




*Avian Conservation and Management*

# Odor swamping did not deter mammalian predators from depredating shorebird nests on beaches

## Inundación con olores no disuadió a mamíferos depredadores de depredar nidos de aves playeras en las playas

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**ABSTRACT.** Reducing the risk of declines to the threatened population of Piping Plovers (*Charadrius melodus*) along the Atlantic coast USA, is a priority for U.S. state and federal agencies. One of plover biologists' key management goals is to reduce nest predation rates. We evaluated a novel non-lethal technique to deter mammalian nest predators by deploying chemically extracted bird odors at scent stations on beaches where Piping Plovers nest. Our goal was to decrease mammalian predator's interest in plover nests by providing unrewarded bird odor at scent stations placed across the landscape. We conducted fieldwork at Trustom Pond National Wildlife Refuge (NWR) and Ninigret NWR and Conservation Area in Rhode Island, USA. The primary mammalian nest predators were coyote (*Canis latrans*), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), and Virginia opossum (*Didelphis virginianus*). From late March through early June (2022–2023), we applied the bird odors extracted from waterfowl and gulls on the beaches at scent stations every three days. We monitored scent stations with trail cameras to record the frequency of predator visits and length of time predators spent at scent stations. Overall, there was high interspecific and annual variation in the number of detections and the length of time mammalian predators spent at scent stations. Total site-level coyote detections declined during the study period at both sites in 2022, but not in 2023; no other species showed potential habituation to scent stations. Odors extracted from waterfowl were more effective in attracting predators, in particular those derived directly from uropygial glands. Overall, we did not document a decline in Piping Plover nest predation rates when we deployed scent stations compared to the two previous years at both sites. This non-lethal technique was not effective at deterring mammalian nest predators at beaches in Rhode Island, USA.

**RESUMEN.** Reducir el riesgo de disminución en la población amenazada del Chorlito Silvadador (*Charadrius melodus*) a lo largo de la costa Atlántica de Estados Unidos, es una prioridad para agencias estadounidenses estatales y federales. Una de las principales metas de manejo de biólogos de chorlitos es reducir las tasas de depredación de nidos. Aquí evaluamos una técnica novedosa no-lethal para disuadir a mamíferos depredadores de nidos, mediante el despliegue de olores extraídos químicamente en estaciones de olor en playas donde los Chorlitos Silvadadores anidan. Nuestra meta era disminuir el interés de mamíferos depredadores en los nidos de chorlitos, proporcionando olor aviar sin recompensa en estaciones de olor ubicadas en todo el paisaje. Realizamos el trabajo de campo en el Refugio Nacional de Vida Silvestre (RNV) Trustom Pond y en el RNV y Área de conservación Ninigret, en Rhode Island, Estados Unidos. Los mamíferos depredadores primarios fueron coyotes (*Canis latrans*), zorros rojos (*Vulpes vulpes*), zorrinos con bandas (*Mephitis mephitis*) y zarigüeyas de Virginia (*Didelphis virginianus*). Desde fines de Marzo hasta inicios de Junio (2022-2023), cada tres días aplicamos los olores extraídos de aves acuáticas y gaviotas en las playas en estaciones de olor. Monitoreamos las estaciones de olor con cámaras trampa para registrar la frecuencia de las visitas de depredadores y el tiempo que los depredadores pasaron en las estaciones de olor. En general, hubo una alta variación interespecifica y anual en el número de detecciones y el tiempo que los depredadores mamíferos pasaron en las estaciones de olor. El total de detecciones de coyotes a nivel de sitio, se redujo durante el periodo de estudio en ambos sitios en 2022, pero no en 2023; ninguna otra especie mostró una habituación potencial a las estaciones de olor. Los olores extraídos de aves acuáticas fueron más efectivos en atraer a depredadores, en particular aquellos directamente derivados de glándulas uropigiales. En general, no documentamos una reducción en las tasas de depredación de nidos del Chorlito Silvadador cuando desplegamos estaciones de olor en comparación con los dos años anteriores en ambos sitios. Esta técnica no-lethal no fue efectiva en disuadir a mamíferos depredadores de nidos en playas en Rhode Island, Estados Unidos.

**Key Words:** *conservation; mammals; Piping Plover; predation management; scent lures; shorebird*

### 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. Piping Plover populations declined because of habitat loss from coastline development and human disturbance (Hecht et al. 1996). Although considerable

achievements have been made since 1986 in addressing human disturbance and habitat degradation (e.g., via symbolic fencing, outreach, and regulatory mechanisms), managing nest predators remains a key management issue (Doherty and Heath 2011, Stringham and Robinson 2015, Stantial et al. 2021).

The Atlantic Flyway Shorebird Initiative highlighted predation as one of four primary anthropogenic threats to shorebird populations in the Atlantic flyway (Hunt et al. 2019). In addition to natural predation, most predators of breeding Piping Plovers

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are drawn to beach nesting habitats by human food subsidies, which requires active and costly management efforts to protect nests and chicks from predation (Hunt et al. 2019, Darrah et al. 2020, Stantial et al. 2021, Anteau et al. 2022, Robinson et al. 2024). Opportunistic predator species in coastal regions in New England, USA, 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 (Melvin et al. 1992, Cohen et al. 2009, Dueser et al. 2013, Johnson 2016). Coyotes (*Canis latrans*) historically did not occupy New England, but now occur widely throughout the region, including beaches used by nesting Piping Plovers, and are attracted by human subsidies (Foster et al. 2002). With increased predator presence on coastal beaches, vulnerable beach-nesting birds face increased predation pressure, thus there is a need to manage their impacts. Lethal predator control is a useful tool in many areas (Stringham and Robinson 2015, Robinson et al. 2024), however, lethal techniques are not feasible on many beaches (Darrah et al. 2020) because of ethical concerns of the public and landowners, lack of funding, staff limitations, and difficulty in implementing lethal methods (Perry and Perry 2008, Gieder 2015). In addition, removing focal predators such as coyotes can have unintended consequences, including mesopredator release, where mid-sized predator numbers increase and the nest success of ground-nesting birds decreases (Harrison et al. 1989, Crooks and Saulé 1999, Ritchie and Johnson 2009, Hunt et al. 2019, Stantial et al. 2021).

Non-lethal strategies are frequently used to manage predators of beach-nesting birds (Hunt et al. 2019). Plover biologists commonly use nest enclosures (Melvin et al. 1992), placing irritating substances in dummy eggs (Hoover and Conover 1998, 2000, Selonen et al. 2022), electric fencing (Mayer and Ryan 1991, Verhoeven et al. 2022), and habitat management (Cohen et al. 2009). Though enclosures 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 foxes can breach enclosures, which forces adult plovers off the nest, enabling the predators to capture plovers or consume their eggs (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 enclosures are not always suitable because of topography and vegetation structure (Murphy et al. 2003, Darrah et al. 2020). Chemical deterrents can be effective, although predators can learn to avoid these deterrents (Hoover and Conover 1998). Electric fencing can prevent predators from entering a localized nesting area, but fences cannot be used in high human-use areas and are difficult to maintain (Gautschi et al. 2024). With all these limitations, there is a pressing need to develop a reliable, cost-effective, alternative non-lethal method of predator management where lethal management is not practical or feasible.

Researchers in Australia and New Zealand developed a novel non-lethal scent-based method to deter mammalian predators from disturbing and preying on 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 bird scent from food. After predators learned that bird odors were not likely to result in a food “reward,” nest survival rates increased by

70% 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 avian scent cues, which could reduce nest depredation rates of ground nesting shorebirds in New Zealand.

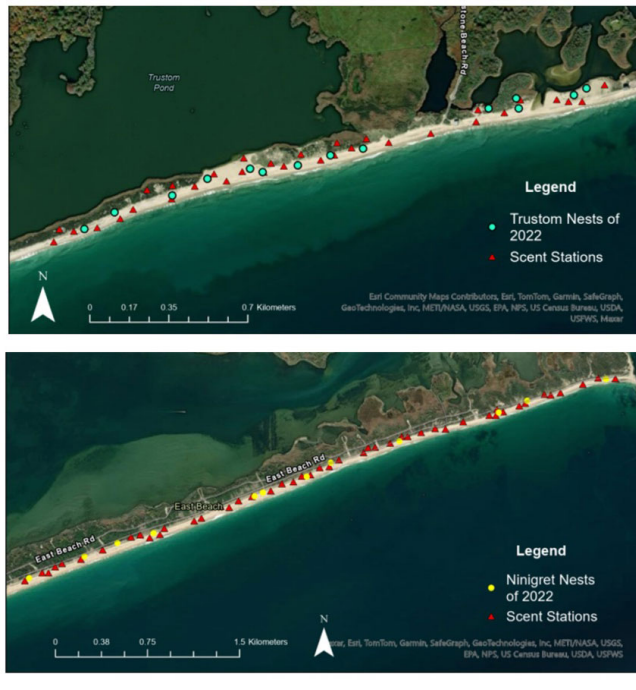
The goal of our study was to implement Norbury et al.’s (2021) non-lethal predator deterrent method on beaches with nesting Piping Plovers in New England within the Atlantic Flyway to evaluate whether mammalian predators are attracted to the scent lures and then become habituated to avian scents. Our objectives were to: (1) create scent lures using waterbird carcasses and uropygial glands in a lab, develop an odor preparation protocol, and deploy scent lure stations on Piping Plover nesting beaches, (2) document mammalian predator interactions with the scent lures using trail cameras to assess 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, (3) determine whether interactions with scents decreased over time, indicating that predators learned to ignore the scent, and (4) evaluate predator-caused nest failures in years prior to the initiation of this study compared to during the scent study. Evidence of conditioning would indicate that this method holds promise for changing predator behavior in response to bird odor. This method could have broad utility for a variety of stakeholders interested in the management of ground-nesting birds vulnerable to mammalian nest predation.

