge/ Conservation Area, Charlestown, Rhode Island. Map shows piping plover nests in 2022 (yellow dots) and scent stations (red triangles) evenly dispersed across piping plover nesting area.

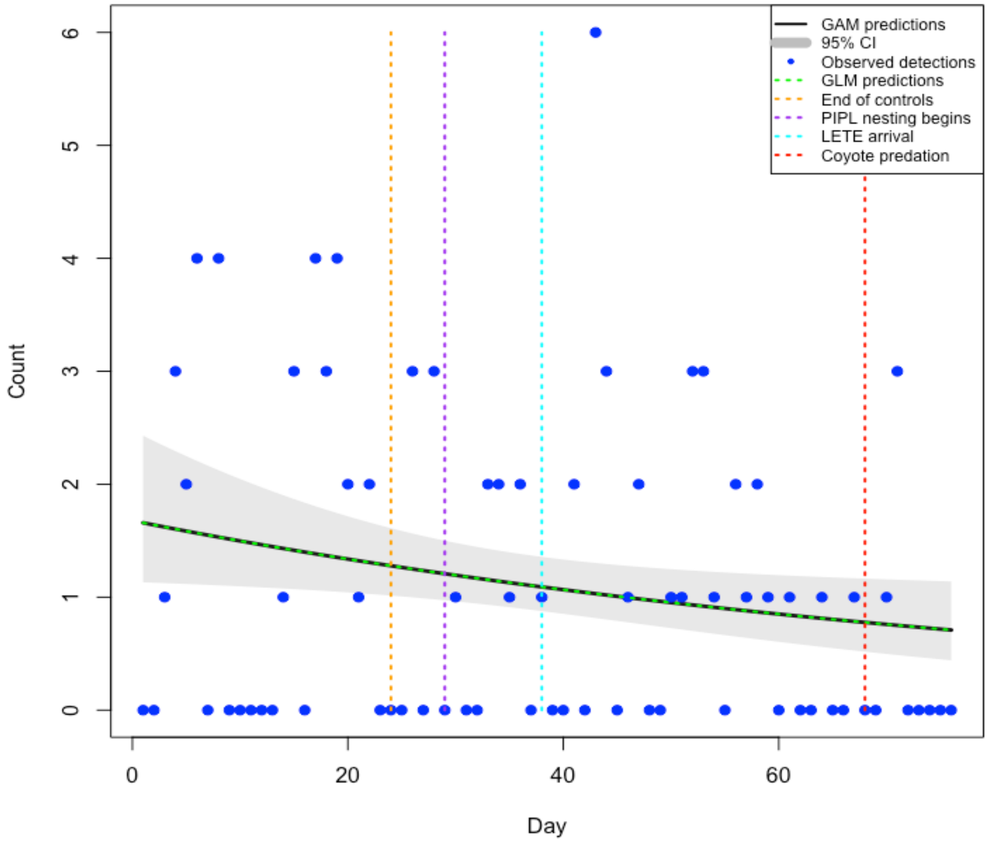

FIGURE 4 Daily variation in coyote detections (blue points) at control points and scent stations at Trustom, Rhode Island from 27 March (day 0) to 10 June (day 76) in 2022. Graph shows the most supported generalized linear model, GLM (green dotted line), which is the Day model (Table 5), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), the arrival of least terns to the study area (aqua), and documented predation of a piping plover nest by a coyote (red).

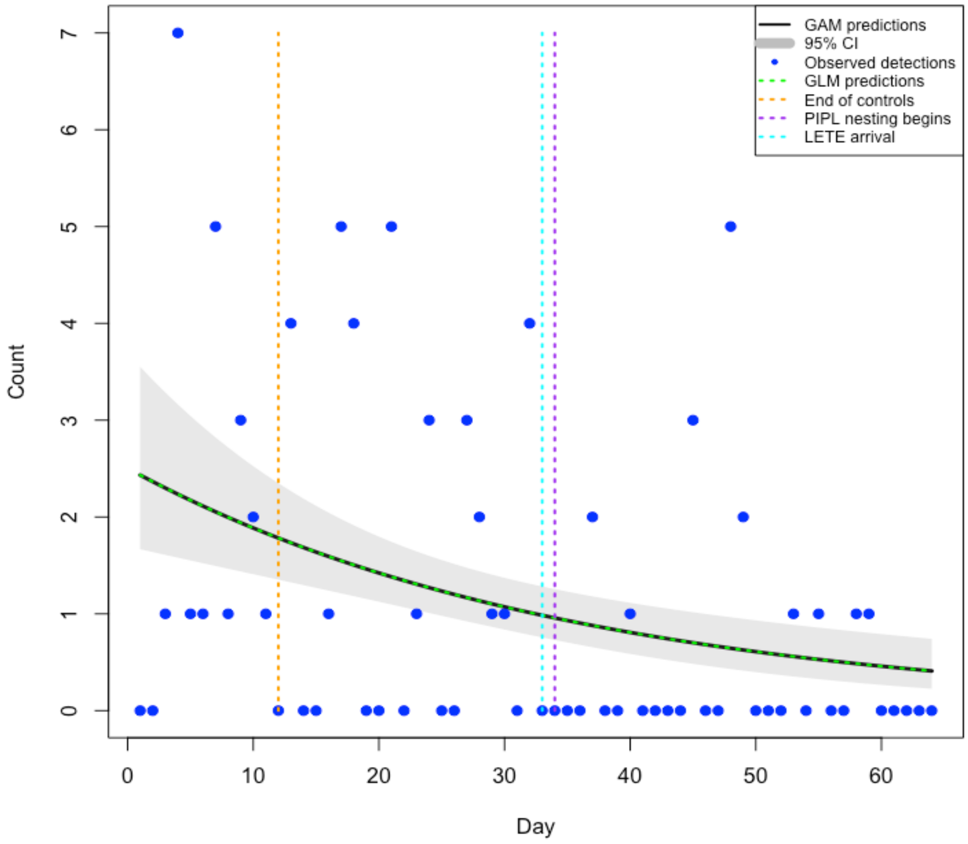

FIGURE 5 Daily variation in coyote detections (blue points) at control points and scent stations at Ninigret, Rhode Island from 8 April (day 0) to 10 June (day 76) in 2022. Graph shows the most supported generalized linear model, GLM (green dotted line), which is the Day model (Table 6), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), and the arrival of least terns to the study area (aqua).

