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Factors Limiting Abundance and Productivity of Piping Plovers (Charadrius melodus) in New Jersey

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FACTORS LIMITING ABUNDANCE AND PRODUCTIVITY OF PIPING PLOVERS

(*CHARADRIUS MELODUS*) IN NEW JERSEY

by

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ABSTRACT

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Successful recovery of endangered species requires an understanding of factors that limit population size and growth rate. Regulatory protection and management interventions for piping plovers have been largely successful in recovering populations throughout the breeding range; however, some subpopulations have not recovered, including the New Jersey population. The goal of this study was to understand how predators, foraging habitat, and management actions affect piping plover population dynamics in New Jersey. Using resighting data, we found that adult survival between 2012–2019 ranged from 0.62 [95% CI = 0.48, 0.74] to 0.85 [0.74, 0.92] for females and 0.65 [0.51, 0.78] to 0.89 [0.80, 0.94] for males and juvenile survival ranged from 0.40 [0.30, 0.51] to 0.70 [0.57, 0.80]. Abandoned nests were associated with lower survival rates, particularly for males. Daily chick survival rates increased with age (days since hatching), decreased with daily precipitation, and were lower when bayside foraging access was not available. Using predator tracking surveys and occupancy modeling, we found that mink occupancy was higher when red foxes were absent (0.787 [95% CI = 0.14, 0.98]) than when they were present (0.05 [0.01, 0.26]). Daily nest predation was similar at sites with red foxes (0.45 ± 0.11 SD) and without red foxes (0.43 ± 0.10) for nests not protected by predator exclosures, but predation rates were higher for exclosed nests at sites without red foxes (0.20 ± 0.08) than sites with red foxes (0.06 ± 0.04). We found evidence that red fox habitat use decreased as the distance to the nearest primary dune increased and that habitat use remained constant throughout the course of the nesting season. Our results will lead to more comprehensive recommendations for predation management and restoration to land managers within New Jersey that will simultaneously reduce predation pressures and create suitable habitat to begin recovery within the state.

Keywords: *Charadrius melodus*, chick survival, ecological trap, mesopredator release, *Neovison vison,* nest survival, true survival, wildlife management, *Vulpes vulpes*

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CHAPTER 1 CONSERVATION OF ATLANTIC COAST PIPING PLOVERS AND CURRENT THREATS TO RECOVERY IN NEW JERSEY

Successful recovery of endangered species requires an understanding of factors that limit population size and growth rate. Population dynamics typically vary depending on the reproductive success of individuals, which can be influenced by several factors including weather conditions, habitat loss and predation. High reproductive success can lead to increases in abundance and dispersal rates, influencing regional population growth. In dynamic landscapes, species may exist in metapopulations or exhibit source-sink dynamics. At sites where the population growth rate exceeds one, the population will either continue to increase or will provide an excess of young individuals which will then disperse from their natal sites and colonize new sites (Diffendorfer 1998). The original site would be categorized as a source population which supplies immigrants to other source populations or to sink populations with population growth rates of less than one (Diffendorfer 1998). The consequences of source-sink dynamics are that sources must be protected to ensure long-term existence of a species and sinks may be harmful because the chances of successful reproduction are low (Timus et al. 2017).

A site may be characterized as a sink due to high predation pressures on threatened species. Predator-prey relationships are complex and have been well-studied and theorized over since 1926 when Alfred Lotka defined his "law of population growth" and introduced the first model of predator-prey interactions (Lotka 1926). Since then, there have been numerous models that attempt to describe the predator-prey relationship, many of which are modifications of the basic Lotka-Volterra model. For example, ratio-dependent predator-prey models predict a steady increase in predator and prey densities as ecosystem productivity increases (Arditi and Ginzburg 1989, Berryman 1992, Schmitz 1992). The Rosenzweig-McArthur predator-prey model, a

modification of the classic Lotka-Volterra model, includes a logistic term in the prey equation to avoid the unreasonable assumption that the prey population would grow infinitely in the absence of predators because the demand for resources, such as food, will eventually exceed the supply, consequently limiting the growth of any population (Berryman 1992). Food availability determines demographic rates and demographic rates determine population growth rate; however, the effects of food availability on population growth rate are modified by predator abundance (Hone and Sibly 2002).

Availability of food resources, anthropogenic disturbance, and predation pressures also affect dispersal probability. Dispersal of individuals from their birth site to their breeding site (natal dispersal), and the movement of individuals from one breeding site to another (breeding dispersal), can influence reproductive success, site-level abundance, and the long-term persistence of a metapopulation (Smith 1993). Understanding dispersal is crucial for managing wild populations and predicting their responses to changes in the environment. Long-range dispersal has a positive effect on persistence in dynamic landscapes, increasing the colonization of regenerated patches of habitat (Johst et al. 2002). However, for long-term persistence, when the number of dispersers is small due to low regional or patch-level growth rates, long-range dispersal is not beneficial to the population (Johst et al. 2002).

The proximity of suitable habitat may increase dispersal success (Bowler and Benton 2005); therefore, spatial structure of habitat is important for understanding the population dynamics of a species. Pulliam (1988) suggested that demographic rates, including dispersal, can be habitat-specific and that in many populations, a large proportion of individuals occur within sink habitat that is locally conserved by continued immigration from more productive nearby sources. These sinks may support a large population even though they would eventually

disappear without continued immigration (Pulliam 1988). Therefore, in spatially heterogeneous environments, dispersal from source habitats can maintain large sink populations while remaining evolutionarily stable (Pulliam 1988).

The Atlantic coast population of piping plovers (*Charadrius melodus*) is a species that is dependent upon dynamic landscapes for nesting, foraging, and wintering. Atlantic coast piping plovers were listed as threatened under the U.S. Endangered Species Act (ESA) in 1986. Since listing, the population has risen from 790 pairs in 1986 to more than 1,898 pairs in 2012 (USFWS 2013), a 140 percent increase. Although overall conservation of this species has shown great recovery success through protection and management, regional population growth has fluctuated. Given that this species exists in dynamic landscapes that are heavily influenced by humans, an understanding of factors that limit population size and growth rate are important to reach recovery.

PIPING PLOVER LIFE HISTORY

There are three distinct breeding populations of piping plovers occurring in North America: the federally endangered Great Lakes population, the federally threatened northern Great Plains population, and the federally threatened Atlantic Coast population (USFWS 1996). Atlantic coast piping plovers nest on barrier islands and coastal beaches from North Carolina to Newfoundland (USFWS 1996). Adults typically arrive on the breeding grounds mid- to late-March, and first nests appear mid-April to early-May. Nest site selection is primarily driven by proximity to adequate moist substrate habitat for foraging (Cohen 2005), which provides more arthropod prey items than other habitat types (Loegering and Fraser 1995). This foraging habitat provides such a reliable food source that adult piping plovers will select nest sites adjacent to

moist substrate despite physical barriers such as houses or dunes that may affect their chicks'

ability to also access this habitat (Fraser et al. 2005, Cohen et al. 2009).

On the Atlantic coast, piping plovers tend to nest in open, sandy, sparsely vegetated sites,

preferring areas which have been recently disturbed by storms. Historically, populations would

colonize these early-successional habitats and abandon sites as they became revegetated or

colonized by predators (Wilcox 1959; USFWS 1996). Piping plovers are distributed along the

Atlantic coast across the historic breeding range except South Carolina, although the amount of

available nesting habitat has dramatically declined leading to decreases in abundance and patchy

distributions.

Upon arrival at the nesting areas, males begin to establish territories through aerial

displays, horizontal threat displays, and parallel run displays which help form territorial

boundaries (Cairns 1982). Territory sizes of Atlantic coast breeders in Nova Scotia range from

$500 - 8000$ m^2, averaging 4000 m^2, and nesting and feeding territories tend to be contiguous

(Cairns 1982). Distances between nests range between $51 - 53$ m in Nova Scotia (Cairns 1982)

and between $85 - 100$ m in New Jersey (Burger 1987). Additionally, Cohen et al. (2009) found

that nesting pair densities on Long Island, New York was a maximum of 1.05 nesting pairs/ha of

potential nesting habitat.

Males perform courtship displays that include nest-cup scraping and tilt displays, that can

result in copulation (Cairns 1982). These courtship events can last several weeks prior to a

female choosing a nest cup for egg laying (Cairns 1982). Females lay one egg every other day

until the clutch is complete (Wilcox 1959, USFWS 1996). In Nova Scotia, the egg-laying period

lasts 5 to 6 days (Cairns 1982) and 4 to 8 days in Manitoba (Haig and Oring 1988b). Males and

females share incubation responsibilities equally (Wilcox 1959, Cairns 1982). Nests hatched

after 27 to 28 days in Nova Scotia (Cairns 1982), 22 to 31 days in Manitoba (Haig and Oring 1988b), and 27 to 31 days on Long Island (Wilcox 1959). Most eggs in a clutch hatch within 4 – 8 h of one another (Wilcox 1959, Cairns 1982).

Piping plover chicks are precocial; upon hatching, they are covered with down and leave the nest within a few hours to begin foraging with supervision by their parents (USFWS 1996). This parental care strategy requires eggs that are energy-rich allowing the hatched chick to be relatively independent of its parent (Ar and Yom-Tov 1978). Chick survival is highly dependent upon availability of food resources, and chicks failing to reach 60 percent of the mean weight by day 12 are less likely to survive than heavier chicks (Cairns 1982). Although piping plover chicks forage without the help of their parents, one or both adults continue to remain with the chicks until fledging to provide shelter during harsh weather and to provide defense against predators (USFWS 1996).

Fledge times of piping plover chicks vary. Wilcox (1959) reported fledging times on Long Island to occur between 30 – 35 days and Cairns (1982) reported fledgling times in Nova Scotia to occur between 25 – 32 days. Southward migration to wintering areas usually begins in late July with most birds having departed their nesting beaches by the end of September (USFWS 1996).

REASONS FOR DECLINE AND THREATS TO RECOVERY

Human population centers tend to be located near coastal areas and beach use for recreational purposes has increased dramatically since the end of World War II (USFWS 1996). Off-road vehicle and recreational vehicle access to beaches has become increasingly popular with beach visitors. According to the U.S. Fish and Wildlife Service Recovery Plan (1996), approximately 4,000 off-road vehicle permits were issued for Sandy Neck Beach in Barnstable,

MA in 1989. At the time that these permits were issued, Sandy Neck Beach supported only 5 pairs of piping plovers (USFWS 1996). However, in 1990 vehicle restrictions were enforced to discourage off-road vehicles from crushing eggs and running over chicks (USFWS 1996). In 2010, the reported number of piping plovers nesting at Sandy Neck Beach, MA was 38 pairs (Melvin 2010). Despite intensive ORV management limiting the number of vehicles passing piping plover broods, chicks have still been documented to have been lost at high rates (Melvin 1994). Off-road vehicles have been shown to cause significant changes in beach-dune morphology (Houser et al. 2013); increasing the rate of erosion of these beaches can lead to additional loss of nesting and foraging habitat for piping plovers. Off-road vehicles also displace invertebrates by decreasing wrack (i.e. organic material such as eel grass cast onto the beach by surf or high tides) and tend to kill other beach dwelling invertebrates (Kluft and Ginsberg 2009), demonstrating the adverse effect that off-road vehicles can have to the prey base of piping plovers.

Pedestrians also cause considerable threats to piping plovers through direct mortality or harassment. Burger (1994) found that within several cover types, piping plovers selected sites that contained fewer people and the time piping plovers spent actively foraging was negatively associated with human presence. Goldin and Regosin (1998) found that piping plover broods with access to salt-pond mudflat foraging habitat experienced higher fledge success than broods limited to ocean side foraging habitat. Additionally, broods with access to salt-pond mudflats for foraging spent only 1.6 percent of the time responding to human disturbance whereas broods with restricted access to oceanside foraging habitat spent 17 percent of their time responding to human disturbance (Goldin and Regosin 1998). Pedestrian disturbance can lead to increased energetic output leading to a lack of sufficient energy reserves for chicks and adults.

Piping plovers are highly dependent on dynamic beach landscapes for successful breeding; they tend to nest in open, sandy, sparsely vegetated sites, preferring areas that have been recently disturbed by storms. One of the first studies of piping plovers on the Atlantic coast examined nesting behavior from 1937 to 1957 (Wilcox 1959). During the first year of the study, the nesting area comprised a 1.6 km stretch of beach on Long Island, New York, east of Moriches Bay, and only four pairs of piping plovers were found to be nesting. Following the initiation of the study, several storms caused overwash events on the beaches, leading to the creation of new piping plover nesting habitat. Following a hurricane in September 1938, the study area had been extended to include a total of seventeen miles of nesting habitat from Moriches Inlet to Shinnecock Bay; between 1940–1942 a peak of 64 pairs of piping plovers were documented nesting in this stretch of beach, until hand-planting of vegetation to stabilize the dunes (Wilcox 1959). Studies have since examined the effects of human-created habitat as well as storm created habitat. Following both storm and human-created habitat improvements for both nesting and foraging, the number of pairs at West Hampton Dunes, Long Island, NY increased from 5 pairs in 1993 to 39 pairs in 2000 (Cohen 2009). The increase in piping plovers at West Hampton Dunes from 1993 – 2000 was followed by a rapid decline which was attributed to human development (Cohen 2009). Beach stabilization processes aimed at diminishing or reversing the impacts of storms often lead to increased rates of habitat degradation and increased human development along the coast leads to decreases in available nesting habitat.