## METHODS

### Study sites

We conducted fieldwork at Trustom Pond National Wildlife Refuge (NWR) in South Kingstown, and Ninigret Conservation Area and Ninigret NWR in Charlestown, Rhode Island, USA (Fig. 1). We selected these sites because over the last 10 years, both had at least 10 pairs of nesting plovers and high nest predation rates (at least 50% of the nests were predated annually) by mammalian predators (USFWS, *unpublished data*). Both study sites were protected barrier beaches located on the southern Rhode Island coast and approximately 8 km away from each other. The beaches were 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). The beach face at Trustom is dominated by a mixed sand and cobble intertidal zone, while Ninigret is composed primarily of sand. Both sites have vegetated dunes comprising American beachgrass (*Ammophila breviligulata*), beach rose (*Rosa rugosa*), beach pea (*Lathyrus japonicus*), and northern bayberry (*Myrica pensylvanica*). The beach at Trustom is closed to public access landward of the mean high tide line starting 1 April for the Piping Plover nesting season. Ninigret had an off-road sand trail situated behind the dunes parallel with the beach. This road allowed the public access to the entire beach throughout the year. Piping Plover nesting areas were roped off with symbolic fencing by United States Fish and Wildlife Service (USFWS) staff and volunteers on the upper beach into the dunes from early April through mid-August.

**Fig. 1.** Map of Trustom Pond National Wildlife Refuge (top) and Ninigret National Wildlife Refuge/Conservation Area (bottom), Charlestown, Rhode Island showing Piping Plover (*Charadrius melodus*) nests in 2022 (aqua and yellow dots) and scent stations (red triangles).



### Odor deployments and camera sampling

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 whole carcasses of gulls (Herring Gull [*Larus argentatus*] and Great Black-backed Gull [*Larus marinus*]; hereafter gull) and waterfowl (Anseriformes; hereafter waterfowl) that contained intact uropygial glands, and from only the uropygial glands of waterfowl that was prepared separately (hereafter glands). Whole gull carcasses were donated by a wildlife rehabilitation center and whole waterfowl carcasses and uropygial glands were donated by local hunters. We mixed multiple bird species into each scent batch (Table A1.1). Each odor batch produced different amounts of bird concentrate: 2 to 3 gull carcasses typically produced 4–5 g of concentrate, 5 to 6 waterfowl carcasses produced 20–25 g, and 36–70 uropygial glands produced 20–25 g. The extracted bird scent contained 40% bird concentrate and 60% Vaseline to ensure the scent was strong and able to adhere to surfaces amid weather events such as rain and wind.

We established 33 scent stations at Trustom and 48 stations at Ninigret (Fig. 1, A2). Each scent station included a trail camera placed 3 m from a small rock, where we deployed 0.10 ml of bird scent concentrate with nitrile-gloved hands. We placed scent stations 40 m apart to ensure the scent was evenly dispersed across each study site. Predators utilize the beach face and the back of

the dunes (Johnson 2016, Kimber et al. 2020, Stantial et al. 2020), so the scent stations were placed in both areas. Because of the limited availability of trail cameras in 2022, we placed cameras at 13 of the 33 scent stations at Trustom, and 19 of the 48 stations at Ninigret on any given day. 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 but omitted two of the 48 existing scent stations at Ninigret because of site erosion.

We deployed odors at three-day intervals (hereafter deployments) starting one month before Piping Plovers initiated clutches and ceased deployments two months post egg-laying (based on nesting chronology in 2021, USFWS’ unpublished data). We deployed controls (Vaseline without bird odor and only cameras) at 25% of the stations (five to six scent stations) for the first four weeks of each study period, along with bird odors at all other scent stations. 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. 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 (Table A2.1). We increased the length of odor deployments by 2.5 weeks in 2023 to expose predators to bird odors for more time at the end of the breeding season.

We used three camera models (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 visited scent stations. All camera models were infrared capable with 24-hour recording. To reduce theft, 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 take three photos per trigger (one second) to capture behavior of the predator as it interacted with the scent. We categorized each detection as a continuous sequence of photos showing the same individual exhibiting the same behavioral response to the scent station. We changed the camera batteries in the field as needed. To categorize and identify predators in the photos, we used the photo identification program, Camelot (Hendry and Mann 2018). We only considered species detections when a predator was within a body length of the scented rock, indicating a potential interaction with the scent. Following Norbury et al. (2021), we classified photographs as independent detections when they were at least five minutes apart. Last, we recorded five mammalian behaviors in relationship to the scent station (e.g., walking past, sniffing scent marking, licking, or rubbing).

### Piping Plover monitoring

Throughout the breeding season (March to late August), USFWS staff monitored breeding Piping Plovers at Trustom and Ninigret. Technicians searched all potential nesting areas at both sites for evidence of possible breeding activity by surveying habitat on foot and identifying any breeding behaviors such as false-sitting, figure-eight flying, broken wing displays, vocalizations, and visual evidence such as tracks or scrapes (Cairns 1982). For any nests found, we installed a trail camera to identify any potential nest predators. Technicians checked nests every one to three days until



hatching or nest failure. Technicians recorded nest locations with a tablet (accuracy  $\pm 3$ m) and nest status (i.e., number of eggs, number of chicks) using the software Survey123 (<https://www.esri.com/en-us/arcgis/products/arcgis-field-maps/overview>). We categorized nest fates as successful, abandoned, flooded, avian predation, mammalian predation, unknown predation, and unknown cause of failure. We classified unknown predators when we could attribute the nest failure to an animal without sufficient evidence to identify the specific predator (nest was lost prior to the expect hatch date, or broken eggshells were detected in the nest, but there were no fresh tracks making it impossible to identify the specific predator). We classified unknown causes of failure when eggs were absent prior to the expected hatching date and there was no evidence of the species of predator (e.g., tracks). Once a nest hatched, technicians monitored the number of chicks present until they fledged, which occurred approximately 25 days after hatching. 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 reduce the potential that the scent station would attract predators to active nests. To assess nest failure rates before and during this study, we summarize nest fates for 2020–2023.

#### **Predator analyses**

We conducted analyses on species that are known predators of Piping Plover nests in New England (Melvin et al. 1992; *personal observation*) and had more than 15 detections in one sampling season and site (i.e., coyote, red fox, opossum, and striped skunk). We conducted two types of analyses separately for each species of predator; first, we considered the count, or number of instances a predator was independently detected at a scent station, and second, we considered interaction time, or the amount of time a predator spent investigating the scent.

For both analyses, we used the R statistical programming language (R Core Team 2023) to summarize, plot, and analyze the camera data. The R-packages we used were ggplot2 (Wickham 2016), ggeffects (Lüdtke 2018), tidyverse (Wickham et al. 2019), dplyr (Wickham et al. 2023), AICcmodavg (Mazerolle 2023), and mgcv (Wood 2011). Throughout, we used a Type 1 error rate of 0.05 to determine statistical clarity (i.e., reject the null hypothesis).

#### *Detection analysis*

We analyzed predator detections at two spatial scales. Site-level analyses pooled all independent detections from scent stations within each of the two study sites to analyze 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 to understand whether detections increased or decreased over the period of interest. Further, we did a 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 fit a single linear trend model using “day” as the temporal covariate for each site and species. We also fit a Generalized Additive Model (GAM) to consider non-linear changes from the effect of “day” on predator detections (Guisan et al. 2002); default thin plate spline regression smoothing (Wood 2011) was used.

For the camera-level analyses, we fit GLMs with one or more spatial or temporal covariates to explain the variation in predator detections; we considered both interactions and additive combinations of variables, where relevant. Covariates included scent types (i.e., control, gull, waterfowl, glands), the presence of active plover nests anywhere on the beach (active nests), and different time periods (daily, deployment 3-d intervals, weekly). For all models including scent types, the intercept represented the control. We compared models for each species using Akaike Information Criterion (AIC) and selected the model with the lowest AIC value (i.e., highest AIC weight [ $w$ ]) as the model that was most supported (Aho et al. 2014).

#### *Interaction time analysis*

For a sequence of photos of a predator examining the scent (or within a body-length of the scent), we calculated time, in seconds, from the first to last photo of an individual exhibiting the same behavior. If the individual was absent from the photos for  $> 5$  seconds, we stopped the interaction time. We fit these data using the GLM framework with a Gamma distribution. We considered combinations of variables in different models as additive or interacting; variables considered were 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**

We detected 11 mammalian species at the scent stations (Table A2.2). In 2022, Trustom had 148 mammal predator detections at scent stations and Ninigret had 92 detections. In 2023, detections increased, likely due to a higher sampling effort, with 484 detections at Trustom and 286 detections at Ninigret (Table A2.2).