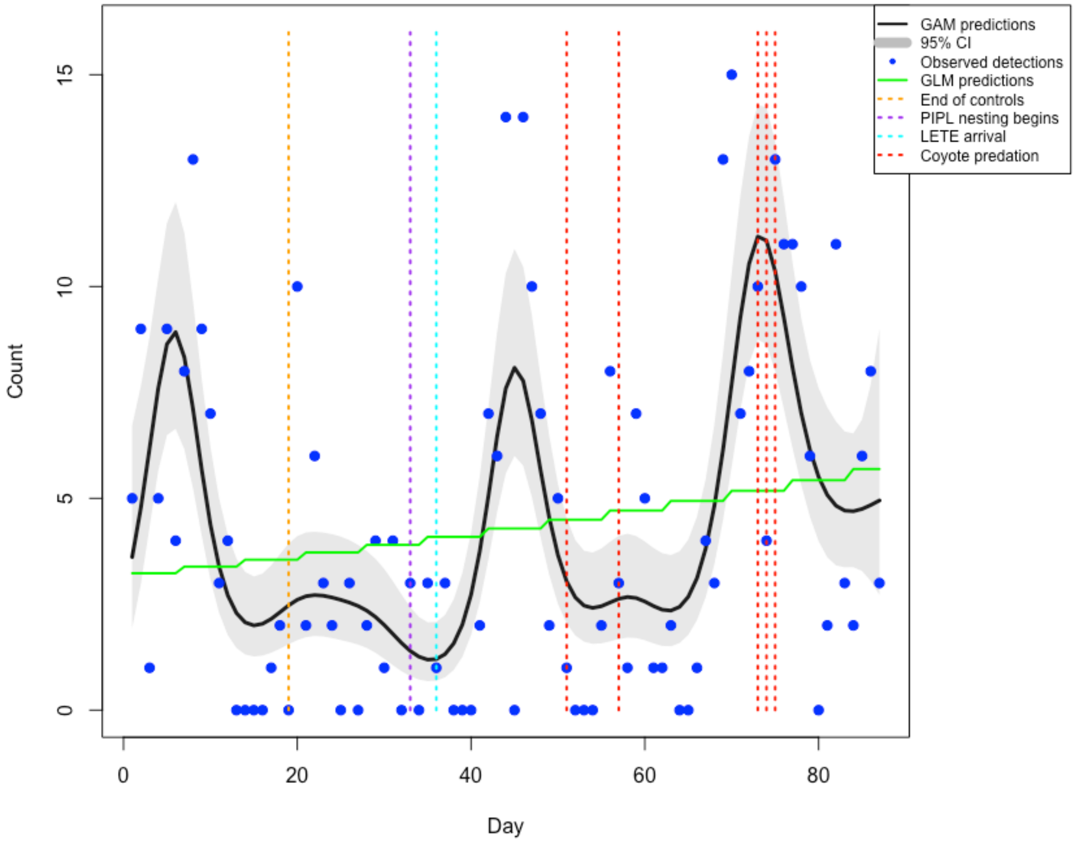

FIGURE 6 Daily variation in coyote detections (blue points) at control points and scent stations at Trustom, Rhode Island from 29 March (day 0) to 24 June (day 87) in 2023. Graph shows the most supported generalized linear model, GLM (green line), which is the Week model (Table 7), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), the arrival of least terns to the study area (aqua), and documented predations of piping plover nests by a coyote (red).

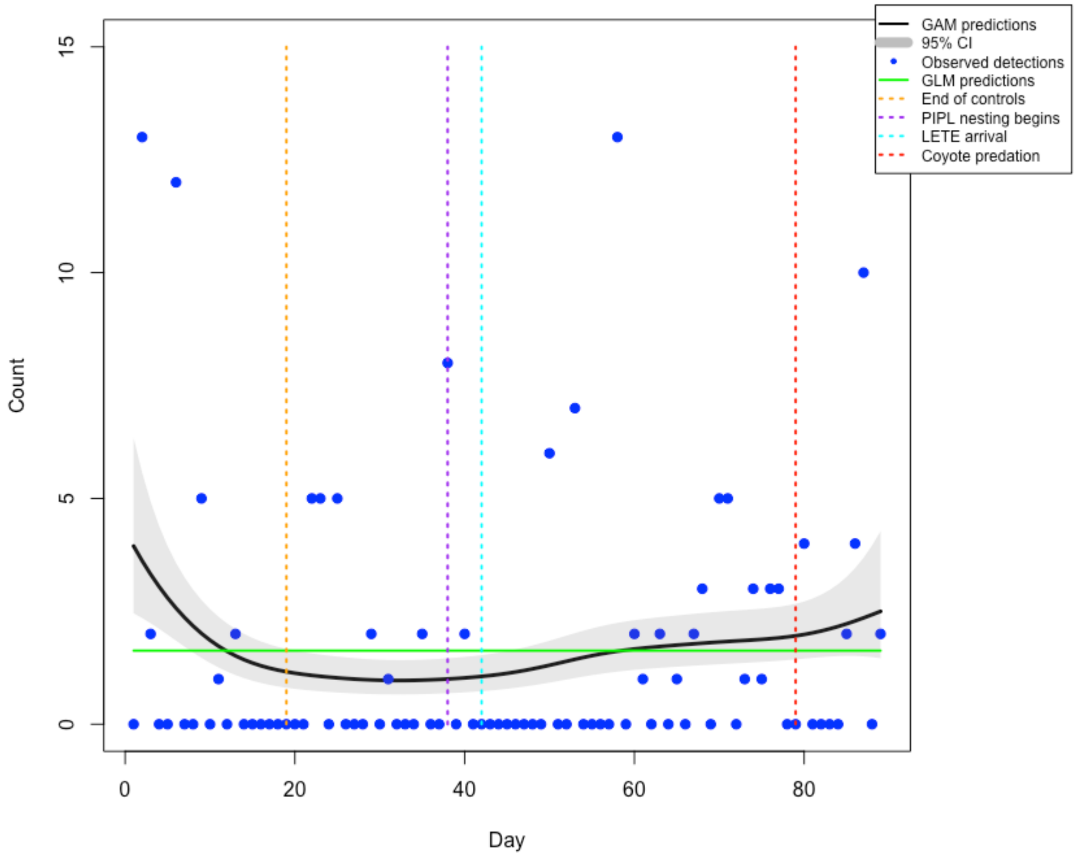

FIGURE 7 Daily variation in coyote detections (blue points) at control points and scent stations at Ninigret, Rhode Island from 29 March (day 0) to 24 June (day 87) in 2023. Graph shows the most supported generalized linear model, GLM (green line), which is the null model (Table 8), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), the arrival of least terns to the study area (aqua), and a documented predation of a piping plover nest by a coyote (red).

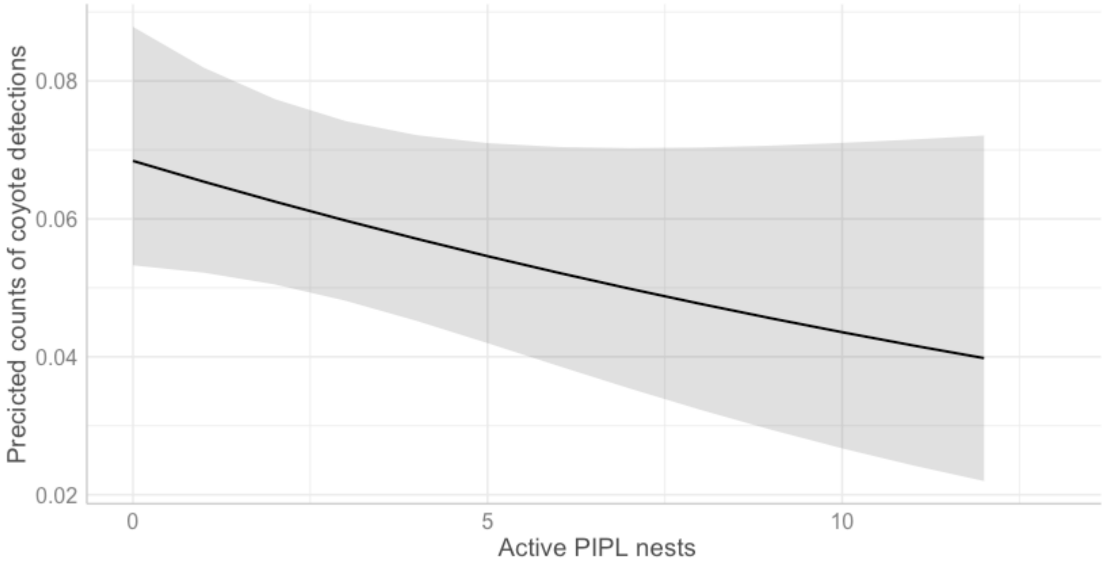

FIGURE 8 Predicted counts of coyote detections considering active piping plover (PIPL) nests at Trustom, Rhode Island in 2022. The shaded area indicates a 95% confidence interval with a negative-sloped prediction line (black line). Graph shows the most supported model, active nests (Table 9).