Increased rates of predation have also contributed to the decline of the population and continue to threaten recovery efforts. Predator types tend to vary by location, but include American crow (*Corvus brachyrhynchos*), common grackle (*Quiscalus quiscula*), Eastern coyote (*Canis latrans*), red fox (*Vulpes vulpes*), striped skunk (Mephitis mephitis), raccoon (*Procyon*

lotor), Virginia opossum (*Didelphis virginiana*), large gull species (*Larus* spp.), great-horned owl (*Bubo virginianus*), feral cat (*Felis catus*), and Atlantic ghost crab (*Ocypode quadrata*) (Patterson et al. 1991, Watts and Bradshaw 1995, USFWS 1996). Nest predation by American crow was the primary cause of nest loss in the Cape Cod National Seashore, Massachusetts in 1993 and 1996, accounting for more than half of the nest failures, followed by abandonment of the nest and predation of the eggs by red fox (Hoopes 1996a, b). Nest predators at Assateague Island National Seashore accounted for 91 percent of nest losses from 1986 – 1987 and included red fox (47.6 percent), raccoon (28.6 percent), and avian predators (14.3 percent) (Patterson et al. 1991). Approximately 30% of nest losses in West Hampton Dunes, NY from 1993-2004 were due to red fox (Cohen et al. 2009). Because predators of piping plovers tend to be generalist species that often respond favorably to human activity, predator abundance appears to have increased as human recreational use and human development have increased (USFWS 1996).

The barrier islands that piping plovers use for nesting and foraging are dynamic landscapes in a continual state of change, and sea-level rise may pose an additional threat to the species continued existence. In addition, the New Jersey coastline has experienced higher rates of erosion due to sea level rise than other parts of the Atlantic coast (Zhang et al. 2004). Human development on New Jersey barrier islands can obstruct the ability of sediment to washover islands, increasing the rate of erosion, and further reducing the amount of sandy beach available for piping plovers to nest (Feagin et al. 2005). Seavey et al. (2011) demonstrated that if washover events are prevented and plover habitat is unable to migrate due to human development, then sea-level rise is likely to reduce the amount of breeding habitat available for piping plovers in New York. While sea-level rise is not an immediate threat, future habitat loss due to sea-level rise is may increase extinction risk for piping plovers.

CURRENT MANAGEMENT STRATEGIES

Population monitoring is an integral part of recovery efforts for Atlantic Coast piping plovers (USFWS 1996, Hecht and Melvin 2009). Monitoring allows wildlife managers to follow nest survival and productivity, assess effects of management actions and regulatory protection, and track progress toward recovery. A coast-wide effort to summarize data on abundance, distribution, and reproductive success of piping plovers has continued since the species' ESA listing. Recovery actions include procedures to reduce the amount of habitat loss due to human development and management techniques to protect adults, eggs, and chicks from predators and disturbance (Hecht and Melvin 2009). Management techniques include extensive monitoring of breeding pairs from the time of arrival on the nesting grounds until the time of departure, symbolic fencing to provide buffers around nesting areas preventing human disturbance, predation management including the use of exclosures to protect nests (Melvin et al. 1992) or lethal predator removal, and off-road vehicle restrictions to allow broods to forage without interference or mortality from vehicles. The financial cost of recovery efforts has been substantial: total estimated expenditures for protecting U.S. Atlantic coast piping plovers were estimated to be $2.28 million in 1993 and $3.44 million in 2002 (Hecht and Melvin 2009). Additionally, paid staff time was estimated to be 93 hours/pair in 1993 and 95 hours/pair in 2002 (Hecht and Melvin 2009). Removal of a species from protections of the ESA requires both increases in abundance, distribution, and reproductive success as well as improvements in factors that led to listing of the species (Hecht and Melvin 2009).

Despite intensive management that aligns with recovery plan guidelines, the population of piping plovers nesting in New Jersey has seen no increase in abundance since the species' listing. Large-scale habitat restoration has been successful for the interior population (Catlin et

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al. 2011); however, restoration on the Atlantic coast has been primarily limited to incorporating habitat improvements into beach stabilization projects and these improvements tend to be based on interior population requirements (Maslo et al. 2011). Maslo et al. (2011) identified specific targets for habitat restoration projects for piping plover nesting areas including the amount of vegetative cover, primary dune, shell/pebble cover, dune height, and dune slope. While these recommendations are useful for creating piping plover nesting habitat, Cohen et al. (2009) found that an increase in nesting habitat does not always lead to an increase in the local piping plover population, even during periods of population growth, because some sites may be limited by foraging habitat. Creating high-quality foraging habitat, especially for piping plover chicks, can lead to increases in overall reproductive success, allowing for local and regional population growth. Determining specific foraging habitat requirements that maximize chick growth rates and survival would allow for more comprehensive recommendations for Atlantic coast piping plover habitat restoration projects. Additionally, understanding factors influencing the spatial and temporal distribution of predators can help inform restoration projects regarding specific habitat configurations because piping plover abundance and reproductive success may also be limited by the presence of predators.

The goal of our study was to understand the roles of predators, foraging habitat, and management actions in piping plover population dynamics in New Jersey. Our results will lead to more comprehensive recommendations for predation management and restoration to land managers within New Jersey that will simultaneously reduce predation pressures and create habitat to begin recovery within the state. Chapter 2 examines the complex interactions among two predator species in New Jersey—red foxes and American mink—and evaluate nest and chick survival at sites where red foxes are absent from the landscape. The audience for Chapter 2

includes wildlife managers who intend to use predator control as a management tool to increase nesting success for birds. Chapter 3 provides estimates of true survival for piping plover adults and juveniles in New Jersey as related to exclosures and abandonment of nests. The audience for Chapter 3 includes wildlife managers that use exclosures to improve nesting success of ground-nesting birds. Chapter 4 examines red fox habitat use across piping plover nesting habitat as it relates to landscape-level features. Chapter 4 was submitted to the Journal of Wildlife Management in November 2019, and revisions will be submitted in April 2020.

CHAPTER 2 MESOPREDATOR RELEASE BY REMOVAL OF A TOP CARNIVORE AFFECTS BEST MANAGEMENT PRACTICES FOR AN ENDANGERED SHOREBIRD

ABSTRACT Management of predators to benefit endangered species can be complicated by interactions among predator species. Removal of top predators may result in mesopredator release, leading to unchanged or even increased predation levels by intermediate predators after management. Moreover, lethal predator removal can be costly and controversial, and the effectiveness therefore needs to be better understood. We examined the effect of red fox (*Vulpes vulpes*) habitat use on American mink (*Neovison vison*) habitat use at sites used by the federally threatened piping plover (*Charadrius melodus*) in New Jersey, 2015-2017. We also examined the relationship between nest predation and chick survival and red fox presence on beaches. We included the effect of predator exclosure cages on nest survival, which exclude red foxes but not mink from predating nests. The average probability of mink occupancy in a beach plot was higher when red foxes were absent (0.79 [95% CI = 0.14, 0.98]) than when they were present (0.05 [0.01, 0.26]). Interval nest predation was similar at sites with red foxes (0.45 ± 0.11 SD) and without red foxes (0.43 ± 0.10) for nests not protected by predator exclosures, but predation rates were higher for exclosed nests at sites without red foxes (0.20 ± 0.08) than sites with red foxes (0.06 ± 0.04). These findings demonstrate the complexity of interactions between predation management techniques and the predator community in determining benefits to endangered beach-nesting birds. The best management decision in our study area depends on which predators are present, and some often-used methods are detrimental in common circumstances.

KEYWORDS American mink, *Charadrius melodus*, endangered species, habitat use, multispecies occupancy, *Neovison vison*, New Jersey, piping plover, red fox, *Vulpes vulpes*

Many complex food webs are regulated by top predators which can influence the density, size, and productivity of prey populations. The actions of such predators can often determine the equilibrium state of ecosystems. For example, in Alaskan coastal areas when sea otters (*Enhydra lutris*) are present, sea urchins, which primarily consume kelp, are rare and kelp is abundant; however, when sea otters are absent from the system, sea urchins are common, and kelp coverage is considerably reduced (Estes and Duggins 1995, Steinberg et al. 1995). Thus, the disappearance or removal of a top predator from an ecosystem can result in the expansion of smaller predator populations and alteration of the food base. This is known as trophic cascade, which can lead to decreases in survival or productivity at lower trophic levels (Ritchie and Johnson 2009, Chakarov and Krüger 2010).

Understanding how removal of top predators from an ecosystem may affect conservation goals is important because trophic cascades may have implications for declines and extinction of species (Palomares et al. 1995, Sovada et al. 1995, Rogers and Caro 1998, Chalfoun et al. 2002). One potential component of a trophic cascade is mesopredator release, in which loss of high level predators increases abundance of lower level predators, with detrimental effects on prey animals. Removal of feral cats (*Felis catus*) from an oceanic island ecosystem, caused declines in success of Cook's petrels (*Pterodroma cookie*; IUCN Red List, Vulnerable) due to an increase in nest predation by the Pacific rat (*Rattus exulans*) at certain elevations (Rayner et al. 2007). Similarly, in the Strzelecki Desert of Australia, Gordon et al. (2017) observed that little button-quail (*Turnix velox*) abundance was much greater in areas where the predator composition was dominated by dingoes (*Canus lupus dingo*) and red foxes (*Vulpes vulpes*) were rare than where red foxes were the main carnivores present. A better understanding of the complexity of species

interactions in multi-predator communities and how they contribute to the maintenance of species diversity is needed in many places where prey species are of conservation concern.

Mesopredator populations may be regulated via two possible biological mechanisms: intraguild predation (Schoener 1983) or avoidance of habitat used by larger predators (Lima 1998). Trophic cascades generated by the decline or removal of dominant predators from the ecosystem may be related to effects of humans on the landscape. Central and eastern populations of fisher (*Pekania pennanti*) are expanding their ranges due to reductions in abundance of predators such as bobcat (*Lynx rufus*), cougar (*Puma concolor*), coyotes (*Canis latrans*) and wolves (*Canis lupus*) due to habitat fragmentation, habitat loss, and overharvest (LaPoint et al. 2015). Fisheries data suggest that increases in fishing effort for large, commercially-valuable fishes have resulted in an increase in the abundance of species of low commercial value such as dogfish, which then prey on small, commercially-valuable fishes such as herring (*Clupeidae* spp.) and mackerel (*Scombridae* spp; Fogarty and Murawski 1998). Predation pressure on vulnerable bird species by native and non-native predators has led to the removal of top predators – by culling or translocation – from ecosystems (Smith et al. 2010), yet the impact of predator removal on the remaining predator communities is not often considered.

Predator removal programs have been implemented to increase nesting success of waterfowl and other game birds (Balser et al. 1968). More recently, wildlife managers have used predator removal to increase nesting success of endangered bird species where predation has become a serious impediment to recovery (Neuman et al. 2004). However, predator removal programs may target an inappropriate trophic level, as many programs to benefit endangered species do not consider the complex competitive interactions among predators. For example, in the Cook's petrel study (Rayner et al. 2007), concurrent removal of feral cats (top predator) and

rats (mesopredator) resulted in higher petrel productivity (Rayner et al. 2007), demonstrating that when mesopredator release occurs, eradication of only a top predator may not be the best solution to protect endangered species. Given the increasing desire to target specific nest predators for species of conservation concern, it is important to understand the potential secondary effects of predator removal programs and plan accordingly.

The effects of predator control on nesting bird populations may differ depending upon the type of predators, intensity of predation, degree of predator control, and prey species being impacted (Wagner et al. 1965, Smith et al. 2010). For example, there was little change in ring-necked pheasant (*Phasianus colchicus*) abundance either where predator control was limited to only one predatory species (NYS DEC 1951) or where only avian predators were controlled (Allen 1956). Additionally, Clark et al. (1995) found that duck nesting success did not increase in areas where only corvids were removed. However, other studies have reported increased survival and higher productivity of birds where predator control was applied to both avian and mammalian predators (Littlefield 2003, Smith et al. 2010, Lavers et al. 2010). These studies indicate that the removal of one predator species from a community of predators may not lead to predictable increases in breeding success of birds of conservation concern. Removal of one predator species may be ineffective due to increasing predation rates by intermediate predators, which potentially supports the mesopredator release hypothesis.

Predator removal has been employed as a management tool to increase productivity of the threatened Atlantic Coast piping plover (*Charadrius melodus*) population in all parts of the species range. Between $2–3 million are spent annually on recovery efforts for this population (Hecht and Melvin 2009), but the efficacy of predation management is still not well understood. Elevated rates of predation on piping plover eggs, chicks, and adults contributed to the initial

decline of the Atlantic coast population which was listed as threatened under the U.S.

Endangered Species Act (ESA) in 1986. Predators of piping plover eggs and chicks tend to be

generalist species with wide distributions that respond favorably to the presence of humans

(Marzluff and Neatherlin 2006, Bino et al. 2010). Nest predators at Assateague Island National

Seashore accounted for 91% of nest losses from 1986–1987 and included red fox (47.6%),

raccoon (28.6%), and avian predators (14.3%; Patterson et al. 1991). Approximately 30% of nest

losses in West Hampton Dunes, NY from 1993–2004 were due to red fox (Cohen et al. 2009).

From 2012–2016, avian and mammalian nest predators in New Jersey accounted for 23.3 to

52.1% of all nest losses (Pover and Davis 2012, 2013, 2014, 2015, 2016).

Because piping plover abundance and reproductive success can be limited by predation, it

is important to gain a better understanding of the management strategies used to mitigate the

impacts of predators. We tested the interaction between red fox and other mesopredator species

at breeding beaches of piping plovers where red foxes are the dominant predator and are

routinely removed. We used a two-species occupancy model, where the probability of occupancy

for one species is conditional upon the presence of a dominant species (Richmond et al. 2010,

Rota et al. 2016), to examine the occupancy probability of mesopredator species (American

mink, *Neovison vison*; raccoon, *Procyon lotor*; striped skunk, *Mephitis mephitis*; Virginia

opossum, *Didelphis virginiana*; subordinate species) when red foxes (dominant species) were

absent. We expected that if mesopredator release was occurring, mesopredator occupancy would

increase in the absence of red fox, as mesopredators may move into areas when red foxes are not

present (Carlsson et al. 2010).