#### **Piping Plover nest predation**

Overall, Piping Plover nest failure rates were similar between the two years prior to the initiation of this study: 54% and 58% in 2020 and 2021, respectively. During this study, overall nest failure rates were 50% in 2022 and 72% in 2023 (Table 1). We attributed 21% of nest failures ( $n = 14$ ) to mammalian predators in 2022 and 24% in 2023 ( $n = 21$ ) while unknown predators or unknown causes accounted for 57% of nest failures in 2022 and 24% in 2023. We documented eight predation events at Piping Plover nests by mammalian predators: 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. Nest predation rates by Fish Crow were low in 2022 (14% of nest failures) and higher in 2023 (47% in 2023).

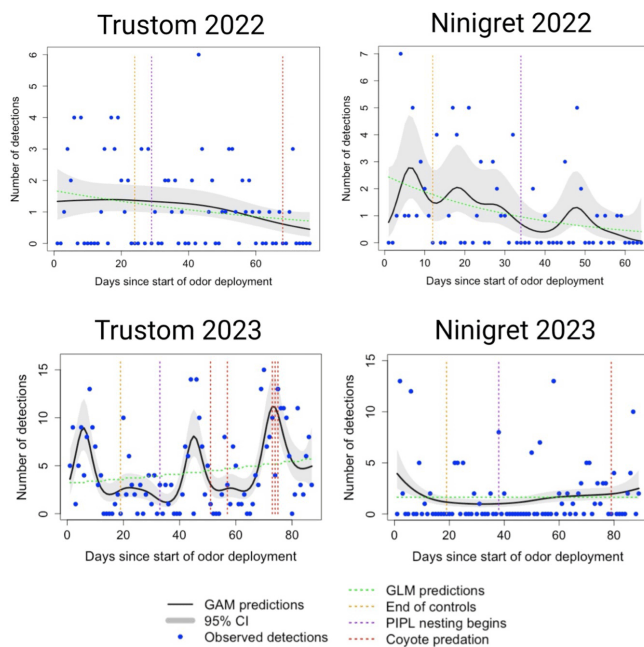
#### **Coyote**

At the site-level, coyote detections decreased through the sampling period at both sites in 2022 (Trustom  $\beta = -0.01$ , Ninigret  $\beta = -0.03$ , both  $P < 0.05$ ;  $\beta$  is the estimated linear trend slope; Fig. 2). We found evidence of a difference between the mean predictions of both the GLM and GAM for 2022. In 2023, there was no evidence of a decrease in coyote detections at either site, but rather a small increase in detections (Trustom  $\beta = 0.01$ ,  $P < 0.05$ , Ninigret  $\beta = 0.001$ ). Comparing the GLM and GAM site-level predictions, there was clear non-linear variation in detections (Fig. 2).

**Table 1.** Piping Plover (*Charadrius melodus*) nest fates two years prior to scent deployments (2020 and 2021) compared to the two years with scent applications (2022 and 2023) at Trustom and Ninigret, Rhode Island.

Type of Nest Failure	2020 (no scent)	2021 (no scent)	2022 (scent)	2023 (scent)	Total
Abandoned/flooded	5	5	1	1	12
Predated/avian	1	4	2	10	17
Predated/mammal	3	3	3	5	14
Predated/unknown	7	2	3	3	15
Unknown cause	3	5	5	2	15
Total Failed Nests	19	19	14	21	73
Total Successful Nests	16	14	14	8	52
Total Nests	35	33	28	29	125

**Fig. 2.** Site-level daily variation in coyote (*Canis latrans*) detections (blue points) at scent stations at Trustom and Ninigret, Rhode Island from 27 March (day 0) to 10 June (day 76) in 2022 and 29 March (day 0) to 24 June (day 87) in 2023. Plotted are mean predictions from the generalized linear model (GLM; green dotted line) and mean predictions (solid black line) along with 95% confidence intervals (gray shaded region) from a generalized additive model (GAM). Vertical dotted lines represent the end of the control deployments (orange), the start of the Piping Plover (*Charadrius melodus*) nesting season (purple), and documented predation of a Piping Plover nest by a coyote (red).



At the camera-level in 2022, the most supported models by AIC weight were active nests for Trustom ( $w = 0.34$ ; Active nests  $\beta = -0.05$ ,  $P = 0.12$ ) and deployments for Ninigret ( $w = 0.47$ ; Deployments  $\beta = -2.65$ ,  $P = 0.38$ ). In 2023, the top models were deployments interacting with scent types for Trustom ( $w = 0.23$ ) and day interacting with scent type for Ninigret ( $w = 0.41$ ). For Trustom, the control effect was statistically significant ( $\beta = -2.81$ ,

$P < 0.05$ ), while for Ninigret, all scent types (except controls) interacting with day were significant (Waterfowl  $\beta = 1.12$ , Glands  $\beta = 0.11$ , Gull  $\beta = 0.14$ ,  $P < 0.05$ ), showing distinct trends for each (see Table A2.3 and Figs. A2.3–A2.5).

The most supported model for coyote interaction time (seconds) in 2022 was scent type interacting with site ( $w = 0.99$ ; Table 4 in A2); however, all coefficient estimates were statistically unclear ( $P > 0.05$ ). Coyotes at Trustom spent the most amount of time (~12 sec) investigating glands, while coyotes at Ninigret showed no preference for a particular scent type (Fig. 3). The highest ranked model for coyotes' interaction time in 2023 was site interacting with day ( $w = 0.99$ ; Table A2.4); all coefficient estimates had  $P < 0.05$ . Mean predictions show coyotes decreasing their interaction time at Ninigret but increasing at Trustom (Fig. 4).

### Red Fox

Red foxes were only detected consistently at Trustom in 2022. At the site-level, red fox detections were fairly constant over the study period (Fig. A2.6). At the camera-level, the most supported model only included scent types ( $w = 0.67$ ; Table A2.5); all coefficient estimates were statistically significant ( $P < 0.05$ ).

The highest ranked model for fox interaction time (seconds) was an additive effect of scent type and day ( $w = 0.65$ ; Table A2.6); all coefficients were statistically significant ( $P < 0.05$ ). Predictions indicated that interaction times decreased over the sampling period for all scent types; the waterfowl scent led to the highest interaction times (Fig. 3).

### Virginia Opossum

Opossums were detected at both sites and years, but only consistently at Trustom in 2023. Even then, detections were sporadic, such that mean detections for both the GLM and GAM were similar and constant, indicating a lack of variation through the study period (Fig. A2.7). 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 toward the end (Fig. A2.7). When detections were at their highest, one plover nest was documented as predated by an opossum.

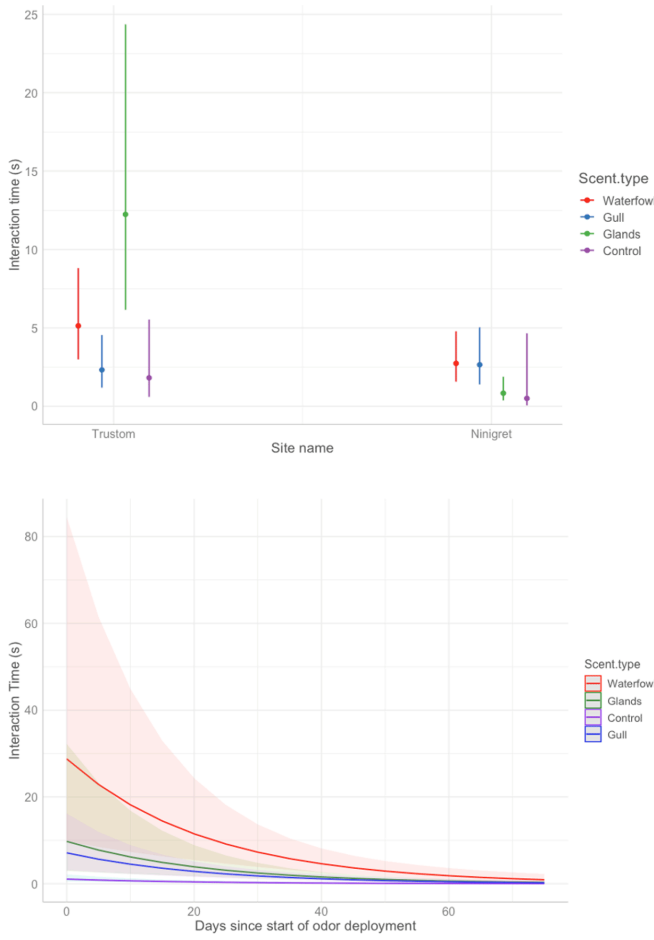
The most supported model for opossum detections at the camera-level at Trustom in 2023 was the null model, indicating no variation in detections over time ( $w = 0.34$ ; Table A2.7). Ninigret's most supported model, deployments, ( $w = 0.59$ ; Table A2.7) had statistical significance for detections and deployments ( $\beta = -7.91$  and  $\beta = 0.17$ ,  $P < 0.05$ , respectively). As the deployment season progressed, opossum detections increased, particularly around the latter half of the deployment season (Fig. A2.7).

The most supported model for opossum interaction times in 2023 was an additive effect of scent type and site ( $w = 0.81$ ; Table 8, A2). Glands was the only statistically significant coefficient ( $\beta = 1.78$ ,  $P < 0.05$ ), showing the greatest mean difference in interaction time (Fig. A2.8).