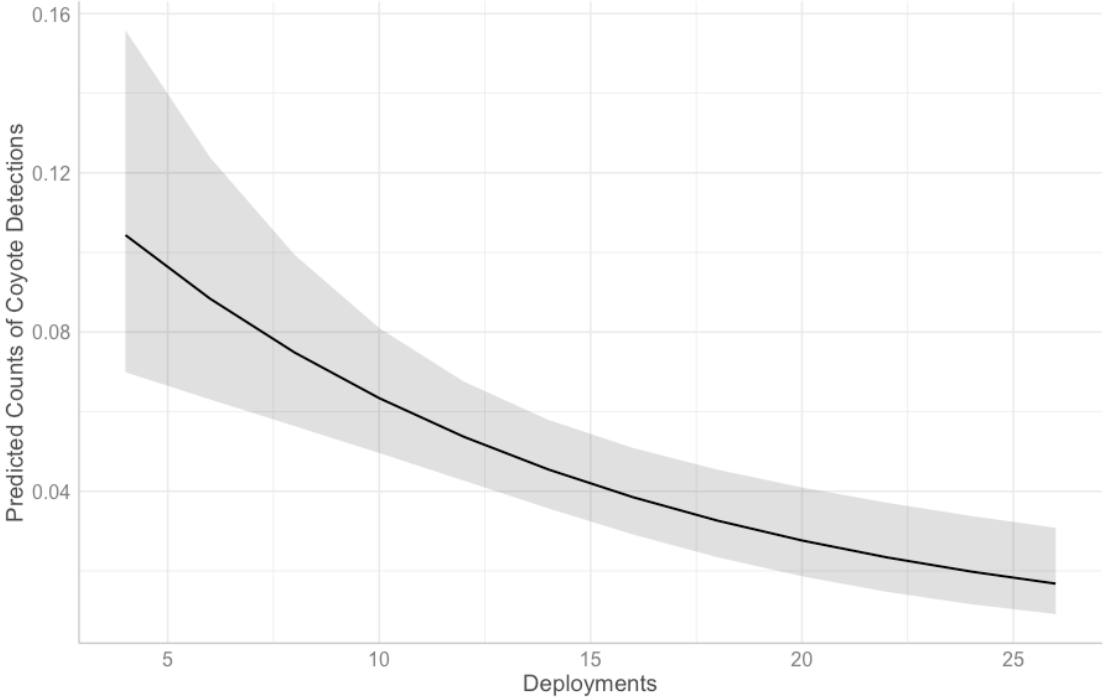

FIGURE 9 Predicted counts of coyote detections at Ninigret, Rhode Island in 2022. Deployment periods are in 3-day intervals. The shaded area indicates a 95% confidence interval with a negative-sloped prediction line (black line). This graph displays the most supported model, deployments (Table 10).

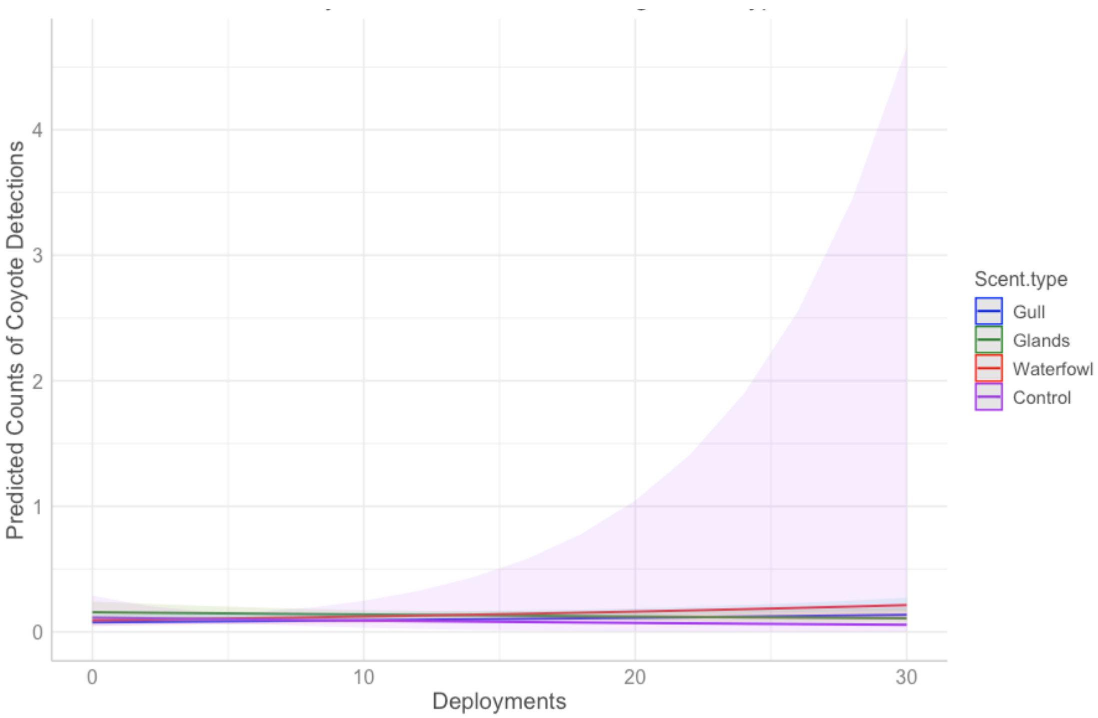

FIGURE 10 Seasonal variation in predicted counts of coyote detections interacting with different scent types at Trustom, Rhode Island in 2023. Scent types included controls (purple line), gull (blue line), uropygial glands (blue line), and waterfowl (red line). The colored shaded areas represent a 95% confidence interval. This represents the most supported model, deployments * scent types (Table 7).

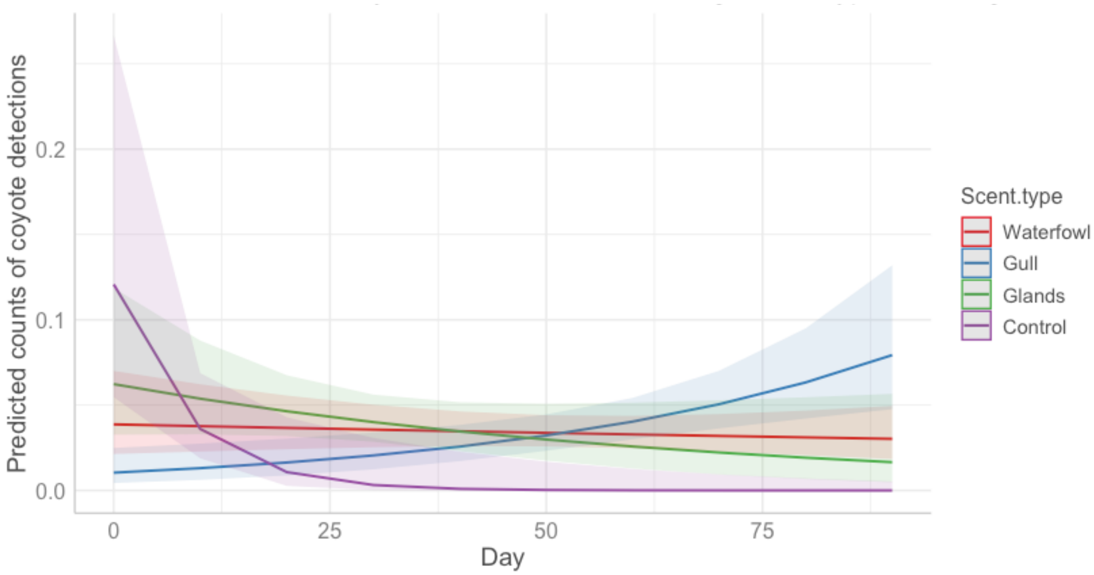

FIGURE 11 Seasonal variation in predicted counts of coyote detections interacting with different scent types at Ninigret, Rhode Island in 2023. Scent types included gull (blue line), uropygial glands (blue line), waterfowl (red line), and control (purple line). This represents the most supported model, day * scent type (Table 12).