We further examined the relationship between red fox occurrence and American mink on

the landscape, as these two mammalian predators were responsible for depredating the most

nests during our study period. We studied daily nest and chick survival of piping plovers in New Jersey from 2015–2017 at sites where the presence of red fox and American mink varied. We expected that if red foxes were either naturally absent or removed from the landscape, and mesopredator release of mink were not occurring, we would see a decrease in nest predation rates; however, if mesopredator release were occurring, then we would expect to see that predation rates on nests and chicks would remain the same or increase. If mesopredator release does not occur, then removing a top predator species from the landscape should help to ease predation pressures; however, if mesopredator release does occur, then a thorough and more comprehensive predation management strategy that targets multiple interacting species may be necessary to promote reproductive success for endangered species.

METHODS

Study Area

We selected eight study sites in southern New Jersey, USA between 2015–2017 (Fig. 2.1). Study sites included Barnegat Lighthouse State Park, Barnegat Light (BALI); Holgate Unit, E.B. Forsythe National Wildlife Refuge, Long Beach Township (HOLG); North Brigantine Natural Area, Brigantine (NBNA); Malibu Wildlife Management Area and Seaview Harbor Marina, Longport (MWMA); Avalon-Dunes, Avalon (AVDU); Stone Harbor Point, Stone Harbor (SHPT); North Wildwood Beach, North Wildwood (NOWI); and Cape May Point State Park and South Cape May Meadows, Cape May Point (CMPSP). We chose study sites that represented a variety of habitat configurations that consisted of differing arrangements of nesting habitat and foraging habitat for piping plovers and various levels of human use. For example, study sites such as NBNA, HOLG, and SHPT occurred at the ends of barrier islands further from human development than other beaches, with large open areas created by storms overwashing the

beach (i.e., overwash fans) that provide habitat for beach-nesting birds. In contrast, sites such as AVDU, NOWI, and BALI were proximal to human development and contained linear dune systems devoid of overwash fans, so birds were confined to linear strips of habitat along the ocean shoreline. Additionally, many anthropogenic and natural factors have likely contributed to a mosaic pattern of red fox abundance along the New Jersey coast, and we incorporated those factors as covariates in our study. While red foxes were removed to some degree at all study sites, not all red foxes were removed from all sites in all years.

Occupancy Modeling

We used occupancy models based on repeated predator track (i.e. footprint) surveys to understand the relationship between red fox and mink occupancy in piping plover nesting habitat. To generate survey plots, we downloaded the 2012 Land Use/Land Cover Map for New Jersey (NJDEP/OIRM/BGIS 2015), then uploaded the GIS data into ArcMap (ArcGIS 10.1) and selected the dune and beach polygons, assuming these would best represent piping plover habitat. We used the random point generator in ArcMap to place random points 50–200 m apart within the dune and beach features. We chose 50 m as our minimum distance to prevent overlapping of survey plots, and 200 m as the maximum distance, which represented half the distance of the widest site. During the first survey period of the study, we ground-truthed each plot location to validate the land cover and marked the plot with a wooden stake for ease of navigation in future surveys. We removed points that were in cover types such as forested areas, thick vegetation, or saltmarsh where identifying predator tracks would not be feasible. Any points that remained contained substrates such as sand, sand/mud, mud, sand/shell, sand/cobble, or bare soil where predator tracking would be practicable.

We recorded detections of mammalian predator tracks at each plot every two weeks between 15 April–15 August to ensure tracks would not persist between survey periods and following at least 24 hr of good weather (i.e. wind <10 kph, no rain within 24 hr) to optimize tracking conditions. Predator tracks were identified by experienced surveyors who were also trained specifically to identify predator tracks by an expert tracker. Further, surveyors were able to reference a field guide in circumstances where tracks might have been difficult to identify (Elbroch 2003).

In order to estimate predator occupancy, we counted the number of trails of tracks by each species present within a 10 m radius of the plot center. We tied a 10 m long string to the wooden stake marking the center point, then walked a circle around the wooden stake to provide an outline for the 10 m radius. Because beach features can change between seasons, we downloaded the 2015 New Jersey High Resolution Orthoimagery (NJOIT/OGIS 2016) to visually classify the anthropogenic and geomorphic features for the 2015 and 2016 field seasons. We then downloaded the 2017 New Jersey High Resolution Orthoimagery (NJOIT/OGIS 2018) to visually classify the anthropogenic and geomorphic features for the 2017 field season. We used the "Near" tool in the ArcMap (ArcGIS 10.5.1) Toolbox (located under "Proximity") to digitize and calculate covariates that may affect the presence of predators including the distance to dunes (nearest m), distance to forest, distance to wetland (fresh or saltwater), distance to overwash, distance to human development, and distance to roads. We digitized areas of human development that included static and stable features such as houses or other buildings, and we digitized roads to include paved roads and parking lots.

Given that a plot was within the home range of a predator, our detection of its tracks depended on 1) whether the predator used that part of its home range just prior to our survey and

2) if it did, whether we were able to discern and correctly identify its tracks. There were few tracks that we were unable to identify (Appendix 2.A). If we were unable to identify a track within a plot with 100% certainty, we recorded the track as unknown mammal and these tracks were not included in the models. We attempted to complete surveys only during periods of good weather; therefore, we did not include weather covariates in our detection models. Additionally, because observers varied by year, we included year as a covariate for detection.

We used a single season, conditional two-species occupancy model (Richmond et al. 2010, Rota et al. 2016) in program R (R Core Team 2019) using package unmarked (Chandler and Fiske 2011) to fit the two-species occupancy model of Rota et al. (2016). Random temporary emigration of a species between surveys was possible; therefore, we interpreted our occupancy parameter as the probability of habitat use rather than occupancy (Kendall et al. 2013). We tested for correlation among land cover covariates (straight line distances to road, wetland, dune, development, forest [m]) using the Pearson's pairwise correlation (Soper et al. 1917) in program R (R Version 3.5.1, www.r-project.org, accessed 7 Feb 2018) using the GGally package (Schloerke et al. 2018), and we did not use variables that were highly correlated in our models ($-0.5 < r < 0.5$; Mukaka 2012, Schober et al. 2018). We ranked the models based on Akaike's Information Criterion (AIC) and selected the best model based on the lowest AIC value (Burnham and Anderson 2002). We considered all models with a likelihood of <0.125 to have some support (Burnham and Anderson 2002). We generated predicted values for Ψ^A = probability of occupancy for red foxes, Ψ^{BA} = probability of occupancy for mink when foxes are present, Ψ^{Ba} = probability of occupancy of mink when foxes are absent, p^A = probability of detection for red foxes, and p^B = probability of detection for mink using the top model or model-averaging if there was ambiguous evidence for a top model (Burnham and Anderson 2002).

Nest and Chick Survival

In our study region, managers often placed wire exclosure fences around plover nests to minimize predation rates (Melvin et al. 1992). We therefore used different traps to capture plovers at nests with no exclosure than exclosed nests. For nests with no exclosures, we captured adult plovers using walk-in funnel traps at active nests (Cairns 1977), whereas for exclosed nests we blocked 75% of the base of the exclosure with 0.6 m-tall chicken wire, leaving an exit into a mist-net funnel (J. Cohen, unpubl. data). We uniquely marked adult piping plovers with either two colored Darvic leg bands (model XCLD, internal diameter 3.1mm, AVINET, Dryden, New York) on each tibiotarsus or a combination of a Darvic leg band on one tibiotarsus and a multi-layered impact acrylic coded flag (internal diameter 3.1 mm, Interrex, Lodz, Poland) on the opposite tibiotarsus, depending on the study site.

Field technicians assessed nest status (i.e., active, hatched, depredated, overwashed, abandoned, buried, or lost to unknown cause; Table 2.1) every 1–7 days. For nests that hatched, we monitored brood status every 1–7 days, identifying broods based on established territories or proximity of banded parents, until all chicks had reached 25 days, were observed flying ≥ 40 m, or were assumed dead based on the absence of the chicks and parents well before the expected fledge date.

We modeled the probabilities of different nest fates (survival, predation, abandonment, weather) as a function of red fox presence (a binary variable based on whether presence was noted at least once during the nesting period [4 May–28 June] during occupancy surveys) using logistic exposure models (Shaffer 2004) extended to multinomial form (Darrah et al. 2018). We also included an effect of nest exclosures and an interaction between exclosures and red fox presence because exclosures should reduce nest predation to near zero if predators cannot get

inside, but it may be above zero if predators can. We used Young Survival models (Lukacs et al. 2004) to compare daily chick survival between broods reared at sites with and without red foxes present. Young Survival models correct for imperfect detection of chicks, account for non-independence among brood mates, and rely on the brood rather than individual chicks being uniquely identified. Baseline probabilities of nest predation and chick survival, and effectiveness of exclosures, may depend on site-specific factors such as predator communities. We therefore included random site intercepts for the linear predictor for predation in our nest fate model and for our Young Survival model. In the Young Survival model, we included a random site intercept for detection probability because visit frequency varied among sites, and longer visit intervals can increase the difficulty in locating broods, which are highly mobile. Models also included a fixed effect of chick age, in days.

We analyzed nest and chick survival in a Bayesian framework by specifying models in the BUGS language, with posterior distributions for parameters of interest estimated using Markov Chain Monte Carlo (MCMC) simulation with Gibbs sampling as implemented in JAGS v. 3.4.0 (Plummer 2013), called from program R via the package jagsUI (Kellner 2017). We used wide non-informative priors for all parameters: a normal distribution with mean 0 and variance 1000 for all coefficients in the linear predictors, and a uniform distribution between 0–50 for all variance parameters. We checked for convergence of 3 parallel MCMC chains per model by visually inspecting the trace plots and by using the Gelman-Rubin diagnostic ($\hat{R}$; Gelman 2004) and considered convergence to be achieved at $\hat{R} < 1.05$ for all parameters. We considered covariates to be important predictors if the 95% credible intervals on the regression parameter did not overlap zero (Kuo and Mallick 1998, Link and Barker 2006).

RESULTS

Occupancy Modeling

We conducted 24 mammalian predator track surveys at 90 plots among 8 study sites between 15 April–15 August in 2015–2017. We had a total of 373 red fox detections, 107 mink detections, 104 skunk detections, 77 raccoon detections, and 41 opossum detections across years and study sites (Fig. 2.2). We found a high degree of correlation between the distance to dune and distance to forest covariates, presumably because most primary dunes are backed by maritime forest on barrier islands. Additionally, we also found a high degree of correlation between the distance to human development and distance to road covariates, likely because all human development is accessed by roads on New Jersey barrier islands. Forests provide denning sites for red foxes but piping plovers are not found in forests, and because we were interested in how predators were using piping plover habitat, we chose to use distance to dune in our models rather than distance to forest. Because roads were associated only with human development at all our study sites except Malibu Wildlife Management Area, we chose to remove distance to road from our models and use distance to human development as the feature that may be most representative of cover areas or sources of human-subsidized food for predators.

Because data for raccoons, striped skunks and Virginia opossums were scarce (multi-species occupancy models would not converge), we were unable to include covariates in the multispecies occupancy models for these species; therefore, we report only the null model results for each of these relationships (Appendix 2.A). Of the 47 candidate models for species occupancy of red fox and American mink, a negative relationship with distance to human development was in 4 of the 5 top models for occupancy for both red foxes and American mink; however, several models strongly competed for the best approximating model, including the null

model for both species (Table 2.2). Model-averaged occupancy probability for red foxes was 0.95 [95% CI = 0.44, 0.99]. Model-averaged occupancy probability for mink when red foxes were absent (0.78 [0.14, 0.98]) was 176% greater than average occupancy probability when red foxes were present (0.05 [0.01, 0.26]); Fig. 2.2). Detection probability was lower for mink (0.13 [0.09, 0.17]) than for red foxes (0.24 [0.21, 0.27]).

Nest and Chick Survival

Of 116 known nest attempts for pairs nesting at sites where red foxes were present, 49.4% were successful (i.e., at least one egg hatched), compared to 43.3% of 125 nest attempts for pairs nesting at sites where red foxes were absent (Table 2.3). As evidenced by tracks at the nest bowl, mink and red fox were responsible for depredating more nests than any other predators (Fig. 2.3). Moreover, no nest predations by opossums, skunks, or raccoons were observed at sites with red foxes (Fig. 2.3). Exclosures had a significant positive effect on nest survival (Table 2.4). Nest predation was lowest for nests that were exclosed at sites with red foxes, although variability was high for all categories (Fig. 2.4). The presence of red foxes at a site had no effect on nest abandonment probability at exclosed or unexclosed nests (Table 2.4). Additionally, chick survival rate was not significantly associated with red fox presence based on the 95% CBI on the regression coefficient, which overlap 0 (Table 2.5), and the confidence limits on model predictions, which overlap between the red fox presence categories.

DISCUSSION

Our results support the hypothesis that red fox removal initiates the release of the American mink, a mesopredator, in southern New Jersey and that the phenomenon may diminish the effectiveness of current best management practices for piping plover conservation. When the dominant predator species in our system was removed from the landscape, a smaller-bodied

mesopredator was more likely to be present, which had a negative association with reproductive success. These findings are in accord with those of Carlsson et al. (2010) in Sweden, who found that mink populations tripled as red fox populations declined due to an outbreak of sarcoptic mange, and as red fox populations recovered, mink populations subsequently decreased. Additionally, Crabtree and Wolfe (1988) found that nest predation rates by predators other than skunks was greater in experimental areas where skunks were removed than in areas where skunks were not removed further suggesting a complex relationship among predators on the landscape. In areas managed for endangered species, stable top predator populations may thus contribute to management objectives by restricting mesopredator access to prey populations.