### Striped Skunk

Striped skunk were only detected at Trustom in 2023. At the site-level, skunks were detected once early in the study period, and not consistently detected until day 70. As such, both the GLM and GAM predictions show an increase in detections through the

**Fig. 3.** Predicted interaction time (seconds) at scent stations for coyotes (*Canis latrans*; top) and red fox (*Vulpes vulpes*; bottom) for four scent types: waterfowl (red), uropygial glands (green), control (purple), and gull (blue), at Trustom and Ninigret in 2022. Shaded areas represent 95% confidence intervals. The most supported models were scent type \* site for coyotes (Table A2.4) and scent type + day for red foxes (Table A2.6).



sampling period, but primarily at the end of the period (Fig. A2.9). The GLM coefficient estimates were statistically significant with  $P < 0.05$  ( $\beta = -7.12$  and  $\beta = 0.09$ ).

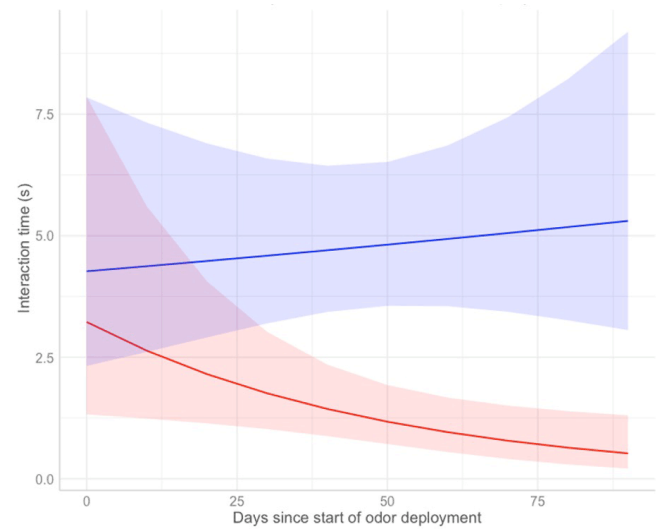
We found similar results at the camera-level, where the most supported model for skunk detections was the single variable day ( $w = 0.40$ ; Table A2.9). The coefficient estimates were statistically significant and indicated longer interaction times at the end of the sampling period. (Fig. A2.10). The most supported model for skunk interaction time (seconds) was an additive effect of scent and week ( $w = 0.40$ ; Table 10, A2); however, there was no statistical significance among coefficients ( $P > 0.05$ ).

## DISCUSSION

### Predator detections

Bird odors attracted interest from four predator species (coyote, red fox, opossum, and skunk) during this study in coastal Rhode Island. There was clear interspecific variation in the number of

**Fig. 4.** Predicted interaction time (seconds) of coyotes (*Canis latrans*) at scent stations at Ninigret (red line and 95% confidence interval area) and Trustom (blue line and 95% confidence interval area) in 2023.



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 have more extensive home ranges than the other focal mammalian predators (Trehwella et al. 1988, Weissinger et al. 2009, Mitchell et al. 2015, Ward et al. 2018, Pearman-Gillman et al. 2020), and feed on a wide range of prey, which could explain the high number of encounters with the bird odors (Latham et al. 2019). In 2022, coyote detections at scent stations were initially high, and then declined dramatically, particularly at Ninigret, suggesting habituation to the bird odors and novel objects (trail cameras). This finding was consistent with mammalian responses to scent stations in New Zealand (Norbury et al. 2021). However, in the second year of this study, detections did not decline to low levels, suggesting no evidence of habituation to the scents.

Red fox, opossum, and skunk did not interact with scent stations as consistently as coyotes. In 2022, red fox detections were relatively constant, though sparse, while in 2023 they only interacted with scents on three occasions. The increase in coyote detections in 2023 could explain the paucity of red fox detections, as coyotes and red fox exhibit interference competition with non-overlapping territories (Major and Sherburne 1987), and coyotes are predators of red foxes (Masters and Maher 2022). This suggests that red foxes at Trustom could be avoiding coyotes (Banks et al. 2016). Yet, in 2022, we saw camera images of red foxes investigating the same scent station one hour after a coyote had visited the same scent station and vice versa. Red foxes did not avoid the areas used by coyotes; rather, they utilized the same spaces but during different time periods.

The inconsistency in detections between years and sites was similar for opossums. Opossums 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 that offers better foraging opportunities and fewer human interactions such as car collisions. This could be why we observed 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. 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, Massachusetts 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**

Based on results from Norbury et al. (2021), we anticipated that interaction times at scent stations 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. Opossums and skunk also showed a slight increase in time spent at the scent stations. Reasons for the increased interest over time for these two species are uncertain, although may be similar to what Norbury et al. (2021) observed with the later emergence of hibernating hedgehogs in their study.

At Trustom, we had photographic 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) described "book-keeping," which is a method that coyote, red fox, and wolves (*Canis lupus*) use to signal to other predators that there is no food remaining 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).

#### **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. Because gland scents were derived directly from the uropygial gland rather than the full carcass, this scent could have been a more potent odor as well. Waterfowl possess larger uropygial glands for waterproofing plumage (Moreno-Rueda 2017), which resulted in higher bird odor yields during extraction compared to gulls.

The bird odor that attracted the lowest interaction times across all mammalian predators was from gulls. 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, Ring-billed Gull [*Larus delawarensis*], and Herring Gull to stage and preen near some scent station areas, which also might explain why there was little interest in the gull scent.

#### **Comparisons with Norbury study**

Our results indicate that Rhode Island mammalian predators showed no consistent patterns in responses to bird odors. Compared to research in New Zealand (Norbury et al. 2021), 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 detected considerable variation in mammalian predator interest throughout the odor deployment period. We did, however, document a decline in the length of time that coyotes at Ninigret and red fox at Trustom investigated scents. The number of predator detections at scent stations was not correlated with the initiation of Piping Plover nesting season. Mammals continued to predate Piping Plover nests during the odor deployment period, regardless of when the birds arrived at our study sites and initiated clutches. Latham et al. (2019) found that although shorebird mammalian predators in New Zealand habituated to the scents, dishabituation did occur, resulting in nest depredations. A similar pattern may have occurred among coyotes at Trustom.

A major difference between this study and Norbury et al. (2021) was the shape and size of two study areas and the density of potential predators. We assume that New Zealand's predators were less likely to encounter a shorebird nest because their study areas were ~1000 ha, while our largest site, Ninigret, was only 57 ha. The dune systems on the southern Rhode Island coast were long, narrow, and linear. Stantial et al. (2020) suggested that the linear nature of these narrow barrier beaches could encourage pursuant mammals to search for prey in a similar, linear 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. Mammalian predators searching along the foot of the dunes were likely to come across a Piping Plover nest, regardless of odor cues. The distribution of Piping Plover nests could allow predators to use



visual cues, such as detecting a disturbed Piping Plover run off their nest, which could help predators locate nests more efficiently. Because New Zealand's habitat was more extensive and non-linear, 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*). Study sites in Rhode Island 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<sup>2</sup> (Hinton et al. 2015, 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<sup>2</sup> (Recio et al. 2010). The combination of a smaller 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. Coyotes are a territorial species, thus detections at multiple scent stations could have been from one individual or multiple individuals. Unfortunately, we did not have an estimate of predator abundance at our study areas. A single coyote could have predated Piping Plover nests throughout the entire season, rather than multiple individuals.

#### MANAGEMENT IMPLICATIONS

Our findings suggest that this novel technique does influence mammalian predators of ground-nesting shorebirds on Atlantic Coast beaches. Chemically extracted bird odors did attract mammalian predators' interest; nevertheless, there was considerable interspecific variation in detection and interaction rates at scent stations. However, there was no indication that odor swamping reduced nest predation rates at Piping Plovers nests, therefore this technique is probably not appropriate for the narrow, linear beaches where we conducted this study. Rather, this approach could be tested in non-linear habitats where predators are more likely to search in multiple directions. We recommend using uropygial glands for extraction because they require less solvents and are equally effective (or in some cases more) in attracting predators compared to the carcass-derived scents. We found using a 40:60 ratio of bird concentrate to Vaseline achieved a mixture with a strong enough smell to lure in predators. 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. We also recommend odors are reapplied every three days to maintain high potency of odors. Continuing to use additional Piping Plover non-lethal predator management practices such as exclosing nests are recommended. Because of the small, linear study areas, this method did not indicate habituation and most importantly, did not decrease

predation rates of Piping Plover nests in this initial trial. Managing Piping Plover predators on beaches surrounded by heavily developed areas with high public use is challenging for wildlife managers, and research evaluating the efficacy of novel tools is greatly needed. Further investigations should be conducted on other types of mammalian predators, larger study areas, and different types of habitats.

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#### Acknowledgments:

*This project was supported by Wildlife Restoration Grants administered by the U.S. Fish and Wildlife Service, Wildlife and Sport Fish Restoration Program: Partnering to fund conservation and connect people with nature; RI W-44-TW-1 Deploying Odor Misinformation Tactics as a Predator Management Strategy for Atlantic Coast Beach-Nesting Birds, (F18AF01111). IACUC approval # AN2122-010.*

#### Data Availability:

*The data/code that support the findings of this study are openly available in Zenodo at <https://doi.org/10.5281/zenodo.12760945>.*

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# APPENDIX 1

## **Bird Collection**

We extracted bird scents from bird species that are typically found occupying southern Rhode Island coastal areas (Table 1). Uropygial glands were removed from the carcass by a local taxidermist and were left whole. We 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 we processed were freshly killed and frozen promptly until needed. We thawed bird carcasses for 12-24 hours prior to the soaking process.