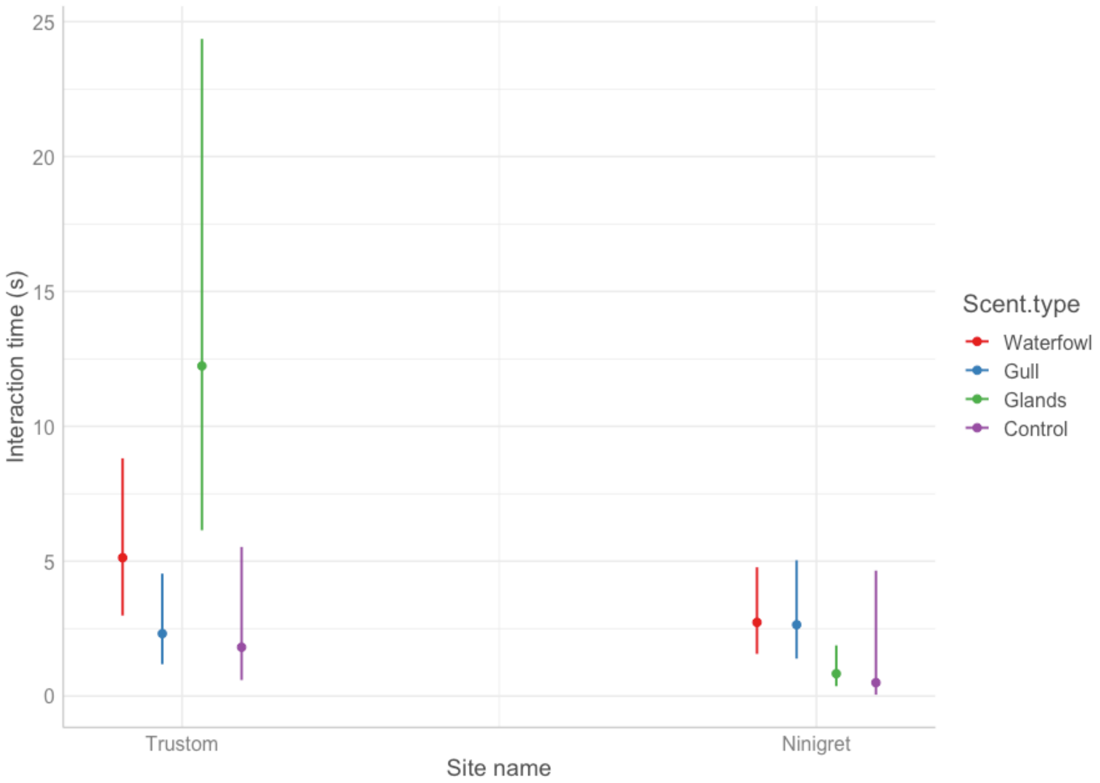

FIGURE 12 Predicted interaction time (seconds) that a coyote spent at a scent station for four scent types at site Trustom (left panel) and Ninigret (right panel) in 2022. Scents are waterfowl (red), gull (blue), uropygial glands (green), and control (purple). This represents the most supported model scent type * site (see Table 13).

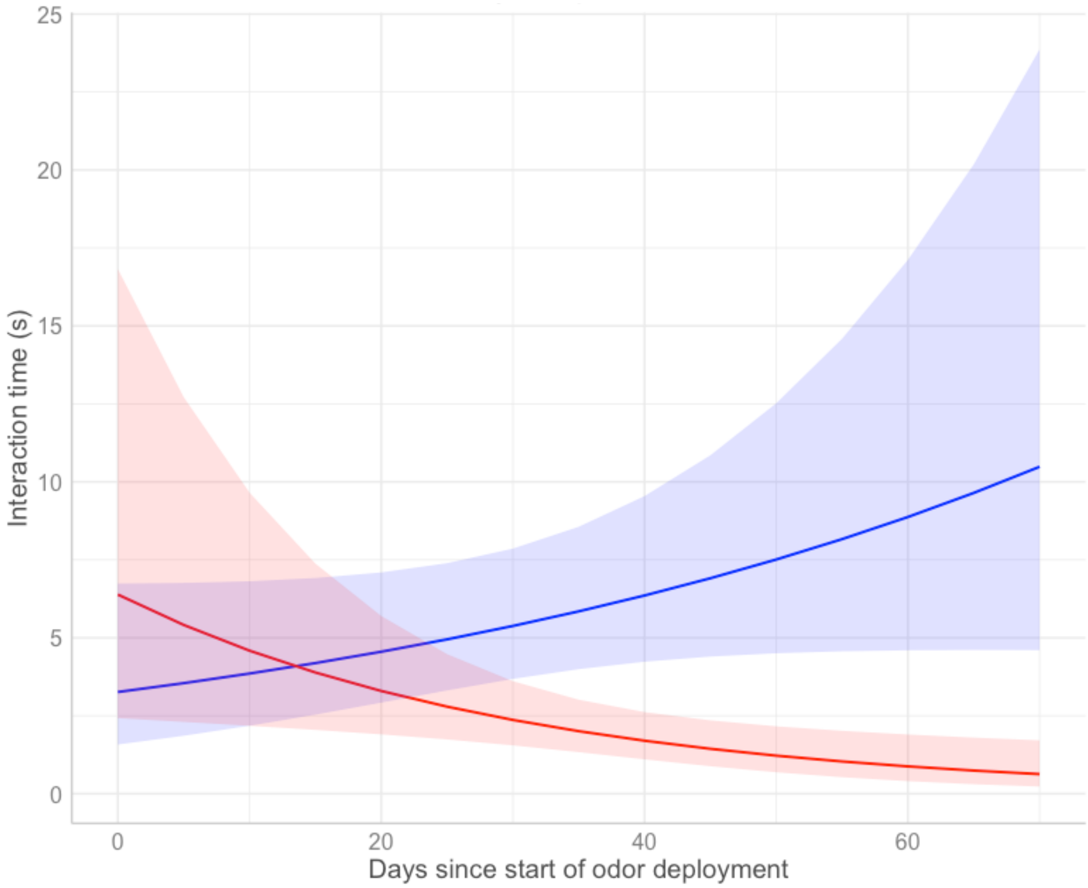

FIGURE 13 Predicted interaction time (seconds) that a coyote spent at a scent station at Ninigret (red line and 95% confidence interval area) and Trustom (blue line and 95% confidence interval area) in 2022.

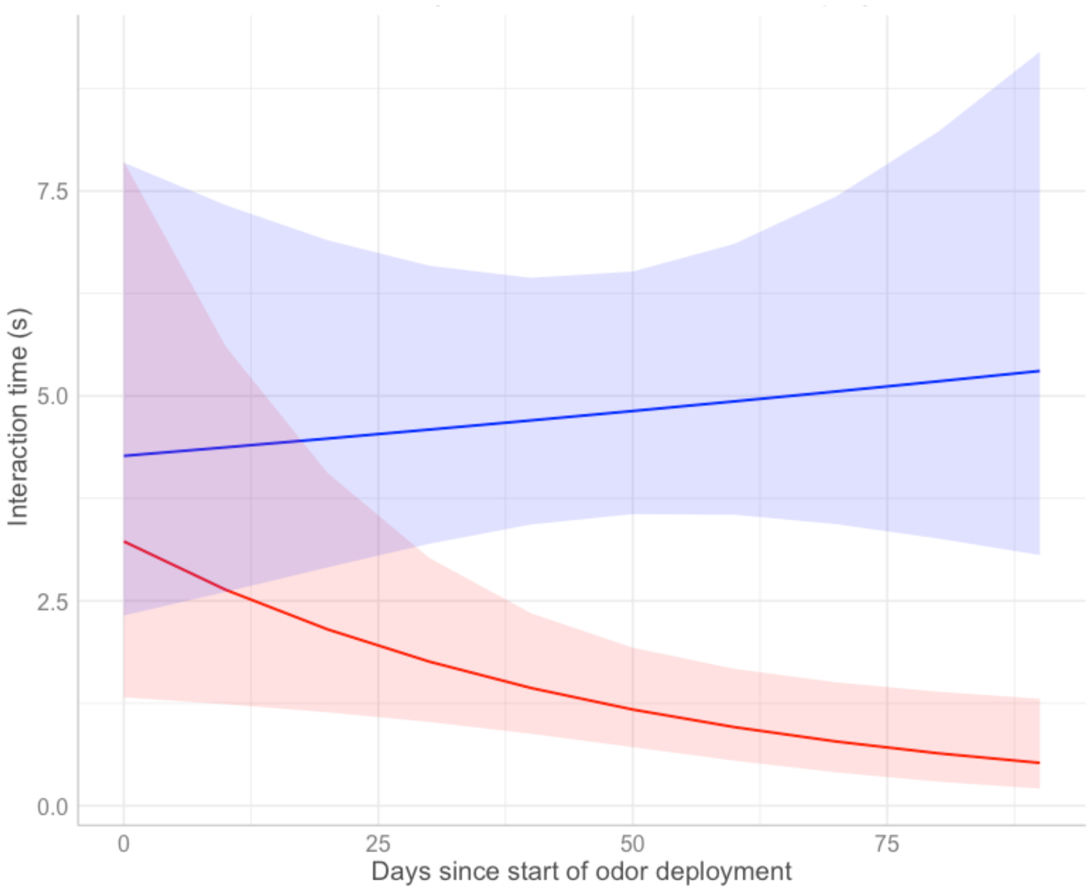

FIGURE 14 Predicted interaction time (seconds) that a coyote spent at a scent station at Ninigret (red line and 95% confidence interval area) and Trustom (blue line and 95% confidence interval area) in 2023.