Nest exclosures have been used as a less labor intensive and more cost-effective management tool to increase hatch success for piping plovers than predator removal; however, our results suggest that mesopredator release on the landscape can negate the effectiveness of nest exclosures in preventing nest predation. Other studies have also shown that the efficacy of deterring predators from nests using exclosures is highly dependent upon the predator species present. Nol and Brooks (1982) found that predator exclosures were an effective method for preventing gull predation of killdeer (*Charadrius vociferus*) nests, yet mammals were responsible for depredating more exclosed nests than unexclosed nests during this study. Specifically, they found that mink and long-tailed weasels (*Mustela frenata*) were able to enter the exclosure to depredate the eggs (Nol and Brooks 1982). Dinsmore et al. (2014) also noted that predator exclosures on snowy plover (*Charadrius nivosus*) nests did not exclude small mammalian predators, including deer mouse (*Peromyscus maniculatus*), short-tailed weasel (*Mustela erminea*), long-tailed weasel, and immature striped skunk. Additionally, the use of exclosures has been known to increase abandonment rates for piping plovers, which may indicate

adult mortality (Murphy et al. 2003, Roche et al. 2010). It is essential to understand the predator

community at a site prior to deploying exclosures because in many cases, enhanced productivity

may be outweighed by risks to adult birds.

Although our study focused on mammalian mesopredator release, trophic interactions

have also been documented between non-mammalian predators. At sites in Florida where

raccoons, a common predator of sea turtle eggs, were removed, Barton and Roth (2008) found

that egg predation rates were highest where raccoon abundance was lowest and ghost crab

(*Ocypode quadrata*) abundance was highest, and that ghost crab density decreased as raccoon

abundance increased. Ellis et al. (2007) found that great black-backed gulls (*Larus marinus*)

reduced the abundance of Jonah crabs at the Isle of Shoals, Maine which allowed common

periwinkles (*Littorina littorea*), dog whelks (*Nucella lapillus*), and blue mussels (*Mytilus edulis*)

to persist in higher numbers than when great black-backed gulls were absent. Trophic

interactions may also occur when non-mammalian mesopredators are removed from an

ecosystem. Bodey et al. (2009) found that when hooded crows (*Corvus cornix*) were removed,

home ranges of common raven (*Corvus corvax*) expanded and predation of artificial nests was

faster. Although we did not study avian or crab predation of plovers and their eggs, both are

known sources of mortality for piping plover eggs and chicks on the Atlantic Coast, adding more

complexity to trophic interactions in our system (Lauro and Tancredi 2002, Kwon et al. 2018).

Considerable resources are expended to manage predator populations of endangered and

threatened species to improve conservation outcomes; however, predator removal can result in

unforeseen consequences. Additionally, bearing in mind the public controversy associated with

removal of predators (Andelt et al. 1999), we encourage further research directed at examining

the interactions between nest predators in response to intensive predator removal as new predators may invade a region as quickly as other predators are removed.

By understanding the complex interactions among predators, wildlife managers may be able to exploit the ability of top predators to limit mesopredator populations and decrease predation pressures on endangered and threatened species. For example, the reintroduction of wolves to Yellowstone National Park in 1995 restored landscapes by suppressing over-abundant deer (Frank 2008, Ripple and Beschta 2012). As largemouth bass (*Micropterus salmoides*) were reintroduced to a Michigan lake, planktivorous fish numbers decreased, large-bodied daphnia (*Daphnia* spp.) species increased, and numbers of small-bodied cladocerans declined restoring the ecosystem to conditions prior to largemouth bass declines (Mittelbach et al. 1995). Our study found that the absence of red fox increased the presence of mink, and nest predation rates increased for exclosed nests at sites where mink were present. We did not find a significant effect of red fox or mink presence on nest abandonment rates and neither negatively affected chick survival. Thus, our results suggest that nest survival itself would be the primary demographic rate affected by managing red fox and mink in our system.

If managers are concerned about high nest predation rates of piping plovers, and lethal predator removal has been identified as a management strategy, a holistic approach to managing predators is necessary. For example, attempting to remove all individuals in a species-specific approach may lead to mesopredator release; however, targeting problem individuals may help to control predation effects by mesopredators. Sanz-Aguilar et al. (2009) found that selectively removing only 16 yellow-legged gulls (*Larus michahellis*) over a 3 year period led to an increase in breeding success of European storm petrels (*Hydrobates pelagicus*) demonstrating that the removal of specialized individuals can be an effective way to improve nesting success. In our

system, rather than targeting problem individuals, another option might be to funnel all predator

removal resources to piping plover source sites that serve as a source of emigrants, then

conducting extensive, on-going predator removal to ensure increased hatch success. On the other

hand, if non-lethal means of management are preferred, the careful use of predator exclosures

(Melvin et al. 1992) or predator harassment (Belant 1997, 2011) should be considered.

Table 2.1. Possible statuses of piping plover nests during nests checks in New Jersey, 2015–2017.

Status	Description
Active	Nest actively being tended by both adults; incubation observed
Hatched	Nest hatched; chicks present
Depredated	Nests lost to predation as evidenced by either 1) predator tracks at the nest bowl or 2) camera trapping photos
Overwashed	Nest lost to flooding as evidenced by the high tide line above the nest bowl, nest bowl no longer visible, and no predator tracks at the nest
Abandoned	Nest inactive; adults not tending eggs; no plover tracks at the nest bowl; eggs cold
Buried	Eggs covered with 3+ inches of sand following a high windstorm event, evidenced by digging out nest cup and finding eggs
Unknown	Eggs missing from the nest scrape with no reliable evidence as to the cause

Table 2.2. Model terms and information-theoretic model selection criteria for top two-species occupancy models examining interactions between red foxes and American mink in New Jersey, 2015–2017. Model parameters are as follows: Ψ^A = probability of occupancy for red foxes, Ψ^{BA} = probability of occupancy for mink when foxes are present, Ψ^{Ba} = probability of occupancy of mink when foxes are absent, p^A = probability of detection for red foxes, and p^B = probability of detection for mink, and a "." indicates an intercept-only model.

Ψ^A	Ψ^{BA}	Ψ^{Ba}	p^A	p^B	K	AIC	ΔAIC	Model likelihood	Model weight
Development	Development	Development	.	.	8	1441.47	0.000	1.000	0.143
Wetland+Development	Development	Development	.	.	9	1442.58	1.110	0.574	0.082
Development	Wetland+Development	Wetland+Development	.	.	10	1442.63	1.160	0.560	0.080
Development+Dune	Development	Development	.	.	9	1443.06	1.600	0.449	0.065
.	.	.	.	.	5	1443.24	1.780	0.411	0.059
.	Wetland	Wetland	.	.	7	1443.72	2.260	0.323	0.046
Wetland	.	.	.	.	6	1443.82	2.350	0.309	0.044
Development	Wetland+Development+Dune	Wetland+Development+Dune	.	.	12	1444.48	3.010	0.222	0.032
Wetland+Dune	.	.	.	.	7	1444.70	3.230	0.199	0.028

Development	Development+Dune	Development+Dune	.	.	10	1444.72	3.250	0.197	0.028
Dune	.	.	.	.	6	1445.17	3.700	0.157	0.022
Development	.	.	.	.	6	1445.23	3.770	0.152	0.022
Wetland	Dune	Dune	.	.	8	1445.26	3.800	0.150	0.021
.	Development	Development	.	.	7	1445.39	3.930	0.140	0.020
Dune	Wetland	Wetland	.	.	8	1445.40	3.930	0.140	0.020
Wetland+Dune+Development	Development+Dune	Development+Dune	.	.	12	1445.48	4.010	0.135	0.019
.	Wetland+Dune	Wetland+Dune	.	.	9	1445.63	4.160	0.125	0.018

Table 2.3. Sample sizes of nesting attempts and renesting attempts of piping plovers at sites where red foxes were present or absent in New Jersey, 2015–2017.

Event	Fox present	Fox absent	Total
Nest attempts	87	90	177
Renest attempts	29	35	64

Table 2.4. Summary statistics for posterior distributions of parameter estimates for multinomial logistic exposure piping plover nest fate model incorporating raw red fox detection/non-detection status from predator tracking surveys, New Jersey, 2015–2017.

Parameter	Mean	SD	2.5%	97.5%
Intercepts				
Predation[a]	-3.85	0.42	-4.80	-3.21
Flooding	-5.31	0.22	-5.78	-4.89
Abandonment	-6.07	0.60	-7.4	-5.04
Exclosure coefficient				
Predation	-1.08	0.39	-1.86	-0.33
Abandonment	0.44	0.77	-0.99	2.01
Fox present coefficient				
Predation	0.02	0.33	-0.61	0.66
Abandonment	-0.12	1.00	-2.25	1.78
Interaction coefficient				
Predation	-1.51	0.93	-3.47	0.18
Abandonment	0.35	1.20	-1.97	2.77
Site random effect SD				
predation, intercept	0.51	0.50	0.01	1.89

[a]Random effect hyperparameter

Table 2.5. Summary statistics for posterior distributions of parameter estimates for Young survival model for southern New Jersey piping plover chicks incorporating raw red fox detection/non-detection status from predator tracking surveys, 2015–2017.

			Quantile	
Parameter	Mean	SD	2.5%	97.5%
Intercepts				
Chick survival[a]	2.97	0.34	2.35	3.70
Detection[a]	2.34	0.19	2.00	2.80
Age coefficient				
Chick survival	0.07	0.02	0.04	0.10
Detection	-0.01	0.01	-0.03	0.00
Fox detection coefficient				
Chick survival	0.32	0.26	-0.21	0.83
Site random effect SD				
Chick survival	0.45	0.35	0.04	1.29
Detection	1.04	0.67	0.39	3.01