## **Soaking process**

Following Norbury et al. (2021), we submerged thawed bird carcasses in a 1:1 solvent mixture of acetone and dichloromethane manufactured by Honeywell. We used approximately four liters of solvents per batch (two liters of each solvent) (2-3 gull carcasses or five to six ducks per batch), or enough liquid to completely submerge the birds. For gland batches, we soaked 36-70 glands in one liter of solvent (0.5 liter of each solvent), or enough liquid to submerge the glands. We soaked carcasses/glands overnight for 12-16 hours in a sealed five-gallon high density polyurethane (solvent-proof) bucket under a fume hood. After the soaking period, we removed the bird carcasses/glands from the solvent mixture and squeezed them until most of liquid dripped off. Throughout the extraction process with solvents, we wore at least 10 mil thick butyl gloves or “Silver Shield” gloves. We 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**

We 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. We poured the filtered solvent mixture into a one L 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). We 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, we reduced the temperature of the water bath and/or the rotation speed of the flask. We evaporated the solvents until there was a thick brown/yellow colored liquid (bird concentrate) sticking to the sides of the flask. We re-used remaining evaporated solvents one to two times for another round of carcass soaking. We 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, we poured it into a 0.2 L glass beaker, making sure to record the weight of the empty beaker first. To ensure all bird concentrate was emptied into the beaker, we 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, we placed the mixture under a fume hood and swirled it occasionally to evaporate off the added

dichloromethane. We continued to circulate the mixture until it was a thick consistency and wafted the scent to our noses (note: we did not put my nose directly next to the dichloromethane) to ensure it smelled similar to a 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 preen glands (36-70 glands) yielded 20-25 g. We reconstituted the bird concentrate with Vaseline on a hot plate at 80 °C, which was hot enough to bring it to a liquid state. We 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, we distributed the mixture into 1g/mL plastic syringes. We then stored the bird odor mixtures in a freezer until we used them, and assumed that odors could retain their odor properties for up to a year in the freezer.



**Table A1.1** Bird species used in the bird odor extraction process and the method in which they were made. The carcass included the full body of the bird, whereas the glands were only the extracted uropygial gland.

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

**Table A1.2** Annual summary of bird odor batches and the number of bird carcasses and glands used in 2022 and 2023.

Year	Batches	Number of Carcasses	Number of Glands
2022	8	13	40
2023	8	12	91

## APPENDIX 2

**Table A2.1** Summary of scent odor deployments to deter mammalian predators at Trustom and Ninigret in southern Rhode Island in 2022 and 2023.

Parameter	Trustom 2022	Trustom 2023	Ninigret 2022	Ninigret 2023
Start Date	27 March	29 March	8 April	29 March
End Date	10 June	24 June	10 June	26 June
Number of days in a deployment season	76	87	64	89
Number of scent stations	33	33	46	46
Number of active scent stations on any given day	13	33	19	46
Number of days between moving scent station	3	3	3	3
Number of scent applications	25	29	21	29

**Table A2.2** 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.

Common Name	Scientific Name	PIPL Predator?	Conducted Species Specific Analysis	2022		2023	
				Trustom detections	Ninigret detections	Trustom detections	Ninigret detections
Bobcat	<i>Lynx rufus</i>	No	No	1	0	8	17
Domestic Dog	<i>Canis lupus</i>	Yes	No	3	1	15	30
Easter Coyote	<i>Canis latrans</i>	Yes	Yes	85	73	376	145
Gray Fox	<i>Urocyon cinereoargenteus</i>	Yes	No	0	0	0	1
House Mouse	<i>Mus musculus</i>	No	No	1	0	0	10
North American River Otter	<i>Lontra canadensis</i>	Yes	No	1	0	0	1
Raccoon	<i>Procyon lotor</i>	Yes	No	5	2	12	9
Red Fox	<i>Vulpes vulpes</i>	Yes	Yes (2022)	38	0	3	1
Striped Skunk	<i>Mephitis mephitis</i>	Yes	Yes (Trustom, 2023 only)	0	0	32	0
Virginia Opossum	<i>Didelphis virginiana</i>	Yes	Yes (2023)	1	1	17	51
White-tailed Deer	<i>Odocoileus virginianus</i>	No	No	13	15	21	21
Total	-	-	-	148	92	484	286



**Table A2.3** Top two models assessing coyote use of different scent stations at Trustom and Ninigret, Rhode Island in 2022 and 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 ( $\Delta AIC_c$ ), and model weight ( $w$ ).

Site	Year	Model	K	$AIC_c$	$\Delta AIC_c$	$w$
Trustom	2022	Active Nests	2	682.81	0.00	0.34
		Null	1	683.40	0.58	0.25
Ninigret	2022	Deployments	2	598.75	0.00	0.47
		Day	2	599.43	0.68	0.34
Trustom	2023	Deployments * Scent type	8	2422.99	0.00	0.23
		Day * Scent type	8	2423.20	0.20	0.21
Ninigret	2023	Day * Scent type	8	1280.21	0.00	0.42
		Deployments * Scent type	8	1280.31	0.10	0.39

**Table A2.4** Assessing coyote interaction times at two beach sites in southern Rhode Island 2022 and 2023. Each model set is separated by a horizontal line. 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 ( $\Delta AIC_c$ ), and model weight ( $w$ ).

Year	Model	K	$AIC_c$	$\Delta AIC_c$	$w$
2022	Scent type * Site	9	682.72	0.00	0.996
	Site * Day	5	693.99	11.27	0.004
2023	Site * Day	5	2126.92	0.00	0.99
	Site + Day	4	2146.92	19.99	4.54E-05

**Table A2.5** 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<sub>c</sub>) and include the number of parameters (K), difference in AIC<sub>c</sub> from the best model ( $\Delta$ AIC<sub>c</sub>), and model weight ( $w$ ).

Model	K	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	$w$
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 A2.6** 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<sub>c</sub>) and include the number of parameters (K), difference in AIC<sub>c</sub> from the best model ( $\Delta$ AIC<sub>c</sub>), and model weight ( $w$ ).

Model	K	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	$w$
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 A2.7** Assessing opossum use of different scent stations at Trustom Pond and Ninigret National Wildlife Refuge, RI in 2023. Model sets are separated by a horizontal line. 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 ( $\Delta AIC_c$ ), and model weight ( $w$ ).

Site	Model	K	$AIC_c$	$\Delta AIC_c$	$w$
Trustom	Null	1	211.73	0.00	0.34
	Scent type	4	213.65	1.91	0.13
Ninigret	Deployments	2	496.33	0.00	0.59
	Day	2	497.42	1.09	0.34

**Table A2.8** 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 ( $\Delta AIC_c$ ), and model weight ( $w$ ).

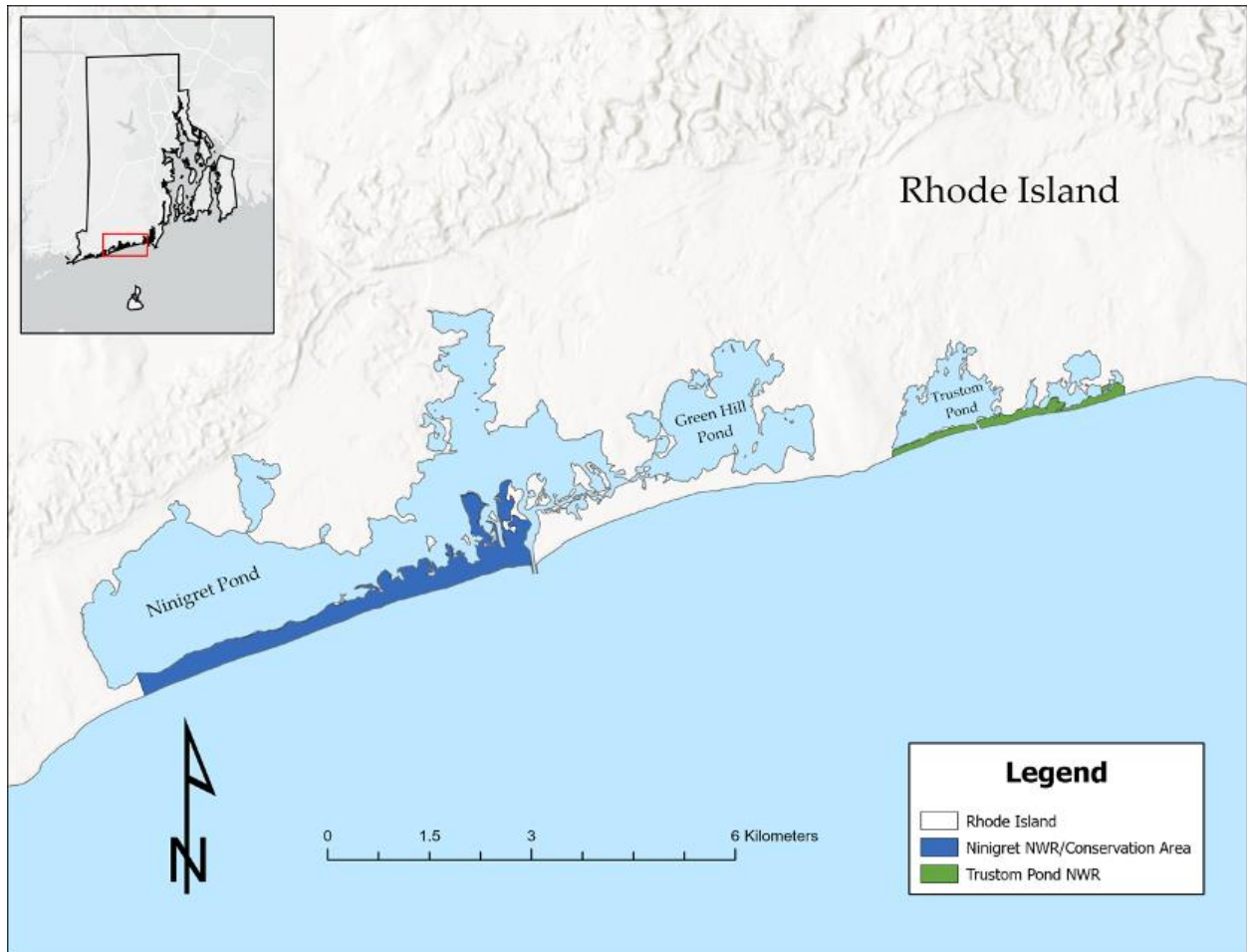
Model	K	$AIC_c$	$\Delta AIC_c$	$w$
Scent type + Site	6	274.99	0.00	0.81
Scent type + Day	6	279.61	4.62	0.08
Scent type + Week	6	279.72	4.73	0.08
Scent type	5	281.43	6.44	0.03
Site	3	288.55	13.56	0.0009
Site + day	4	290.59	15.60	0.0003
Day	3	294.98	19.99	3.69E-05
Null	2	295.30	20.31	3.15E-05