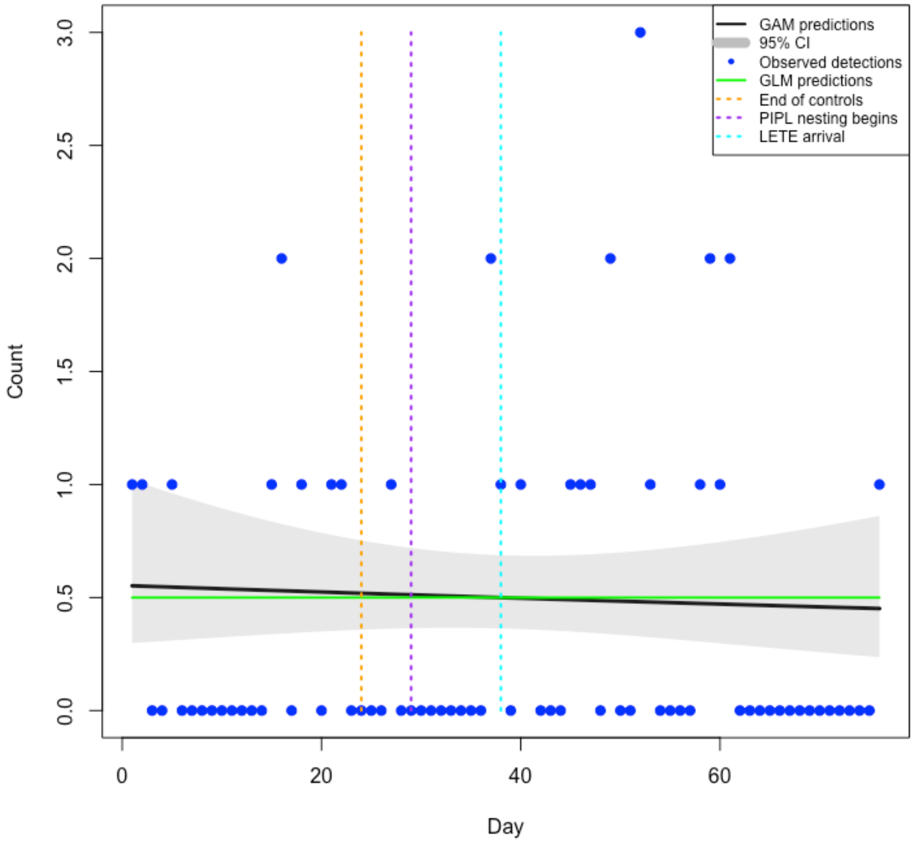

FIGURE 15 Daily variation in red fox detections (blue points) at control points and scent stations at Trustom, Rhode Island from 27 March (day 0) to 10 June (day 76) in 2022. Graph shows the most supported generalized linear model, GLM (green line), which is the null model (Table 15), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), and the arrival of least terns to the study area (aqua).

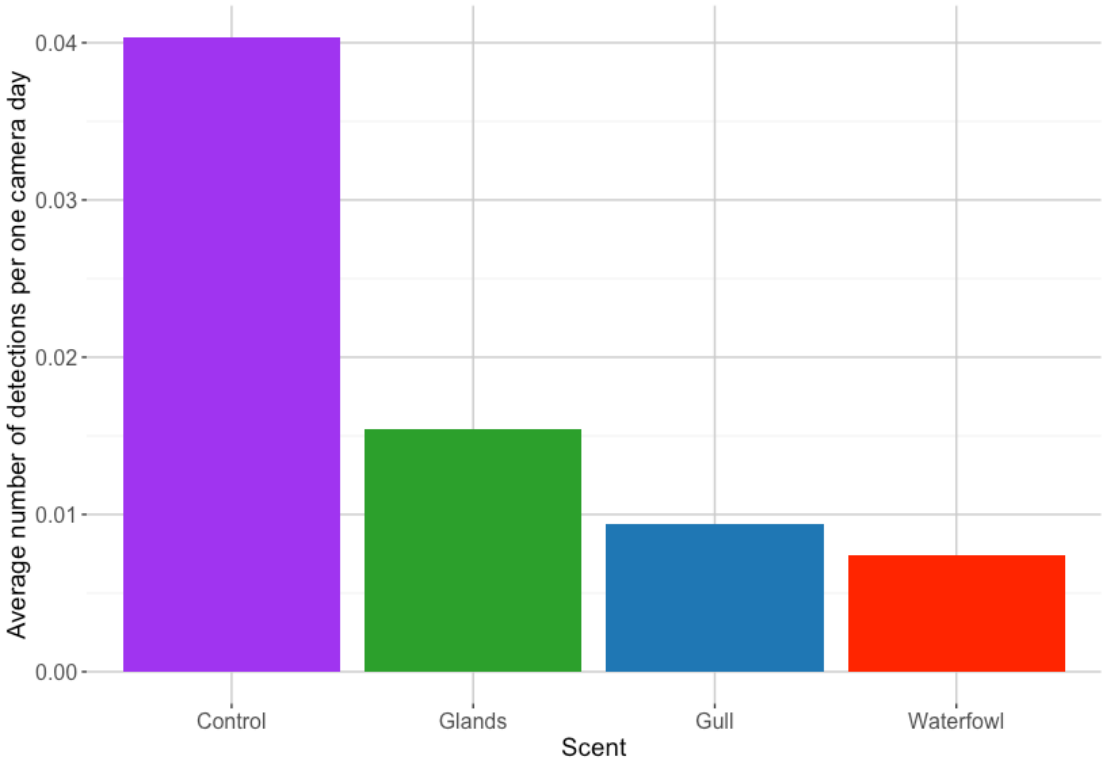

FIGURE 16 Variation among four scent types in the mean number of daily detections by red fox at scent stations at Trustom in 2022; Control (purple), uropygial glands (green), gull (blue), and waterfowl (red). This represents the most supported model, scent type (Table 16).

FIGURE 17 Predicted interaction time (seconds) that a red fox spent at a scent station for four scent types at Trustom in 2022. Scent types were waterfowl (red line), uropygial glands (green line), control (purple line), and gull (blue line). The shaded areas correspond with the line colors of each scent type and represent a 95% confidence interval. Represents the most supported model, scent type + day (Table 17).