[a]Random effect hyperparameter
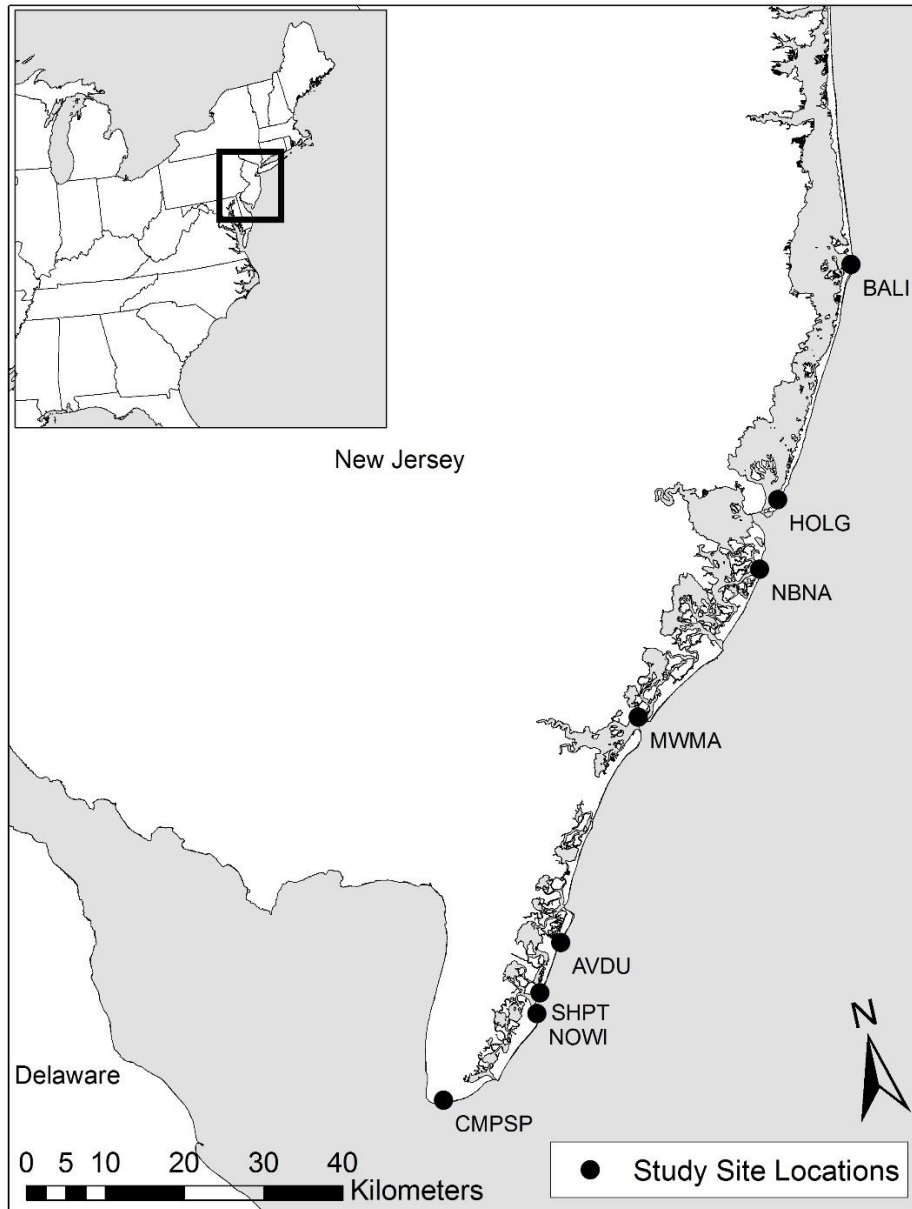
Figure 2.1. Locations of study sites for predator habitat use in piping plover nesting areas in New Jersey, 2015–2017. Study sites are labeled as follows: BALI, Barnegat Lighthouse States Park; HOLG, Holgate Unit, E.B. Forsythe NWR; NBNA, North Brigantine Natural Area; MWMA, Malibu Beach Wildlife Management Area; AVDU, Avalon-Dunes; SHPT, Stone Harbor Point; NOWI, North Wildwood; CMPSP, Cape May Point State Park.
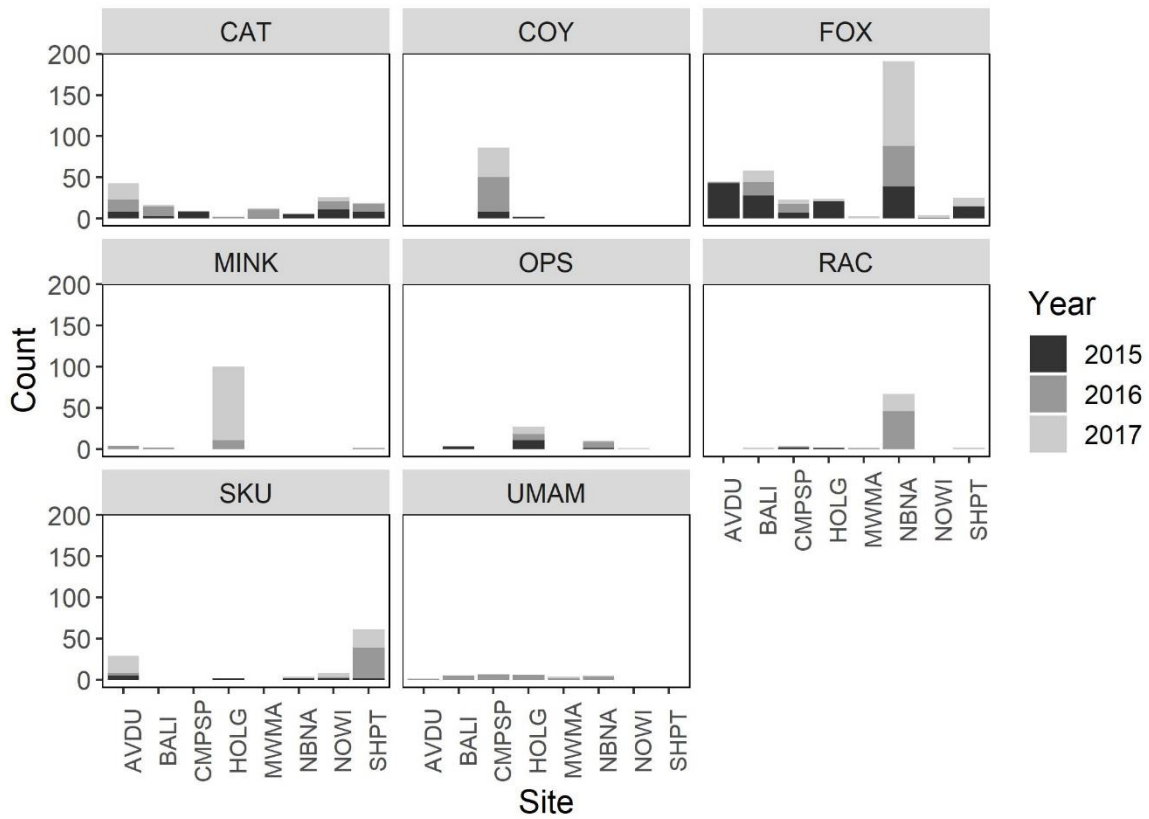
Figure 2.2. Number of detections of all mammalian predators at each study site in New Jersey, 2015–2017. Study sites are labeled as follows: BALI, Barnegat Lighthouse States Park; HOLG, Holgate Unit, E.B. Forsythe NWR; NBNA, North Brigantine Natural Area; MWMA, Malibu Beach Wildlife Management Area; AVDU, Avalon-Dunes; SHPT, Stone Harbor Point; NOWI, North Wildwood; CMPSP, Cape May Point State Park. Predator species include: feral cat, CAT; coyote, COY; red fox, FOX; American mink, MINK; Virginia opossum, OPS; raccoon, RAC; striped skunk, SKU; and unknown mammalian predators, UMAM.
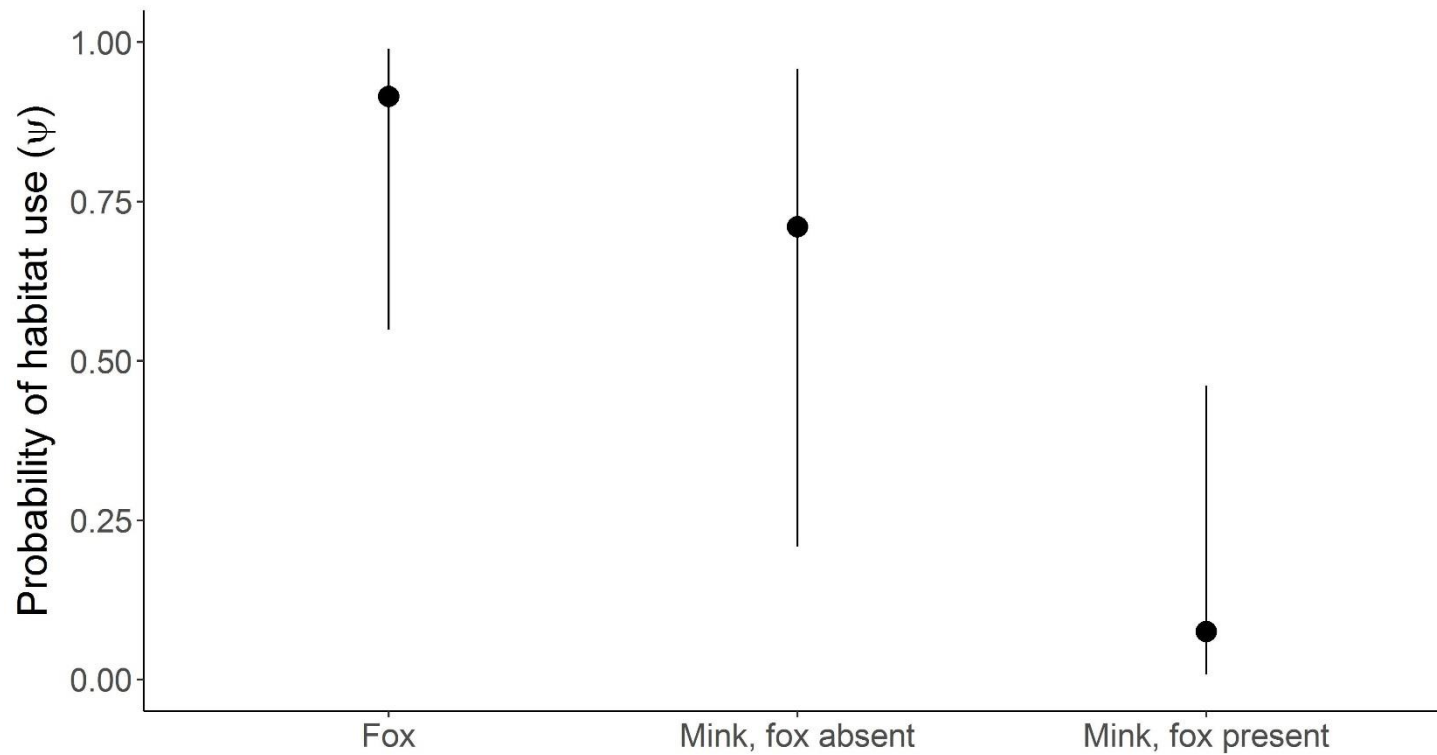
Figure 2.3. Model-averaged occupancy estimates from 46 candidate models for red foxes, mink when foxes were absent, and mink when foxes were present during the piping plover breeding season in New Jersey, 2015–2017, using predictions from a single season occupancy model based on predator track survey data (N = 90 plots, n = 24 surveys). Dots represent model-averaged estimates, whiskers represent 95% confidence intervals.
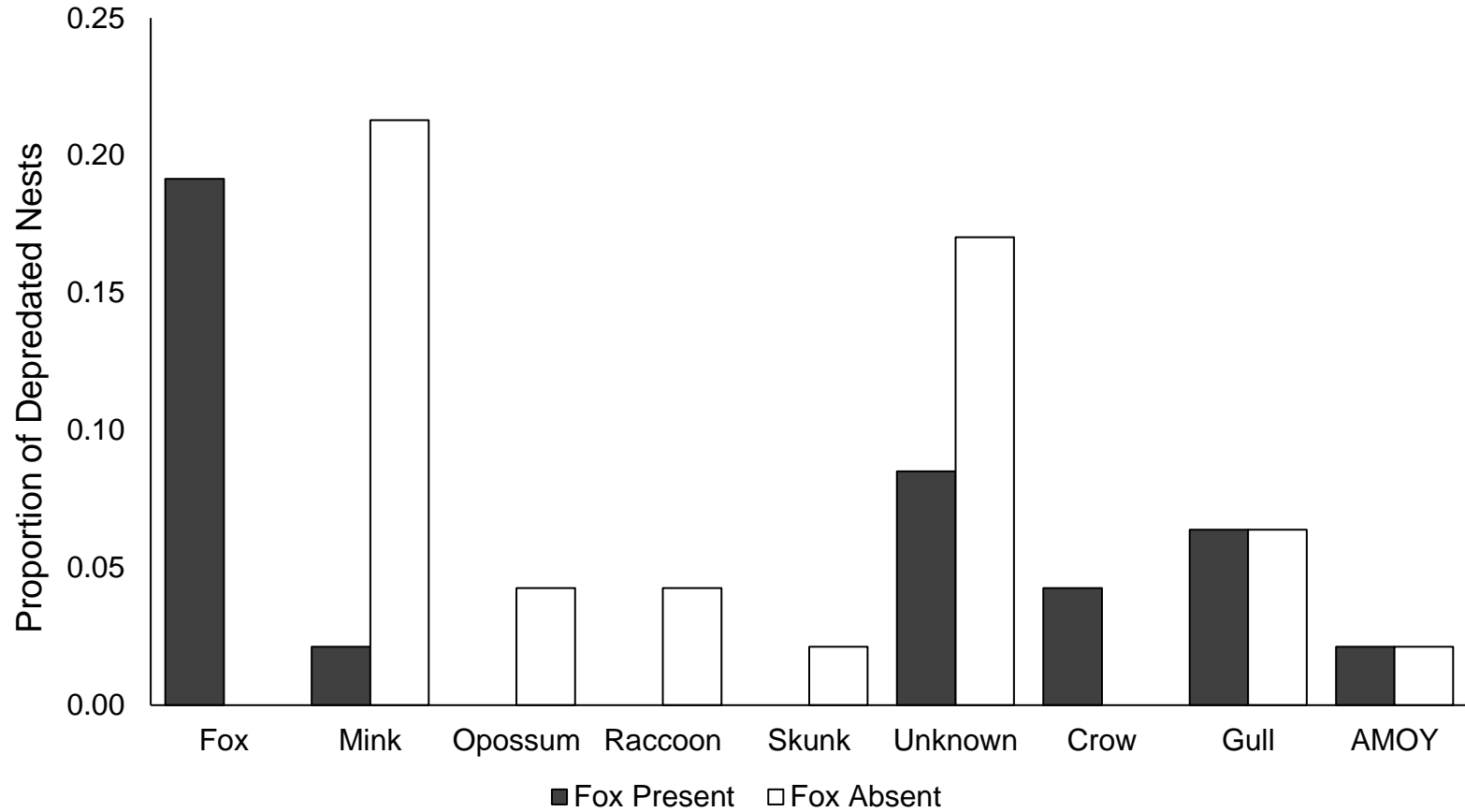
Figure 2.4. Proportion of depredated nests of piping plovers at study sites where red foxes were present and sites where foxes were absent in New Jersey, 2015–2017.
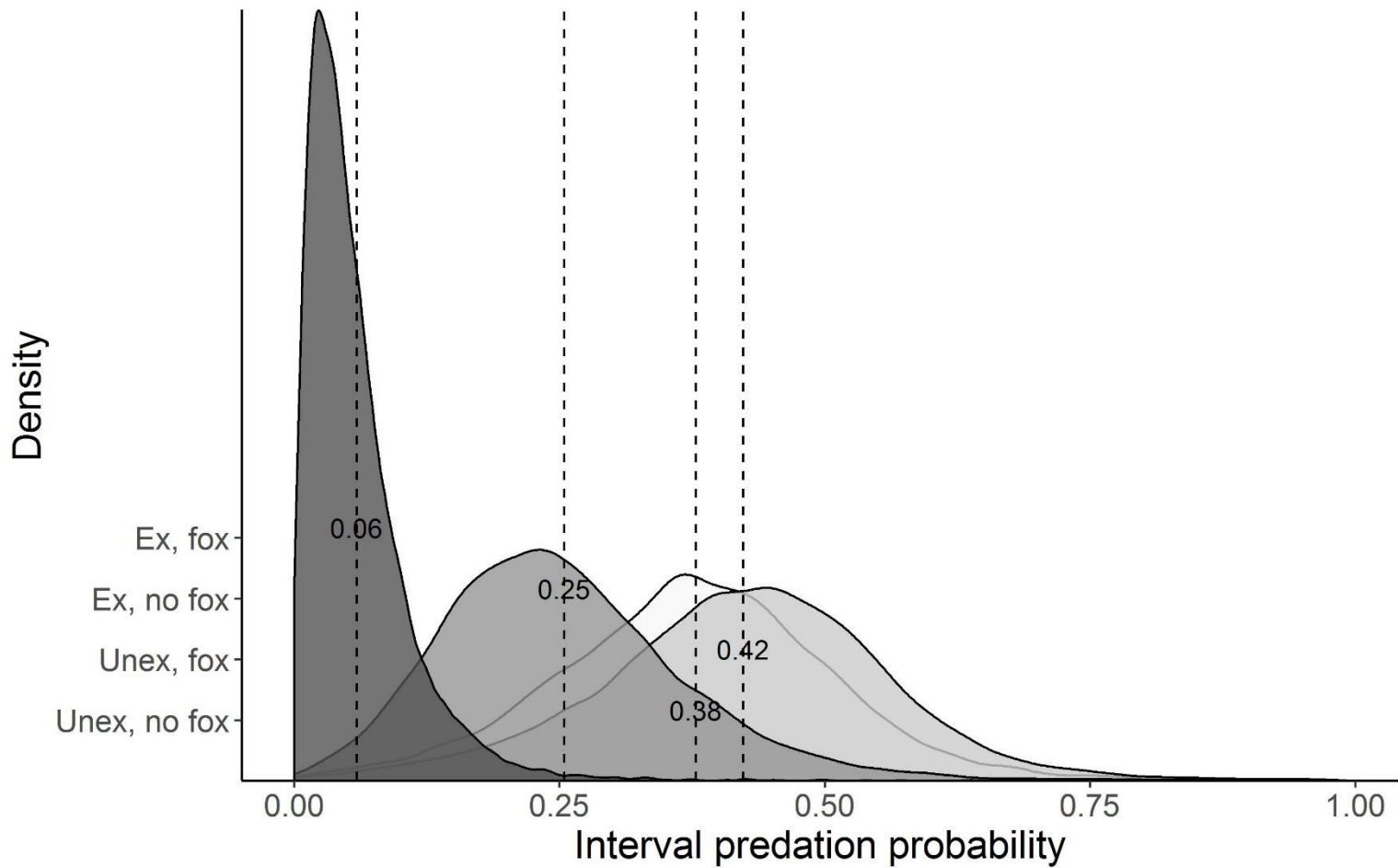
Figure 2.5. Interval nest predation probability density for piping plover nests at sites where red foxes were present (fox) and where foxes were absent (no fox) with (Ex) and without (Unex) nest exclosures in New Jersey, 2015–2017.