**Table A2.9** 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<sub>c</sub>) and include the number of parameters (K), difference in AIC<sub>c</sub> from the best model ( $\Delta$ AIC<sub>c</sub>), and model weight (*w*).

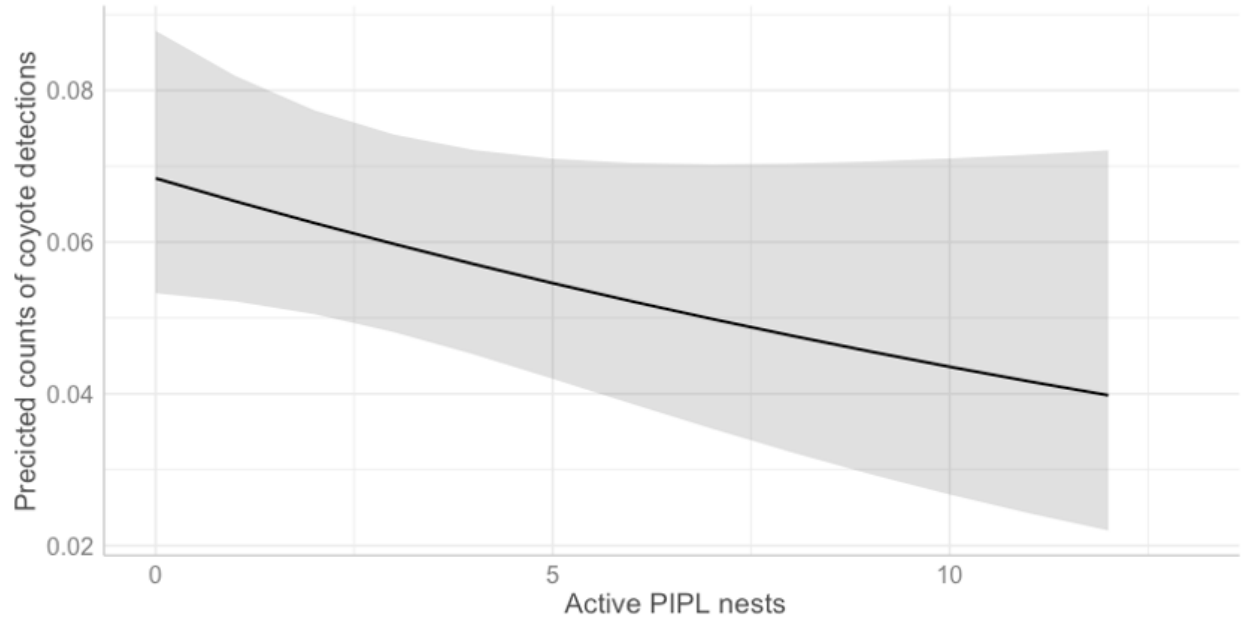
Model	K	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	<i>w</i>
Day	2	287.94	0.00	0.40
Week	2	288.31	0.37	0.33
Deployments	2	289.21	1.28	0.21
Day * Scent type	8	293.64	5.70	0.02
Week * Scent type	8	293.97	6.03	0.02
Deployments * Scent type	8	296.03	8.09	0.01
Scent type	4	346.96	59.03	6.14E-14
Null	1	356.47	68.54	5.28E-16
Active Nests	2	358.22	70.29	0.00

**Table A2.10** 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<sub>c</sub>) and include the number of parameters (K), difference in AIC<sub>c</sub> from the best model ( $\Delta$ AIC<sub>c</sub>), and model weight (*w*).

Model	K	AIC <sub>c</sub>	$\Delta$ AIC <sub>c</sub>	<i>w</i>
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

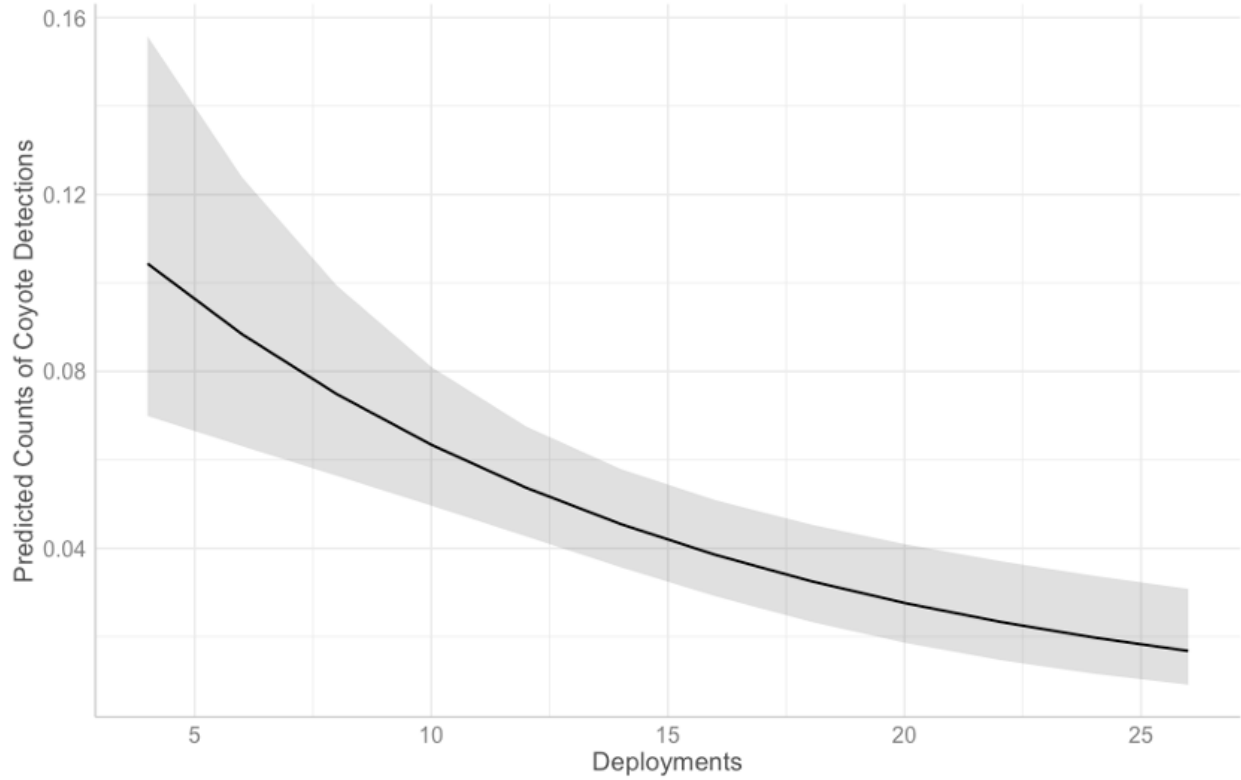


**Fig. A2.1** Map of two study sites in Rhode Island, USA: Trustum Pond National Wildlife Refuge (green) and Ninigret National Wildlife Refuge/ Conservation Area (blue).