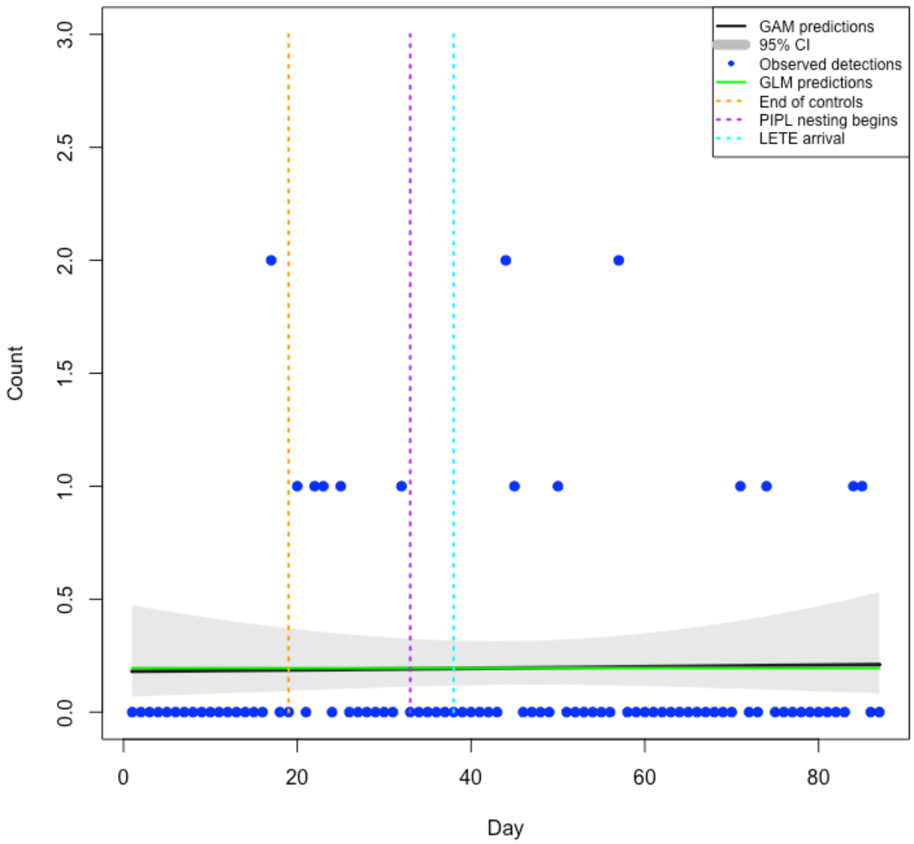

FIGURE 18 Daily variation in opossum detections (blue points) at control points and scent stations at Trustom, Rhode Island from 29 March (day 0) to 24 June (day 87) in 2023. Graph shows the most supported generalized linear model, GLM (green line), which is the null model (Table 18), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), and the arrival of least terns to the study area (aqua).

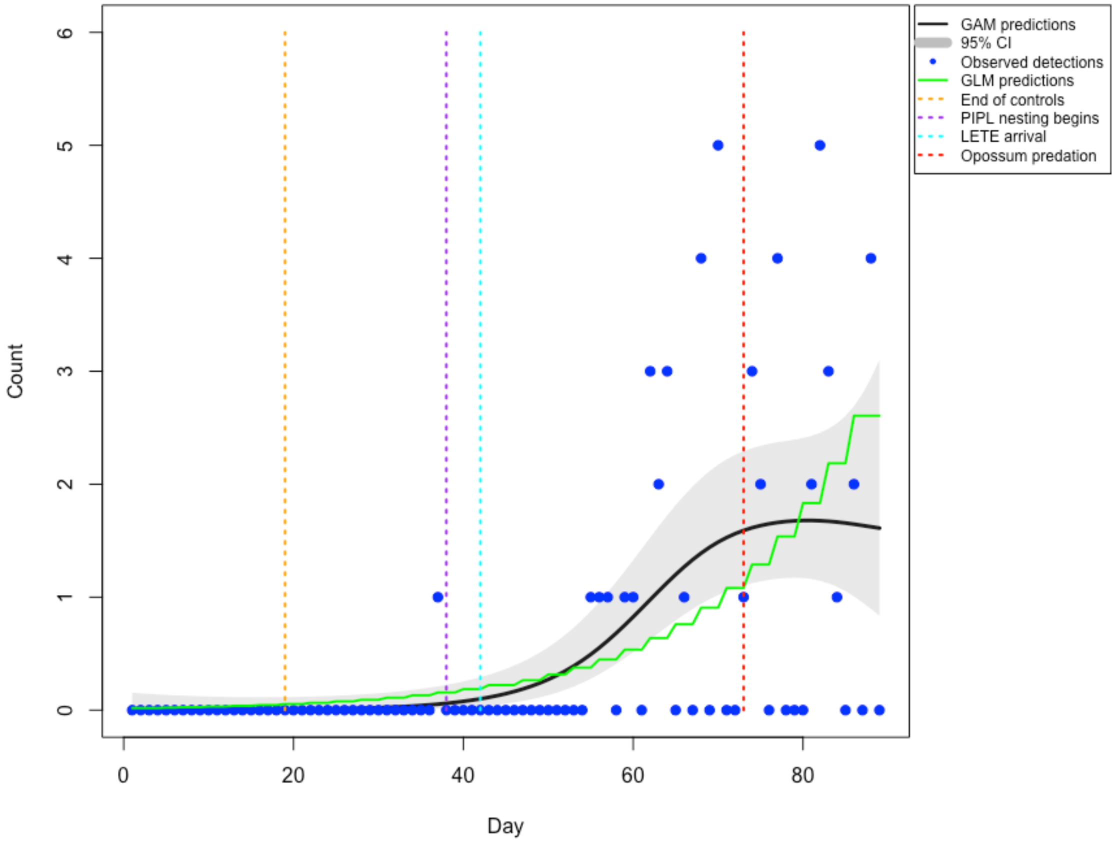

FIGURE 19 Daily variation in opossum detections (blue points) at control points and scent stations at Ninigret, Rhode Island from 29 March (day 0) to 24 June (day 87) in 2023. Graph shows the most supported generalized linear model, GLM (green line), which is the Deployments model (Table 19), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), the arrival of least terns to the study area (aqua), and a documented predation of a piping plover nest by an opossum (red).

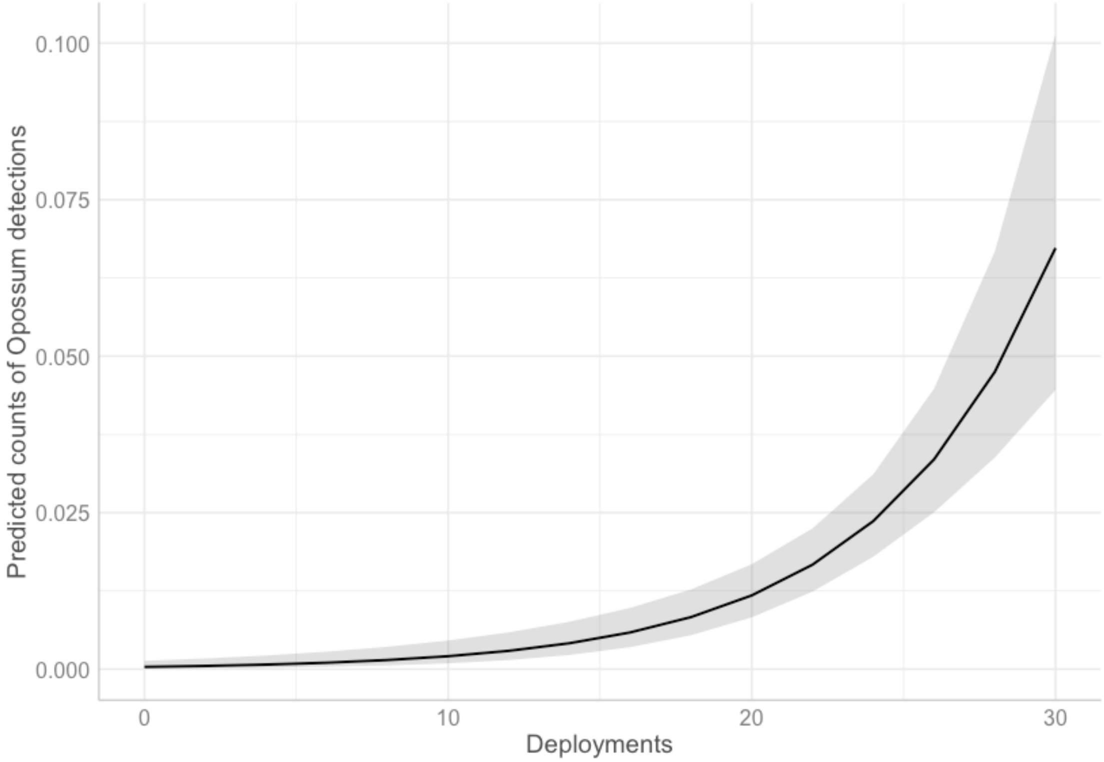

FIGURE 20 Predicted counts of opossum detections at Ninigret, Rhode Island in 2023. The gray- shaded area indicates a 95% confidence interval with a prediction line (black line). This graph displays the second most supported model, Deployments (see Table 21).