APPENDIX 2.A. NULL MODEL PARAMETER ESTIMATES FOR TWO SPECIES OCCUPANCY MODELS

Null model parameter estimates and standard errors for two-species occupancy models examining the interactions between striped skunk, raccoon, and Virginia opossum occupancy when red foxes are present and absent in southern New Jersey, 2015–2017. Model parameters are as follows: Ψ^A = probability of occupancy for red foxes, Ψ^{BA} = probability of occupancy for mink when foxes are present, Ψ^{Ba} = probability of occupancy of mink when foxes are absent, p^A = probability of detection for red foxes, and p^B = probability of detection for mink.

Parameter	Striped skunk		Raccoon		Virginia opossum		Fox	
	Estimate	SE	Estimate	SE	Estimate	SE	Estimate	SE
Foxes present (Ψ^{BA})	0.35	0.26	0.38	0.24	0.33	0.18	0.73 (Ψ^A)	0.09
Foxes absent (Ψ^{Ba})	0.10	0.09	0.10	0.09	0.53	0.13	-	-
Detection (p^B)	0.15	0.02	0.11	0.02	0.09	0.02	0.24 (p^A)	0.01

CHAPTER 3 PATTERNS OF ADULT SURVIVAL IN A STRUGGLING SHOREBIRD POPULATION SUGGEST DETRIMENTAL EFFECTS OF PREDATION MANAGEMENT

ABSTRACT Physical cues from the environment are often used by animals to direct habitat choices. However, anthropogenic activity has turned many landscapes into ecological traps for endangered species, although such traps have mostly been examined from the point of view of reproductive output. Understanding natural and anthropogenic factors affecting adult survival and dispersal can greatly inform conservation strategies and allow for the projection of future growth as a function of management. We studied adult survival and dispersal rates for the New Jersey population of piping plovers, which has failed to increase despite regional population growth, using mark-recapture data from 2012–2019. We found that adult survival between 2012 and 2019 ranged from 0.62 [95% CI = 0.48, 0.74] to 0.85 [0.74, 0.92] for females and 0.65 [0.51, 0.78] to 0.89 [0.80, 0.94] for males. Juvenile survival ranged from 0.40 [0.30, 0.51] to 0.70 [0.57, 0.80]. Exclosed, abandoned nests were associated with lower survival rates, particularly for males. Further, we found that females that abandoned their first nesting attempt of the season dispersed 10 times farther than males and females whose first nest attempts were lost predation or flooding. Dispersal distances of males and females that lost their last nest attempts of the season to predation and flooding (females,14.28 km [95% CI = 8.26, 20.54]; males, 1.43 [-4.04, 7.58]) were less than dispersal distances for individuals of both sexes that abandoned their last nesting attempt of the season (females, 21.78 [-3.02, 46.19]; males, 35.90 [9.09, 61.70]). Our results corroborate previous studies documenting adverse impacts of exclosure use on adult survival. Importantly, surviving mates (particularly females) emigrate from the breeding site, exacerbating the effect of mortality on local population viability. The results of our survival

analysis can be used to support the refinement of decision support tools to provide better information for exclosure use decisions, as exclosures may be further contributing to an ecological trap for piping plovers.

Adaptation-based theory predicts that animals use information from the environment to estimate habitat quality and decide where to live and breed (Schlaepfer et al. 2002, Kristan 2003, Morris 2011). In systems where cues match the true quality of the environment, the associated choice is expected to lead demographically to a source–sink dynamic (Dias 1996). The concept of sources and sinks suggest that some populations are strong contributors to overall population growth while others are not because habitat varies in quality across the landscape (Pulliam 1988). High quality patches have positive growth rates and are a source of emigrants whereas low quality patches have negative growth rates (Hanski 1991). Animals will settle in the superior habitat until it fills, and the remaining individuals must settle in the inferior habitat (Fretwell 1972, Parker and Sutherland 1986). However, it is possible that a low quality patch, or sink, may be chosen over higher quality patches because a recent anthropogenic change amplifies the cues for habitat choice making an area more attractive, despite being of poorer quality, leading to an ecological trap (Schlaepfer et al. 2002, Robertson and Hutto 2006).

Ecological traps can occur due to various mechanisms. Patches may become more attractive to individuals yet experience no change in suitability, habitat quality may be reduced without a loss in attractiveness, or both may occur simultaneously (Robertson and Hutto 2006). Ecological trap theory suggests that the presence of a trap on the landscape will drive a local population to extinction in the absence of immigration, because individuals will continually choose to settle in poor quality patches (Battin 2004). Much of the research documenting ecological traps has found them in landscapes that have been altered by humans. One of the most well-known examples of an ecological trap is that of artificial lighting disrupting sea turtle hatchling orientation from the nest and impairing an individual's ability to navigate to the sea (Witherington 1991, Lorne and Salmon 2007). Malik et al. (2010) found that asphalt roads can

reflect horizontally polarized light leading insects to mistake asphalt surfaces for water and to use the asphalt as an oviposition site where the eggs perish due to dehydration. In these cases, the historical signals for choosing optimal habitat have changed, leading to an ecological trap.

Ecological traps may present a serious threat to conservation of wildlife populations. However, restoration or reversal of the ecological trap can be achieved by understanding why immigrants continue to choose to settle within the trap and what causes vital rates to be low. When an ecological trap does occur and can be identified, Gilroy and Sutherland (2007) suggest that population impacts might be avoided by creating strong settlement cues in alternative patches, improving the quality of the trap, or both. For example, Kershner and Bollinger (1996) found that overall nest success of grassland birds at airports in Illinois was only 14% compared to 43% in pastures and that most of the known nest failures at airports were due to mowing. They suggested adjusting the mowing schedule to prevent nest destruction and increase nest success at airports where this management option was possible; however, at airports where adjusting the mowing schedule might not be possible, the better management option might be to discourage birds from nesting in these landscapes (Kershner and Bollinger 1996). In some cases, minor management actions could reverse ecological traps and help to maintain connectivity among populations.

Habitat fragmentation can be a generator of sink patches, and if individuals choose to utilize them at a higher rate than would be expected based on the quality of the habitat, it can lead to an ecological trap. Ecosystems have become increasingly fragmented due to human development, and as a result many wildlife populations are now more likely to be small, restricted in distribution, increasingly isolated from one another, and more vulnerable to extinction (Honnay et al. 2005). If a source population becomes a sink through an ecological

trap, a population may not reach its threshold size or nearby sinks may also decline to extinction

as they would be cut off from their source population (Templeton et al. 1990, Hanski 1999).

Eberhart-Phillips and Colwell (2014) found that a small, isolated population of snowy plovers

(*Charadrius nivosus*) in northern California was a sink reliant upon immigrants from adjacent

populations, and that population persistence would require continued management targeted

towards increasing productivity at nearby source populations. Similarly, Shitikov et al. (2012)

found that three species of nesting birds within an isolated meadow in Russia were all supported

by immigration. Natal and breeding dispersal play important roles for maintaining isolated

populations, and because dispersing individuals will continue to settle within ecological traps,

restoration of the trap may be vital to preserving connectivity between populations.

Quantitative assessments of habitat preference and reproductive success are often used to

support the concept of an ecological trap. Studies often aim to link nest site selection within an

ecological trap with higher predation rates and lower fledge success, whereas nest site selection

outside of the ecological trap leads to higher annual productivity (Weldon and Haddad 2005,

Rantanen et al. 2010, Rodewald et al. 2010, Latif et al. 2011, Demeyrier et al. 2016).

Additionally, adult and juvenile survival may decline in human-modified ecosystems, which

could critically affect long-term population growth. For example, Sherley et al. (2017) found that

African penguins (*Spehniscus demersus*) follow historical cues for prey-rich waters which have

recently been depleted by industrial fishing and climate change, leading to low juvenile survival

in populations selecting degraded areas. Further, low juvenile survival seems to be limiting the

growth of the African penguin population in Namibia (Simmons et al. 2015). Rather than address

the adult survival consequences of ecological traps, wildlife managers often focus on restoration

efforts that are aimed at improving reproductive success to match non-impacted ecosystems,

because reproductive success is more tractable. For example, Rodewald et al. (2010) suggested that ecologists may be able to predict which exotic plants may be most likely to negatively affect nest success of Northern cardinals (*Cardinalis cardinalis*) allowing restoration efforts to focus on controlling specific exotic plant species. Robertson (2012) suggest several habitat alteration strategies that include the creation of snags and selective harvest of tree species in order to eliminate an ecological trap for olive-sided flycatchers (*Contopus cooperi*) which leads to lower reproductive success and higher nest predation risk. While habitat restoration efforts may lead to an increase in reproductive success for nesting birds, the effects of these ecological traps (and their subsequent remediation efforts) on adult and juvenile survival have yet to be thoroughly investigated.

The piping plover (*Charadrius melodus*) is a small-bodied, migratory shorebird that breeds in coastal ecosystems in the United States and Canada that have been highly fragmented due to human development (Elliott-Smith and Haig 2004), with many patches serving as potential traps in the absence of strong intervention. These patches are subject to several anthropogenic stressors and varying degrees of connectivity. Regulatory protection and management interventions for piping plovers have been largely successful in recovering populations throughout the breeding range via intensive management of site-specific stressors such as predation and human disturbance, without addressing habitat loss and fragmentation directly (Melvin et al. 1991, USFWS 2009). However, the population in the New York-New Jersey region, which is considered a distinct Recovery Unit in the species recovery plan, decreased 35.5% between 2007–2013 (USFWS 2016). At the time of listing the total number of pairs nesting within the NY-NJ Recovery Unit was 208 (NY, 106; NJ, 102; USFWS 2016). The NY-NJ recovery unit has increased to 497 nesting pairs from 1986–2017, yet NY has seen most

of that increase (NJ, 105 pairs in 2017; USFWS 2019). Approximately 96% of the New Jersey coastline is managed for human recreation (Maslo et al. 2018), and the remaining coastline offers a fragmented landscape of remnant habitat available for nesting and foraging piping plovers.

Piping plover populations are distributed as metapopulations throughout their geographic range, both naturally and as a result of anthropogenic landcover change. Nesting areas are separated by uninhabitable expanses of anthropogenic development and recreational land use along the Atlantic Coast (USFWS 1996). Moreover, piping plover subpopulations tend to nest in ephemeral patches which they eventually abandon as these become unsuitable for nesting through successional processes (Catlin et al. 2016). On the Atlantic Coast, such patches are storm-created overwash fans on barrier islands. Following both storm and human-created nesting and foraging habitat improvements for piping plovers, the number of pairs at West Hampton Dunes, Long Island, NY increased from 5 pairs in 1993 to 39 pairs in 2000 (Cohen 2009). Following a severe flooding event on the Missouri River, large expanses of natural sandbar habitat was created through sediment deposition processes. As a result, piping plover demographic rates increased leading to population growth following the flood (Hunt et al. 2018). Conversely, beach stabilization processes often lead to increased rates of habitat degradation, which leads to decreases in available nesting habitat. The increase in piping plovers at West Hampton Dunes from 1993–2000 was followed by a rapid decline which was attributed to human development (Cohen et al. 2009) and mediated by declining site fidelity (Cohen et al. 2006). Thus, throughout their range, piping plovers rely on disturbance to refresh habitat and dispersal to recolonize newly available habitat and, even historically, habitat patches may have turned into ecological traps prior to becoming totally unusable. Current conservation strategies,

however, are aimed at maintaining beach-nesting species within limited extant patches rather than facilitating habitat dynamics and population connectivity.