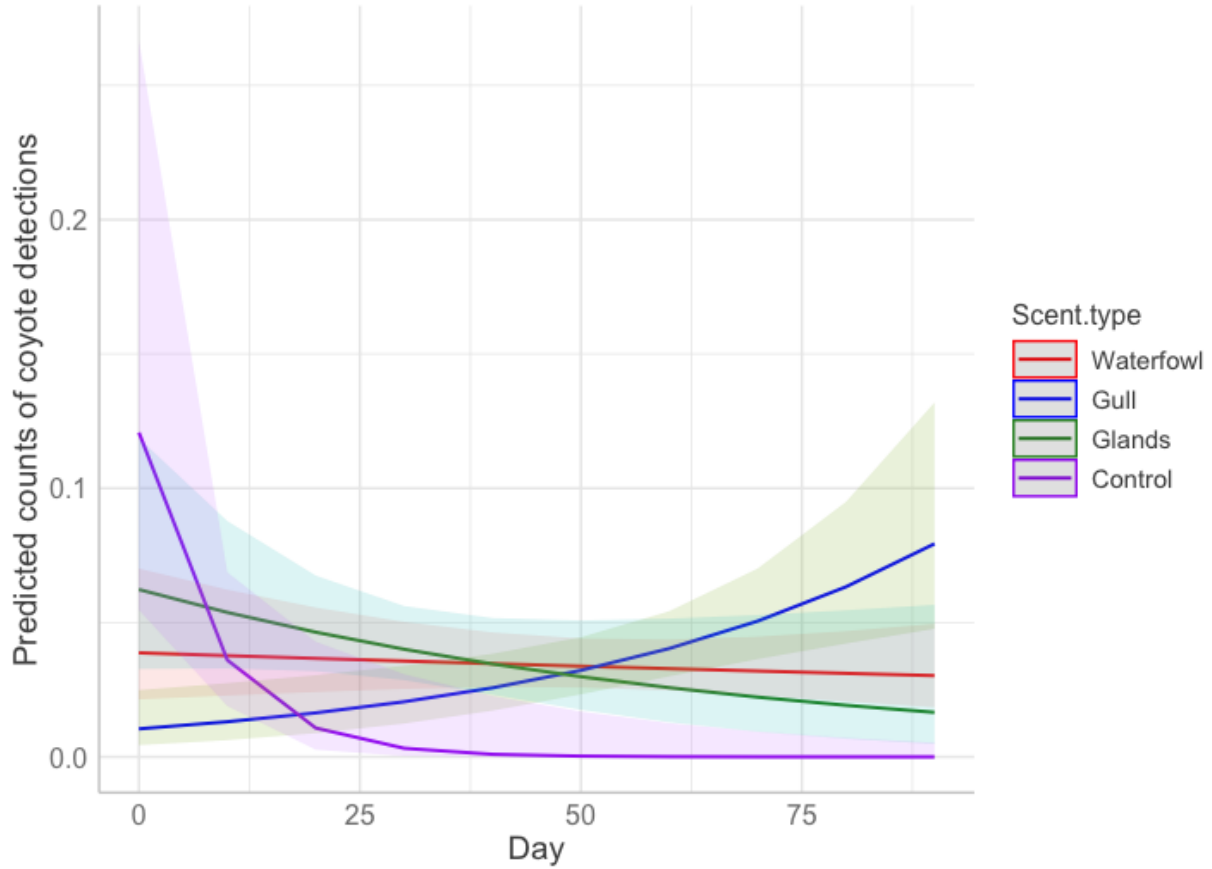


**Fig. A2.2** Predicted counts of coyote detections considering active Piping Plover (PIPL) nests at Trustom, Rhode Island in 2022. The shaded area indicates a 95% confidence interval with a negative-sloped prediction line (black line). Graph shows the most supported model, active nests (Table 3).



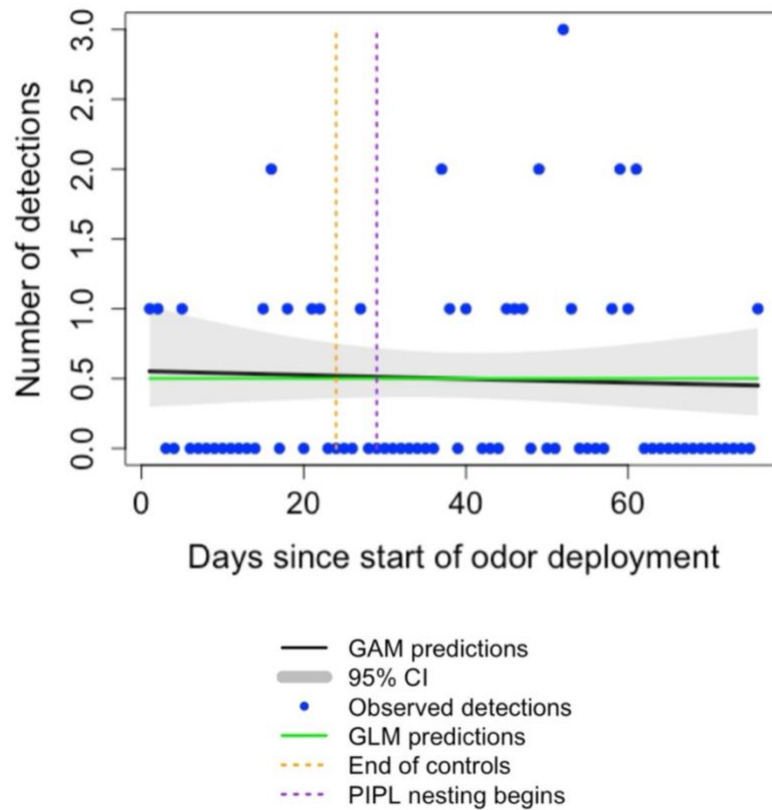


**Fig. A2.3** Predicted counts of coyote detections at Ninigret, Rhode Island in 2022. Deployment periods are in 3-day intervals. The shaded area indicates a 95% confidence interval with a negative-sloped prediction line (black line). This graph displays the most supported model, deployments (Table 3).

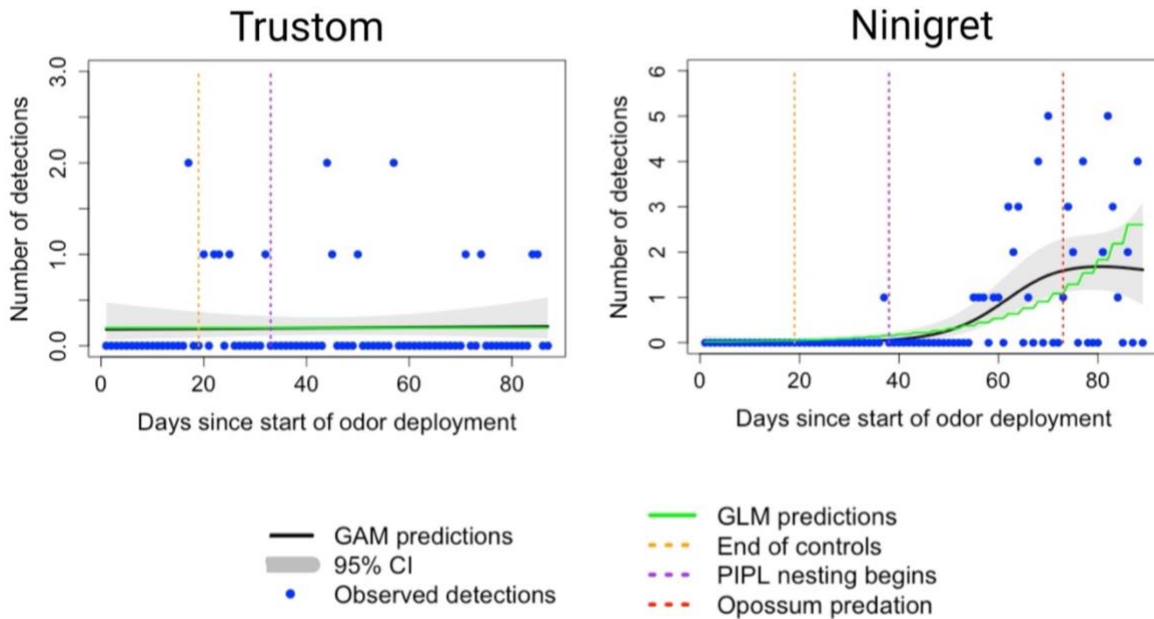


**Fig. A2.4** Seasonal variation in predicted counts of coyote detections interacting with different scent types at Ninigret, Rhode Island in 2023. Scent types included gull (blue line), uropygial glands (blue line), waterfowl (red line), and control (purple line). This represents the most supported model, day \* scent type (Table 3).