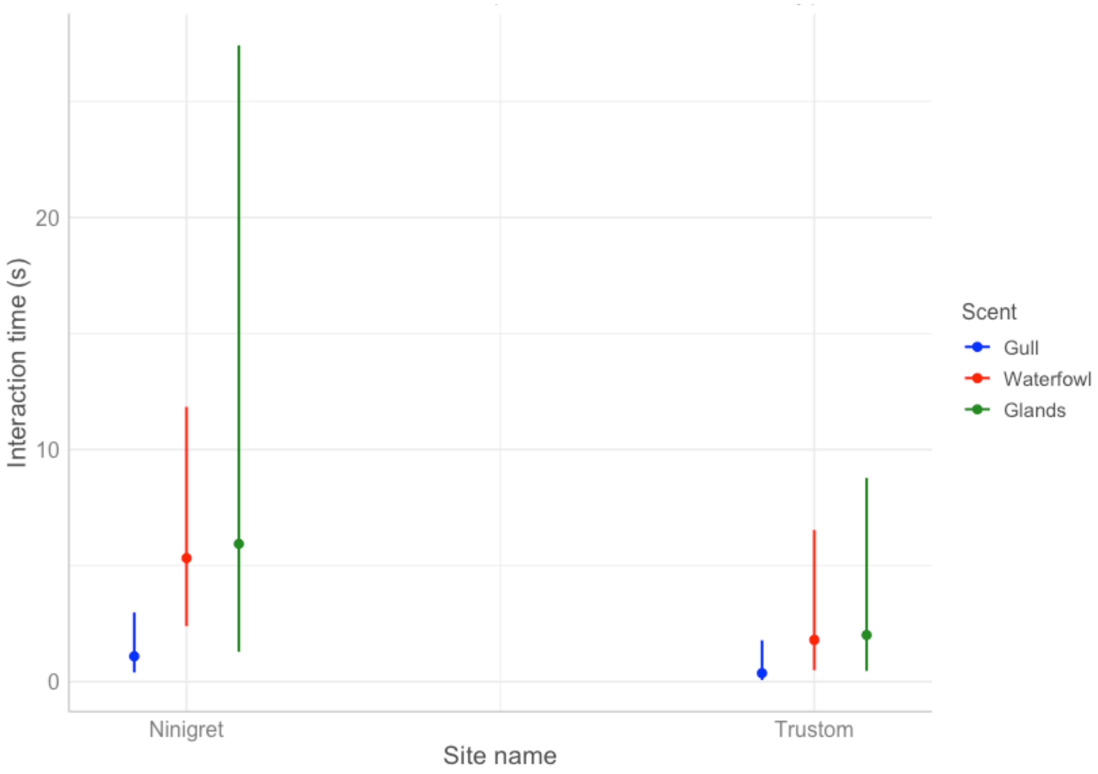

FIGURE 21 Predicted interaction time (seconds) that an opossum spent at a scent station for four scent types at site Ninigret (left panel) and Trustom (right panel) in 2023. Scents are gull (blue), waterfowl (red), and uropygial glands (green).

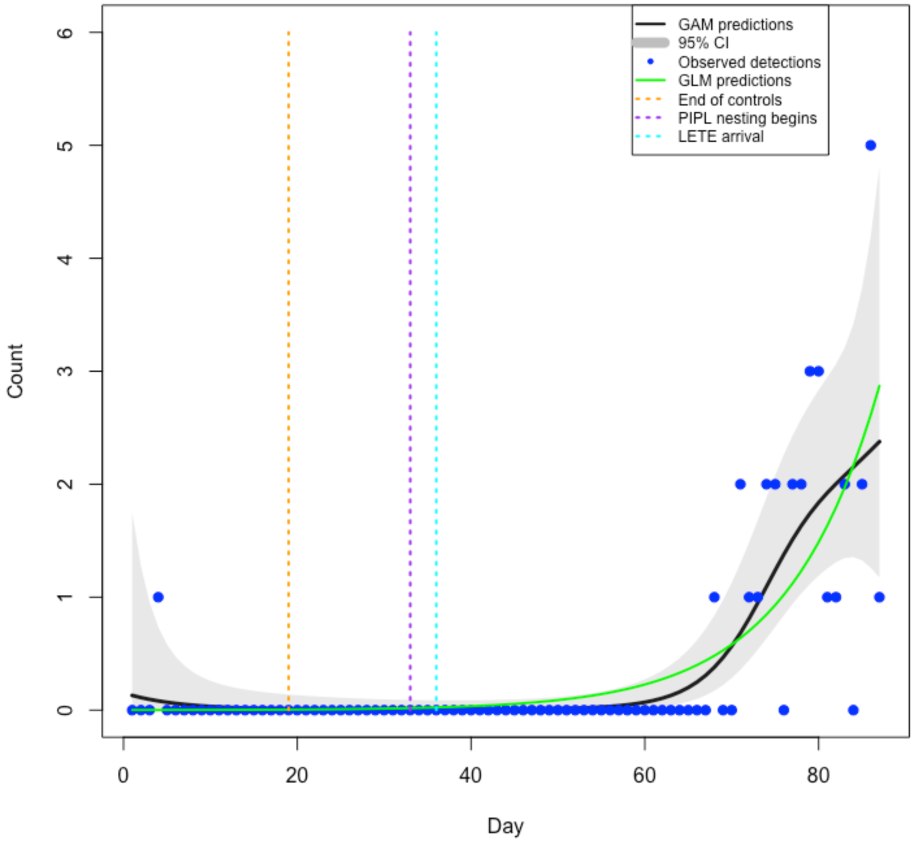

FIGURE 22 Daily variation in skunk detections (blue points) at control points and scent stations at Trustom, Rhode Island from 29 March (day 0) to 24 June (day 87) in 2023. Graph shows the most supported generalized linear model, GLM (green line), which is the null model (Table 23), and a 95% confidence interval (gray shaded region) which is derived from a generalized additive model, GAM (solid black line). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), and the arrival of least terns to the study area (aqua).

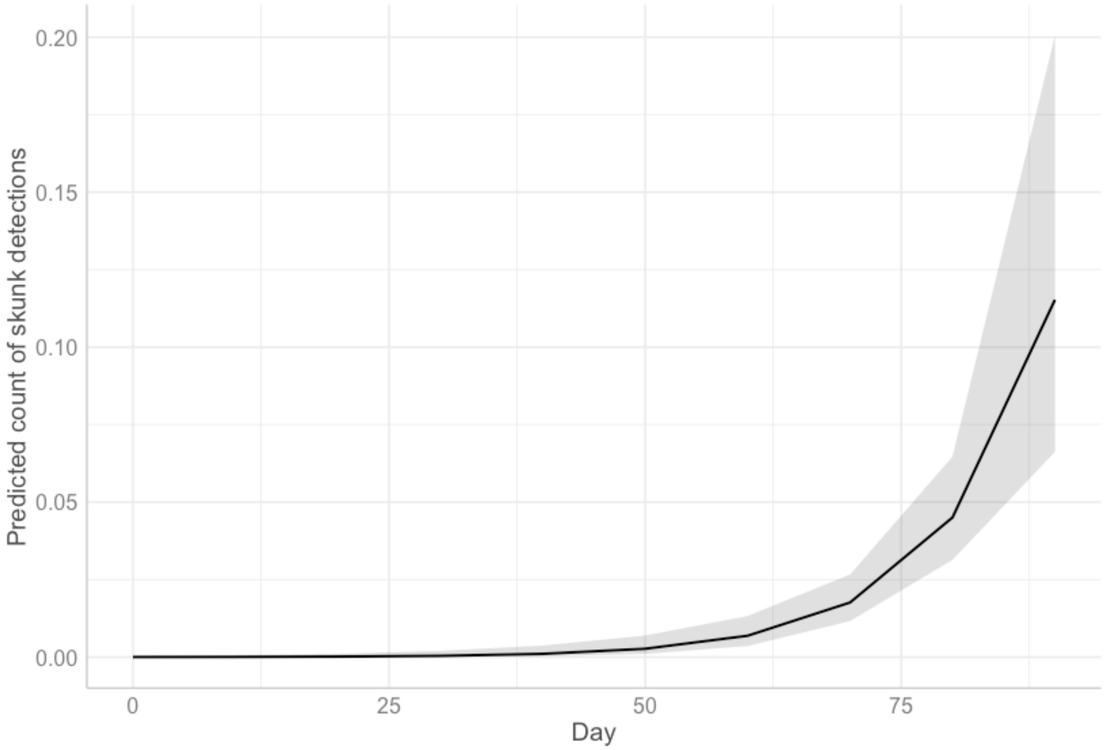

FIGURE 23 Predicted counts of skunk detections at Trustom, Rhode Island in 2023. The gray- shaded area indicates a 95% confidence interval with a prediction line (black line). This graph displays the second most supported model, Day (Table 24).