Piping plover nesting sites often fall into the category of ecological traps because nest site selection is primarily driven by proximity to adequate moist substrate habitat for foraging (Cohen 2005), which provides more arthropod prey items than any other habitat types (Loegering and Fraser 1995, DeRose-Wilson et al. 2013). This foraging habitat provides such a reliable food source that adult piping plovers will select nest sites adjacent to moist substrate despite physical barriers such as houses or dunes that may affect their chicks' ability to also access this habitat (Cohen 2005, Fraser et al. 2005). Adult piping plovers wearing GPS units nesting on wide, sparsely vegetated oceanfront beaches with adequate nesting substrate have been documented foraging away from nesting areas (Stantial, unpubl. data). However, once chicks hatch, they are restricted to foraging in the oceanside intertidal zone and wrack. Further, piping plover chicks in New Jersey are typically hatching out onto beaches from late-May into July, during which time levels of human recreation are beginning to increase. Piping plovers are attracted to nesting on wide, sparsely vegetated oceanfront beaches with adequate nesting substrate and low-levels of human recreation with access to high-quality foraging through flight. However, as a result of habitat fragmentation and human recreation, chicks are unable to access that same foraging habitat and experience decreased survival rate and growth rates, leading to an ecological trap.

Current management techniques for piping plovers aim to reduce factors that turn patches into ecological traps, mainly by improving reproductive success. They include symbolic fencing to provide buffers around nesting areas preventing human disturbance, the use of exclosures to protect nests from predators (Melvin et al. 1992), and lethal predator removal. Exclosures

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increase hatch success for several species of ground-nesting birds. Pectoral sandpiper (*Calidris melanotos*) nests in Alaska that were protected using wire mesh exclosures had a daily survival rate of 98.2% while unexclosed nests had a daily survival rate of 71.7% (Estelle et al. 1996). Apparent nesting success of snowy plovers in coastal Oregon was greater for exclosed (68%) than for unexclosed (25%) nests (Dinsmore et al. 2014). However, it has also been demonstrated that exclosures can increase abandonment rates that may indicate adult mortality. Isaksson et al. (2007) found that predation on adult redshanks (*Tringa totanus*) was higher for exclosed (9 adults of 37 nests) than unexclosed nests (1 adult of 31 nests). Long-tailed jaegers (*Stercorarius longicaudus*) learned to key into predator exclosures used to protect western sandpiper (*Calidris mauri*) in Alaska and pursued adult sandpipers as they exited exclosures (Niehaus et al. 2004). Moreover, Roche et al. (2010) found that nest abandonment was the most common cause of nest loss in Great Lakes piping plovers, and that among abandoned nests, 70% were abandoned simultaneously with the disappearance (and likely death) of one or both adults. Failure to recognize that a nest abandonment is often attributed to the death of one or more adults could have population level impacts, as the true costs associated with abandonment are far greater than the loss of a single clutch of eggs and a source population could potentially become a sink if this issue were not adequately addressed (Cohen et al. 2016).

The objectives of this study were to 1) estimate annual adult and juvenile survival, site fidelity probabilities, and dispersal distances to understand their role in population dynamics of an imperiled population and 2) to determine the relationship between adult survival, nest fate and exclosure use in New Jersey. We hypothesized that exclosures would have a negative effect on true survival, which could be partly predicted by nest abandonment probabilities. We hypothesized that exclosures would have a positive effect on site fidelity, as exclosures reduce

nest predation which may attract a pair to return to the site the following year. We hypothesized that both breeding and natal dispersal distances for males would be much shorter than for females, as males are the primary territory holders. Additionally, we hypothesized that an abandonment at an exclosure may lead to further breeding dispersal distances for females when compared to unexclosed females and females who lost their nest to other causes. Our results will lead to more comprehensive recommendations for management of this system relative to potential ecological traps and functional connectivity to promote persistence of this species in New Jersey.

METHODS

Study Area

We studied piping plover demographics at study sites in southern New Jersey between 2012–2019 (Fig. 3.1). Our study area spanned from Seabright Beach-North (SBNO; latitude 40.33°N, longitude -73.97°W) located at the southern border of Gateway National Seashore to Cape May Point State Park (CMPSP; 38.93° N, -74.95° W) located north of the mouth of Delaware Bay. Barrier islands of the New Jersey coast run north-south and are located in the temperate climate zone. During the breeding season (Apr-Aug) the mean temperature is 22.14°C ±0.15 SE (range = 8.90-32.60°C) and precipitation averaged 3.79 cm ±0.34 (range = 0.00–137.40 cm; Atlantic City International Airport; National Oceanic and Atmospheric Administration 2019).

Coastal beaches on New Jersey barrier islands are characterized by open, sandy areas with sparse vegetation and both natural and human-created sand dunes. Piping plover nesting areas are often characterized by storm-created habitat whereby vegetation is scoured by tidal flooding and bayside intertidal sand flats are created. However, coastal storms often do not form

overwashes in areas that are backed by human development. Coastal sand dunes are dominated

by American beachgrass (*Ammophila breviligulata*) and other beach-adapted plants including

seaside goldenrod (*Solidago sempervirens*), beach pea (*Lathyrus japonicus*), and trailing wild

bean (*Strophostyles helvola*). Many study areas were inhabited by other beach-nesting birds that

were federally and/or state listed such as American oystercatcher (*Haematopus palliatus*), least

tern (*Sternula antillarum*), and black skimmer (*Rynchops niger*).

Study sites included Barnegat Lighthouse State Park in Barnegat Light (BALI, 2015–

2019); Holgate Unit of E.B. Forsythe National Wildlife Refuge, in Beach Township (HOLG,

2015–2019); Little Beach Unit of E.B. Forsythe National Wildlife Refuge in Long Beach

Township (LIBE, 2017–2019); North Brigantine Natural Area in Brigantine (NBNA, 2015–

2019); Malibu Wildlife Management Area and Seaview Harbor Marina in Longport

(MWMA/SHMA, 2015–2017); Avalon-Dunes in Avalon (AVDU, 2012–2018); Stone Harbor

Point in Stone Harbor (SHPT, 2012–2019); North Wildwood Beach in North Wildwood (NOWI,

2015–2017); Island Beach State Park in Berkley Township, NJ (IBSP, 2017–2019); Seabright

Beach in Seabright (SBNO, 2018–2019; SBSO, 2018–2019), Monmouth Beach in Monmouth

(MBNO, 2018–2019; MBSO, 2018–2019), Seven Presidents Oceanfront Park in Long Brach

(7PRES, 2018–2019), and the National Guard Training Center in Sea Girt (NGTC, 2019).

Field Methods

To locate breeding pairs, trained observers visited current nesting locations and potential

nesting sites with adequate substrate and foraging habitat across the study area. Most sites were

surveyed daily to weekly, although locations without recent breeding activity may only have

been visited during the annual piping plover breeding census between 1–9 June. In our study

region, managers often placed wire exclosure fences around plover nests to minimize predation

rates (Melvin et al. 1992). We therefore used different traps to capture plovers at unexclosed nests than exclosed nests. For nests with no exclosures, we captured adult plovers using walk-in funnel traps or drop traps (Cairns 1977), whereas for exclosed nests we blocked 75% of the base of the exclosure with 0.5 m tall chicken wire, leaving an exit into a bird-netting funnel (J. Cohen, unpubl. data) or used drop traps inside the exclosure. Hatch year birds were captured as chicks by hand, and typically marked in the nest bowl at hatching. We uniquely marked 222 adults and 482 chicks with either two colored Darvic leg bands (model XCLD, internal diameter 3.1mm, AVINET, Dryden, New York) on each tibiotarsus or a combination of a Darvic leg band on one tibiotarsus and a multi-layered impact acrylic coded flag (internal diameter 3.1 mm, Interrex, Lodz, Poland) on the opposite tibiotarsus, depending on the study site and year.

We attempted to resight all color-banded birds at each study site once per week at sites with known breeding activity. Two or more observers surveyed transects through all known nesting, roosting, and foraging areas between 0600 and 2000. For each banded bird encountered, we recorded the time of the observation, the band combination of the individual, and the breeding status of the individual. Additionally, if newly arrived banded birds were encountered during regular nesting monitoring activities outside of resighting surveys, those individuals were recorded.

During the nonbreeding season, uniquely marked individuals were reported to us both through incidental sightings by non-trained observers as well as through consistent monitoring of several known migration stopover sites and important wintering areas by trained individuals. Additionally, marked birds were reported during migration and wintering through eBird (Sullivan et al. 2009) and confirmed using photographs that were concurrently submitted.

Analytical Methods

We modeled true annual adult and juvenile survival and site fidelity using the Barker model (Barker 1997) run in the package RMark (Laake 2013) in program R version 3.6.1 (R Core Team 2019). The Barker model has seven parameters that apply to either primary survey occasions (when standardized surveys are performed such as the breeding season in our case) or the interval between primary occasions (the nonbreeding season in our case). These parameters are: S, true survival probability; p, detection probability in primary occasions; r, recovery probability given that the animal died in the interval between primary occasions; R, recapture/resight probability in the interval between primary occasions given that the animal survived the interval; R', recapture/resight probability during the interval between surveys given that the animal died in the interval; F, fidelity probability to the capture area, and F', probability that an animal re-immigrates into the capture area if it emigrated (Barker 1997, 2002). We modeled S as a function of the following individual covariates and biologically meaningful interactions: year, sex, whether the last known nest was exclosed, whether the last known nest was abandoned, the number of January days below 0°C at the coastal Brunswick/Malcom-McKinnon weather station in GA, and the number of hurricanes in the Atlantic Ocean (Table 3.1). Additionally, we included an age effect in all models to separately model adult and juvenile survival rates. We nested the exclosure and abandonment effects within the adult age category because juveniles do not nest in their hatch year. Following the notation of Lebreton et al. (1992), we used the subscript (t) to indicate full temporal variation (i.e., unique estimates of the parameter for each year, year treated as categorical) and (T) to indicate a linear trend across years (year treated as continuous). We modeled F as a function of the following individual covariates and biologically meaningful interactions: year, sex, whether the last known nest was exclosed,

and whether the last known nest was abandoned (Table 3.1). Additionally, we included an age effect in every model to separately model adult and juvenile site fidelity. We nested the exclosure and abandonment effects within the adult age category because juveniles do not nest in their hatch year. We fixed $r = 0$ for all intervals because we only included resightings of live birds. Because reimmigration into our study area was not documented in any year, we fixed $F' = 0$ for all intervals. Because survey efforts and environmental conditions affecting resighting efficacy of plovers were relatively constant over our study period, we modeled p, R, and R' as constant. We compared model fit using Akaike's Information Criterion adjusted for small sample size (AIC_c) and considered models with a relative likelihood (likelihood ratio between a given model and the top model) of ≥ 0.125 to have some support (Burnham and Anderson 2002).

We modeled Euclidian dispersal distance using a linear mixed effects model (McCulloch et al. 2011) with individual as a random effect. We modeled within season breeding dispersal distance (distance between the first failed nest attempt and the second nest attempt of the season) and between season breeding dispersal distance (distance between the last known nest attempt in year t and the first known nest attempt in year $t+1$) as a function of sex, whether the previous nest was abandoned, and their interaction. Additionally, we modeled natal dispersal as a function of sex, theorizing that second-year females would disperse farther than second-year males. We fit the models in a Bayesian framework by specifying models in the BUGS language, with posterior distributions for parameters of interest estimated using Markov Chain Monte Carlo (MCMC) simulation with Gibbs sampling as implemented in JAGS v. 3.4.0 (Plummer 2013), run from program R via the package jagsUI (Kellner 2015). We used wide non-informative priors for all parameters: a normal distribution with mean 0 and variance 1000 for all coefficients in the linear predictors, and a uniform distribution between 0–50 for all variance parameters. We

checked for convergence of 3 parallel MCMC chains per model by visually inspecting the trace plots and by using the Gelman-Rubin diagnostic ($\hat{R}$; Gelman et al. 2004) and considered convergence to be achieved at $\hat{R} < 1.05$ for all parameters. We considered covariates to be important predictors if the 95% credible intervals on the regression parameter did not overlap zero (Kuo and Mallick 1998, Link and Barker 2006).

RESULTS

We do not report the list of all tested Barker models because our approach produced 552 models. We detected support for an effect of exclosures on both survival probability and site fidelity, and evidence for the effect of sex and year and an interaction between abandonment and exclosure use on adult survival as these effects appeared in the top two models (Table 3.2). Because a single top model was not clear, we model averaged predictions for *S* and *F* (Appendix 3.A). Exclosures had no effect on male survival, but survival of males at abandoned nests was lower than survival of males whose last known nest was not abandoned (Fig. 3.2). For females, no relationship between survival, exclosures, and abandonment was clear as the confidence intervals on all estimates overlapped heavily, although the point estimate for unexclosed and not abandoned was greater than all other categories (Fig. 3.2). Survival rates for males, females and juveniles varied by year, with yearly survival lowest in 2017 and highest in 2018 (Fig. 3.3). While not statistically different based on confidence interval overlap, there was some suggestion that site fidelity for piping plovers was higher for adults with exclosed nests than for those with unexclosed nests (Fig. 3.4). Site fidelity increased throughout time and was highest in 2018 (Fig. 3.5). On the breeding grounds, piping plovers had a high probability of being detected ($p = 0.99$ [95% CI = 0.95, 1.00]). Detection probability for non-breeding piping plovers that survived the winter (*R*) was 0.51 (95% CI = 0.46, 0.56), and detection probability for non-breeding plovers

that died during the winter (R`) was lower (0.25 [95% CI = 0.20, 0.31) than for plovers that survived.