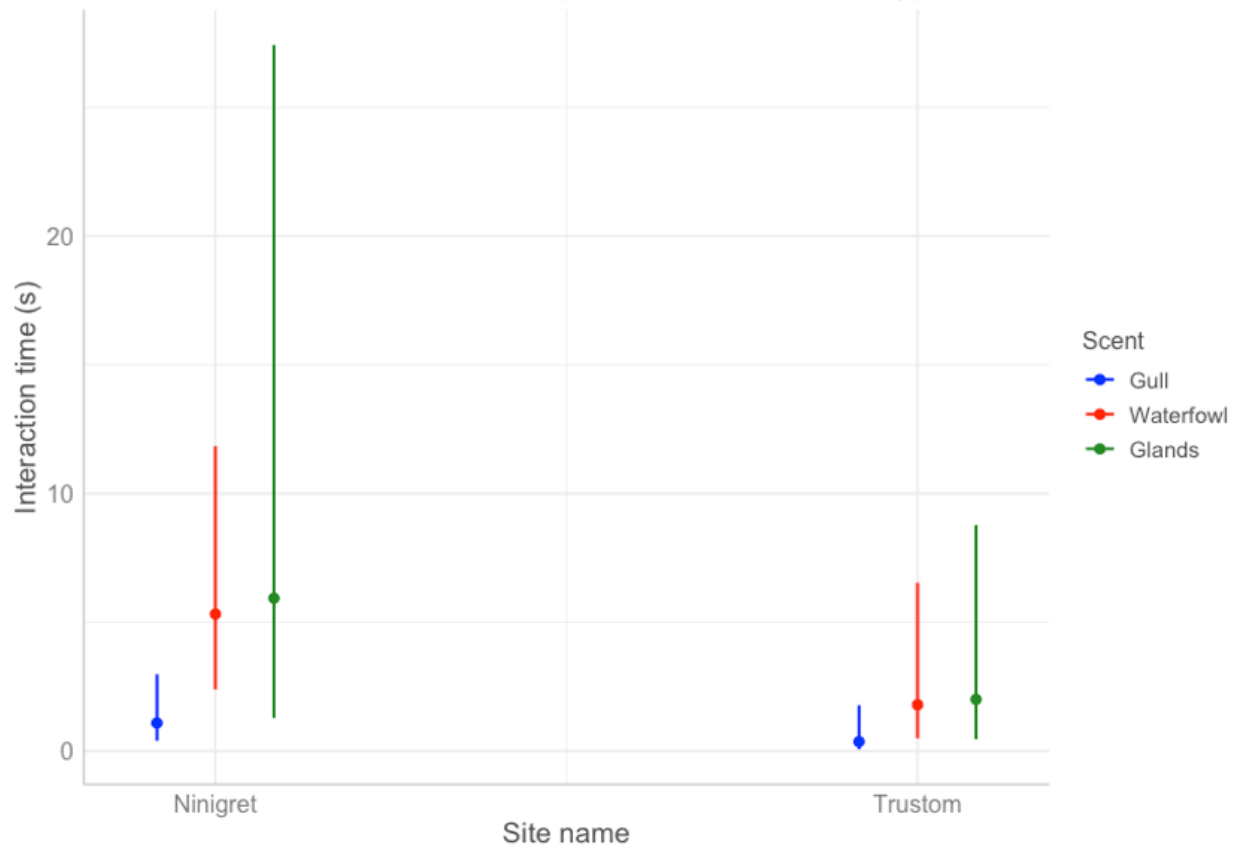
# Trustom



**Fig. A2.5** 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 11), 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), and the start of the piping plover nesting season (purple).

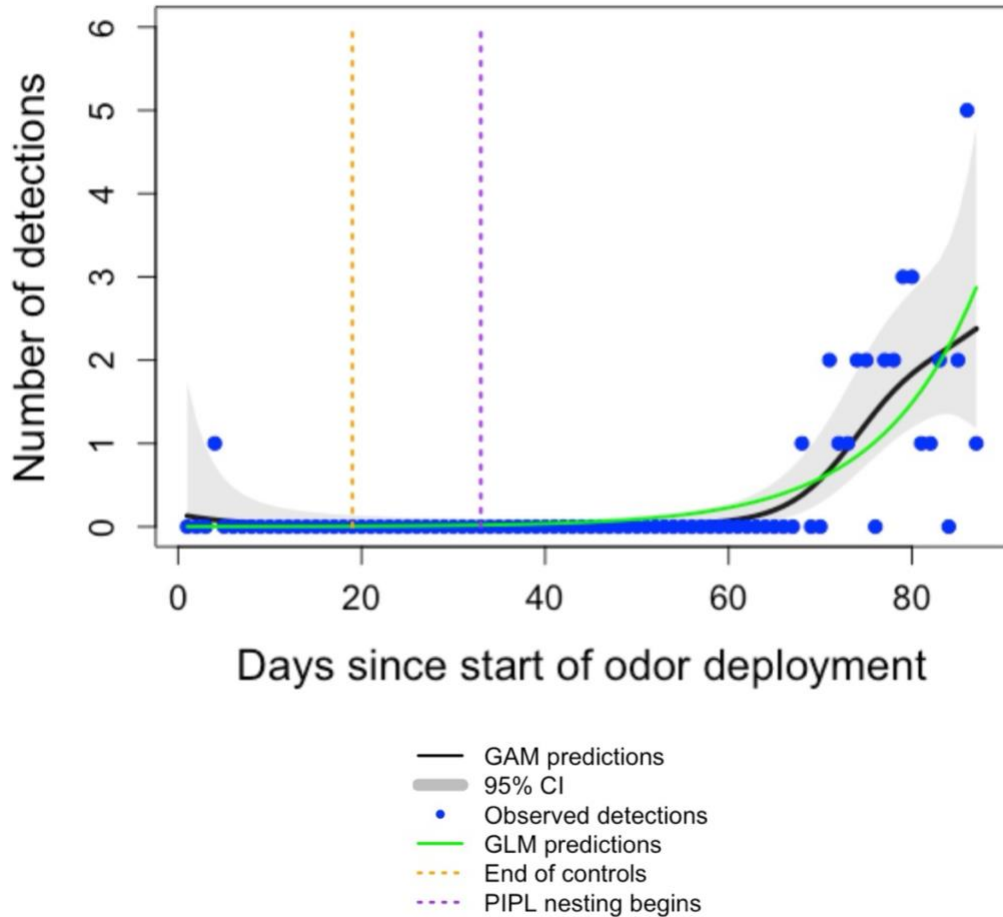


**Fig. A2.6** Site-level daily variation in opossum detections (blue points) at scent stations at Trustom and Ninigret, Rhode Island from 27 March (day 0) to 10 June (day 76) in 2022 and 29 March (day 0) to 24 June (day 87) in 2023. Plotted are mean predictions from the generalized linear model (GLM; green dotted line) and mean predictions (solid black line) along with 95% confidence intervals (gray shaded region) from a generalized additive model (GAM). Vertical dotted lines represent the end of the control deployments (orange), the start of the piping plover nesting season (purple), and documented predation of a piping plover nest by an opossum (red).



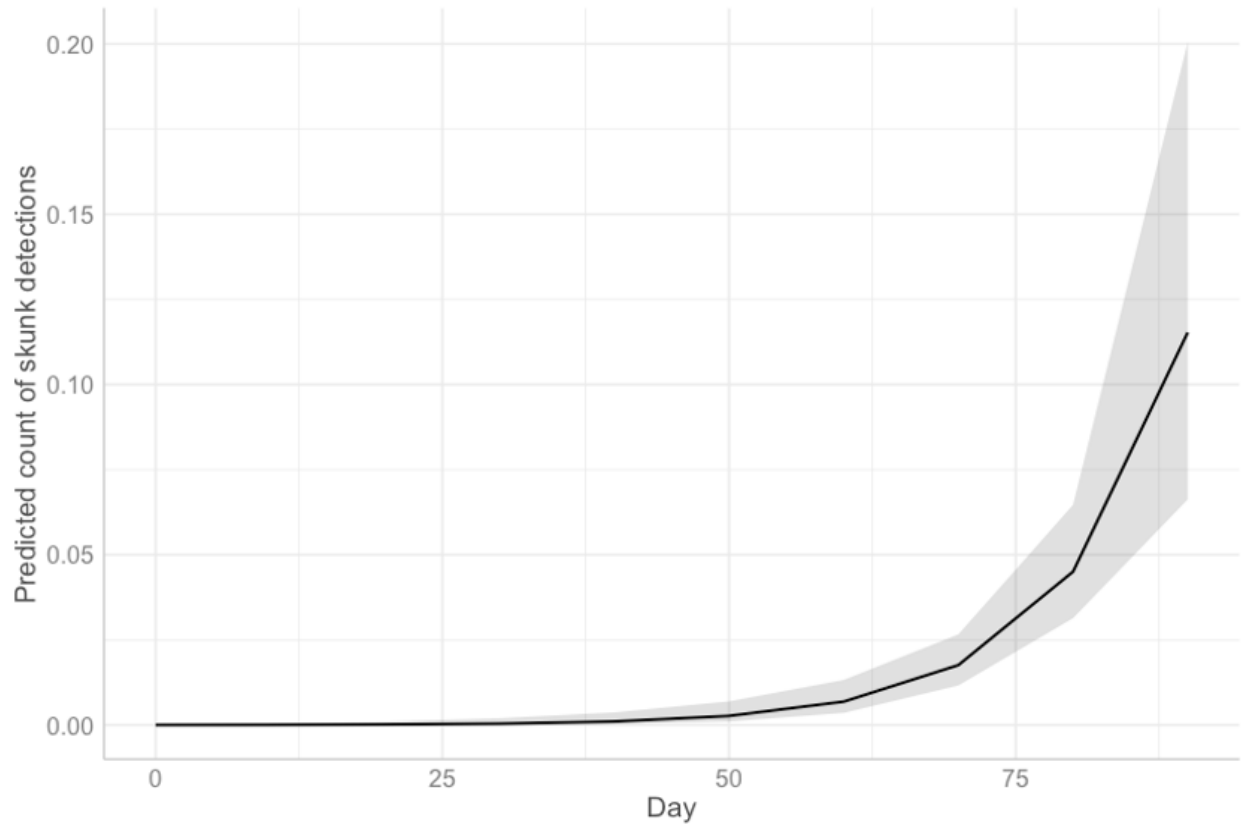
**Fig. A2.7** Predicted interaction time (seconds) that an opossum spent at a scent station for four scent types at site Ninigret (left panel) and Trustom (right panel) in 2023. Scents are gull (blue), waterfowl (red), and uropygial glands (green).

# Trustom



**Fig. A2.8** 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), and the start of the piping plover nesting season (purple).





**Fig. A2.9** 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 10).