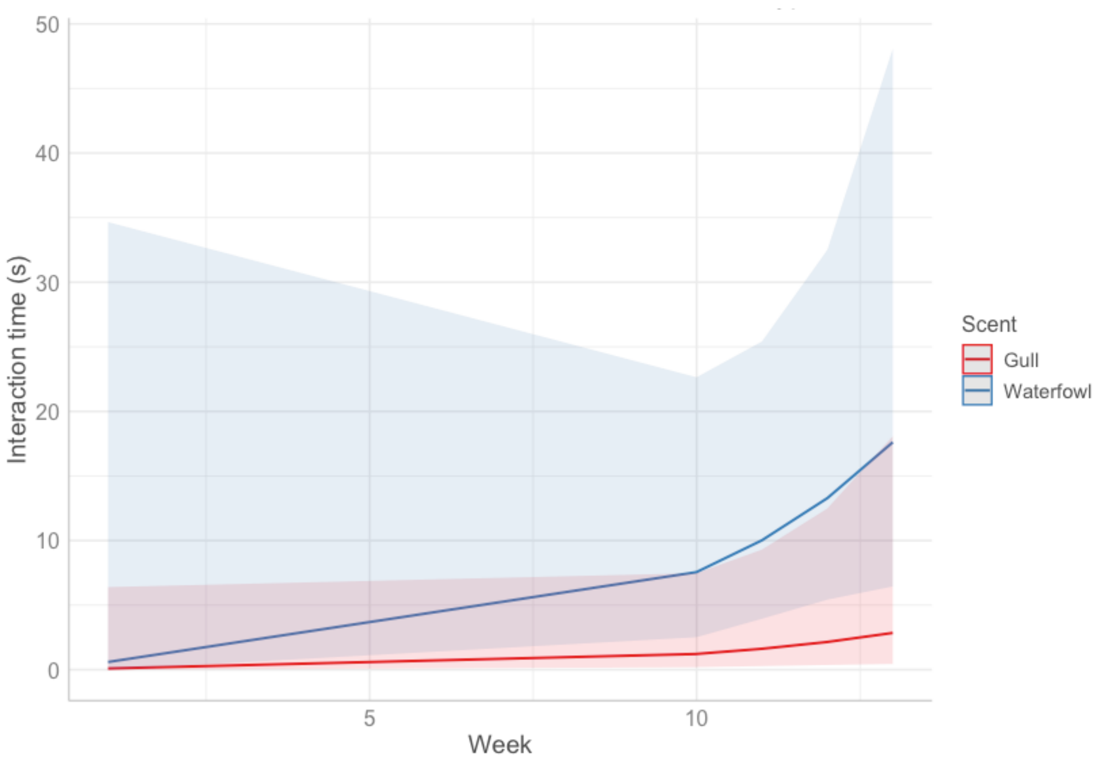

FIGURE 24 Predicted interaction time (seconds) that a skunk spent at a scent station for four scent types at Trustom in 2023. Scent types were waterfowl (blue line), and gull (red line). The shaded areas correspond with the line colors of each scent type and represent a 95% confidence interval. This rsepresents the most supported model scent type + week (Table 25).

APPENDIX 1

Bird Odor Methods

Bird Collection

I extracted bird scents from bird species that are typically found occupying southern Rhode Island coastal areas (Table 1). Preening glands were removed from the carcass by a local taxidermist and were left whole. I obtained the gull carcasses from a wildlife rehabilitation clinic in Rhode Island and the duck carcasses and waterfowl glands were donated by hunters. All carcasses I processed were freshly killed and frozen promptly until needed. I thawed bird carcasses for 12-24 hours prior to the soaking process.

Soaking process

Following Norbury et al. (2021), I submerged thawed bird carcasses in a 1:1 solvent mixture of acetone and dichloromethane manufactured by Honeywell and > 99.5% pure alcohol. I used approximately four liters of solvents per batch (two liters of each solvent), or enough liquid to completely submerge the birds. I soaked carcasses overnight for 12-16 hours in a sealed five-gallon high density polyurethane (solvent-proof) bucket under a fume hood. After the soaking period, I removed the bird carcasses from the solvent mixture and squeezed them until most of liquid dripped off. Throughout the extraction process with solvents, I wore at least 10 mil thick butyl gloves or "Silver Shield" gloves. I then poured the solvent mixture through 18.5 cm diameter filter paper (pore size 25.0 um) to strain out any particles such as feathers. Once filtered, the solvent mixture had a relatively clear appearance, although it did have a color tint.

Rotary evaporation process

I used a Buchi R-Rotavapor system for the rotary evaporation process. The submersible centrifugal pump (115V AC, 7 ft Max Head, ¼ in Intake and Disch), which feeds into the evaporator, sat in an ice bath that was continuously replenished. There was enough water in the ice bath for the pump to intake water. I poured the filtered solvent mixture into a one-liter sized round bottom flask, which was only filled halfway so the solvent did not get sucked up into the rotary evaporator from the vacuum seal. The vacuum utilized was a 115 VAC 60 Hz 3.3 A. The evaporator was set at a mild vacuum with the round flask in a water bath of 40-42 °C (104-107.6 °F). I set the rotation speed of the flask to a three out of nine at a medium speed. Usually, it was important to keep the flask spinning to prevent the solvent from bubbling up and getting drawn up into the rotary evaporator. If the bird-solvent mixture was sucked into the evaporator, I reduced the temperature of the water bath and/or the rotation speed of the flask. I evaporated the solvents until there was a thick brown/yellow colored liquid (bird concentrate) sticking to the sides of the flask. I re-used remaining evaporated solvents one to two times for another round of carcass soaking. I retained all the accumulated bird concentrate in the flask until all solvents were processed for the batch.

To remove the bird concentrate from the round bottom flask, I poured it into a glass beaker, making sure to record the weight of the empty beaker first. To ensure all bird concentrate was emptied into the beaker, I placed a small quantity of dichloromethane into the flask and swirled it around the flask to help remove all extra material from the flask walls. In addition, I placed the mixture under a fume hood and swirled it occasionally to evaporate off the added dichloromethane. I continued to circulate the mixture until it was a thick consistency and wafted the scent to my nose (note: I did not put my nose directly next to the dichloromethane) to ensure it smelled like bird and not solvent.

Each batch produced different amounts of bird concentrate. The gull carcasses (two to three gulls) typically made 4-5 g, duck carcasses (five to six ducks) created 20-25 g, and preening glands (36-70 glands) yielded 20-25 g. I reconstituted the bird concentrate with Vaseline on a hot plate at 80 °C, which was hot enough to bring it to a liquid state. I used a 40:60 ratio of bird concentrate to Vaseline (i.e., 0.4 g of bird to 0.6 g of Vaseline) to create the mixture placed in the field at scent stations. While still in a liquid state, I distributed the mixture into 1g/mL plastic syringes. I then stored the bird odor mixtures in a freezer until I used them, and assumed that odors could retain their odor properties for up to a year in the freezer.