Within-season breeding dispersal distance (distance between the first nest attempt and second nest attempt of a given year) was higher for females whose first nest attempt was abandoned than for females whose first nest attempt was lost to any other cause (Table 3.3). Females whose first nest attempt was lost to abandonment dispersed 28.07 km (95% CBI = 11.13, 45.24), farther than males whose first nest attempt was lost to abandonment (Fig. 3.6). Similarly, between season breeding dispersal distance was greater for females whose last nest attempt of the previous season was not abandoned (14.18 km [95% CBI= 7.98, 20.40]) than males whose last nest attempt was not abandoned (1.74 km [95% CBI = -3.97, 7.57]), and greater for both males and females whose last nest attempt of the previous season was abandoned (males, 36.17 km [95% CBI = 9.13, 61.09]; females, 22.13 km [-1.71, 45.60]; Table 3.4). We did not detect differences of natal dispersal distances between second-year male and female piping plovers (males, 22.49 km [95% CBI = 1.25, 43.75]; females, 43.12 km [20.53, 64.64]; Table 3.5).

DISCUSSION

Our estimates of true adult survival of male piping plovers for unexclosed nests that were not abandoned was high (0.85 $\pm$0.07 SE) compared to mean true adult survival estimates for Atlantic Coast piping plovers within the same recovery unit and within the same time period (New York males 0.73 $\pm$0.07 SE; Weithman et al. 2019). Our estimates for adult survival for unexclosed nests that were not abandoned were also higher than estimates of true survival in the Great Lakes (0.76; LeDee et al. 2010) and Great Plains (0.76, Catlin et al. 2015). However, our estimates of true adult survival for male piping plovers whose last nest attempt was exclosed and

abandoned was much lower than true survival estimates reported for piping plovers anywhere

else in the range (0.08 ±0.08 SE), yet our estimates of true adult survival for female piping

plovers at exclosed and abandoned nests was 0.67 ±0.17 SE. We suspect that most adult

mortality occurs from dusk to dawn by crepuscular or nocturnal predators such as American

mink (*Neovison vison*), great-horned owls (*Bubo virginianus*), or peregrine falcons (*Falco*

peregrinus) that target nest exclosures. Stantial (2014) observed that as part of the piping plover

mating system, males tend to perform most of the night-time incubation, subjecting them to

crepuscular or nocturnal predators. Many *Charadrius* species of plover such as common ringed

plovers (*Charadrius hiaticula*), two-banded plovers (*Charadrius falklandicus*), Wilson's plovers

(*Charadrius wilsonia*), and red-capped plovers (*Charadrius ruficapillus*) share incubation duties

between males and females, with males attending the nest largely at night (Thibault and McNeil

1995, Wallander 2003, St Clair et al. 2010, Ekanayake et al. 2015). Because male piping plovers

are the primary territory holders, as corroborated by their short between-season dispersal

distance that we found during this study, and due to their increased length of parental care (Haig

and Oring 1988b), males play an important role in the mating system for this species.

The negative relationship between adult survival rates and abandonment together with the

positive relationship between site fidelity and exclosure use suggest that exclosures may be

further exacerbating an already existing ecological trap as piping plovers are drawn to return to

sites where nest exclosures are used but are then subjected to continued predation risk.

Additionally, the increased within-season dispersal distance for adult females whose nests have

been abandoned (and likely had their mate killed) can lead to a functional loss of both adults at a

nesting site, furthering the negative effects of exclosure use on the local landscape. These

cascading effects of ecological traps can quickly lead to population declines. Lamb et al. (2017)

found that grizzly bears in Alberta, Canada were attracted to an area with high fruit availability but also high human density, leading to an 8% annual population decline within the area of high human density but also leading to a 1.5% annual population decline for the source populations outside of the areas of high human density. If source populations are small and sites that impose ecological traps are especially attractive to individuals, population declines can be severe and should be considered a major conservation concern for threatened and endangered species.

Exclosures offer an attractive strategy for wildlife managers to reverse population declines of piping plovers; however, nest exclosures are unlikely to be successful at all sites and any benefits can be offset by an increase in adult mortality (Murphy et al. 2003, Roche et al. 2010) as evidenced from a decrease in male survival at exclosed nests. If nest abandonment rates are high at a site but plover nests are experiencing high nest predation pressures within a season, wildlife managers need to evaluate the tradeoffs between increased hatching success and increased adult mortality on population growth rates given the use of exclosures (Cohen et al. 2016).

Habitat fragmentation can have ecological effects within patches and affect dispersal among them (Holderegger and Di Giulio 2010). The New Jersey coastline is approximately 290 km, and numerous communities within the coastal zone artificially manipulate their beaches and dunes (Valverde et al. 1999), producing a patchy landscape with habitat of varying suitability for piping plover nesting. We did not find differences in dispersal distance between second-year males and females, yet dispersal distance was generally high (> 22 km). This may suggest a lack of suitable habitat adjacent to nesting sites that chicks were reared at; however, this may also be an adaptive mechanism to avoid in-breeding. Between season dispersal distance can be higher for adults whose last nest attempt of the year was abandoned than for adults whose last nest

attempt of year was not abandoned, which may be due to a lack of suitable habitat patches

adjacent to the nesting site from the previous year. Additionally, we found that average within-

season dispersal distance for females whose first nest was abandoned was high, suggesting either

a lack of suitable habitat adjacent to current nesting sites or the inability for the female to find a

suitable mate or both. Furthermore, for some abandoned nests we received confirmation of

female dispersal outside of New Jersey to adjacent states such as Delaware, New York, and

Virginia. Similar to our findings, Rioux et al. (2011) found that for adult piping plovers that did

not breed successfully in the previous year, mean dispersal distance was greater. Because

dispersal distances increased with abandonment and adult survival was lower at exclosures that

have been abandoned, we further emphasize that exclosure use should be thoughtfully

considered prior to deployment as the risk to losing both breeding adults is intensified.

Nest predation rates vary depending on the number and types of predators on the

landscape (Fontaine and Martin 2006; Cox et al. 2012), and predation rates vary depending on

the configuration of the habitat (Major et al. 1999, Hawlena et al. 2010). Stantial et al. (In

Review) found that red foxes may be attracted to dune systems which provide cover and high-

quality foraging opportunities. Because much of the New Jersey coastline is managed for

recreational beach use (Maslo et al. 2018), dune systems are artificially manipulated for coastal

resiliency, and overwash fans are not maintained for piping plovers. Burger (1997) found that

piping plovers at North Brigantine Natural Area shifted their nest locations away from dunes in

response to heavy red fox predation. However, Darrah et al. (2018) found that nests in >20%

vegetation experienced lower predation rates than nests in 0–20% vegetation, which is contrary

to what might be expected given the probability of predators using vegetated areas for cover.

Dion et al. (2000) studied the effects of vegetation characteristics on ground-nesting songbirds

and found that successful nests had less grass cover than depredated nests, further suggesting that piping plovers nesting in moderately vegetated dunes may be at greater risk. While we did not have data on habitat characteristics at the nest to test this hypothesis, we did find differences in predation rates among the various nesting sites in New Jersey indicating that predation rates may depend on site-specific factors such as habitat configuration and predator abundance, and habitat that favors predator activity may increase the effect of an ecological trap (Chapter 2).

Most studies evaluating the use of exclosures at nesting sites have used retrospective nesting data to evaluate their effectiveness (Melvin et al. 1992, Mabee and Estelle 2000, Roche et al. 2010), and few studies have implemented exclosures according to any experimental framework. However, there are specific tools designed to evaluate the tradeoff between the benefits and negative consequences of exclosures (Darrah et al. 2020). While exclosures have not been evaluated in a before/after/control/impact framework, they are clearly considered to be an important tool for wildlife managers in population recovery. Our study highlights the various reasons that caution should be used when deploying exclosures, especially in areas with high predation rates without exclosures, high abandonment rates with exclosures, and high dispersal distances for adults from abandoned nests. The results of our survival analysis can be used to support the refinement of decision support tools (i.e. PiperEx) to provide better information for exclosure use decisions, as exclosures may be further contributing to an ecological trap for piping plovers.

We tested the effect of cold snaps on true survival of piping plovers because Gibson et. al (2017) demonstrated a decline in apparent winter survival for piping plovers in Georgia, USA. Gibson et al. (2017) compared apparent winter survival rates for piping plovers at sites in coastal Georgia and the Gulf of Mexico and found that plovers in Georgia were exposed to the coldest

temperatures recorded across the entire study and that plovers wintering at sites on the Gulf of

Mexico did not experience the same decline in winter survival as the Georgia plovers under

comparable changes in temperature (Gibson et al. 2017). We documented only 11 New Jersey

piping plovers using the U.S. Atlantic Coast during the months of December, January and

February from 2012–2019 whereas the majority of New Jersey piping plovers that were reported

overwintered in the Bahamas (n=76); thus, our findings (no effect of cold temperatures) are

consistent with those of Gibson et al. (2017) and it is reasonable that we did not see decreases in

survival rates in years with longer cold snaps. It is possible that winter temperatures at sites

outside the U.S. Atlantic Coast are rarely low enough to damage the prey base, leading to higher

survival rates for piping plovers wintering in the Caribbean and along the Gulf Coast. In addition

to food shortages, cold temperatures may also limit a piping plover's ability to thermoregulate.

True adult survival (S) in our population averaged 0.78 and site fidelity (F) averaged

0.85. By multiplying our estimate of true survival (S) by site fidelity (F), we can obtain a naïve

estimator of apparent survival ($S \times F = 0.78 \times 0.85 = 0.65$). This estimate is consistent with

apparent survival estimates for New Jersey using a Cormack-Jolly-Seber model (Lebreton et al.

1992) and a subset of the same data ($\varphi_{no\ tag} = 0.57$, $\varphi_{tag} = 0.67$; Stantial et al. 2019). Apparent

survival rates of adult piping plovers tend to range between 0.51–0.81 for the Great Plains

population (Prindiville-Gaines and Ryan 1988, Larson et al. 2000, Roche et al. 2010, Catlin et al.

2015, Hunt et al. 2020), 0.71–0.78 for the Great Lakes population (Roche et al. 2008, Roche et

al. 2010), and 0.56–0.83 for the Atlantic Coast population (Melvin and Gibbs 1996, Calvert

2006, Roche et al. 2010, Stantial et al. 2019). Estimates of true survival are unbiased by

emigration (Barker 1997) and it is therefore unsurprising that our true survival estimate was

higher than apparent survival estimates from previous studies. However, our estimate of apparent

survival rates for New Jersey piping plovers in this study appears to be on the lower end of Atlantic coast piping plovers. The apparent survival we estimated is lower than the value of 0.74 used in the species recovery plan to calculate productivity needed for a stationary population (USFWS 1996). This low apparent survival may be the result of emigration outside of New Jersey. We can calculate the probability of emigration as $1 -$ (apparent survival/true survival) which yields an estimated annual probability of emigration as $1 - (0.65/0.78) = 0.17$. If, on average, 17% of after hatch year adults emigrate from New Jersey in a given year, emigration could have a large influence on population change.

Our estimates of detection probability are similar to previously reported estimates of detection probability on the breeding grounds (p) for Great Lakes piping plovers ($p = 1.00$; LeDee et al. 2010) and higher than estimates in New York and North Carolina ($p = 0.87$, Weithman et al. 2019). Our estimates for the probability of detection for nonbreeding plovers banded in New Jersey was high relative to estimates from Saskatchewan, Canada ($R = 0.24$; Cohen and Gratto-Trevor 2011), similar to estimates from the Great Lakes from 2006 ($R = 0.50$, females; LeDee et al. 2010), and lower than estimates from New York and North Carolina ($R = 0.72$, adults; $R = 0.88$, hatch year; Weithman et al. 2019). Our estimates for the probability of detection for birds that died prior to returning to the breeding grounds was higher than Saskatchewan, Canada ($R` = 0.09$, Cohen and Gratto-Trevor 2011) and the Great Lakes ($R` = 0.16$, females; LeDee et al. 2010), but similar to estimates from New York and North Carolina ($R` = 0.22$; Weithman et al. 2019). Nonbreeding resightings provide an important way to separate survival and site fidelity, and our estimates of detection probabilities of New Jersey piping plovers have led to higher confidence in the estimates of survival and site fidelity in our study area.

Ultimately, ecological traps may present a serious threat to conservation of piping plovers, and management actions that intensify this effect should be carefully evaluated. Understanding the various mechanisms leading to an ecological trap is important for understanding how to reverse it. Further, understanding which demographic rates are most sensitive to the effects of an ecological trap can potentially allow wildlife managers to avoid population impacts. Restoration or reversal of the ecological trap can be achieved by understanding what causes vital rates to be low and why immigrants continue to choose to settle within the trap, leading to the development of management options for mitigating their demographic impacts. The results of our adult survival analysis can be used to support the refinement of decision support tools to provide better information for exclosure use decisions, as exclosures may be further contributing to an ecological trap for piping plovers.

Table 3.1.List of variables and their interactions used for survival (S) and site fidelity (F)

parameters in true survival modeling of adult piping plovers in New Jersey, 2012–2019.

Parameter	Variable	Description
S, F	AHYF	Adult female
	AHYM	Adult male
	AHY	Adult, either sex
	e	Last nest of year *t* exclosed
	a	Last nest of year *t* abandoned
	Time	Year treated as continuous
	time	Year treated as categorical
	e:AHYF	Adult female interaction with exclosures
	e:AHYM	Adult male interaction with exclosures
	a:AHYF	Adult female interaction with abandonment
	a:AHYM	Adult male interaction with abandonment
	e:AHY:a	Adult interaction with exclosures and abandonment
S	cold	Number of days below freezing (0°C) at the Brunswick/Malcom-McKinnon weather station in January of a given year
	h	Number of hurricanes in the US Atlantic Ocean during a given year

Table 3.2. Model parameters, parameter counts, and information theoretic model selection criteria for true survival models for piping plovers in New Jersey, 2012–2019. The model parameters are true survival (S), detection (p), recovery of dead animal between primary occasions (r), resight between primary occasions given the animal survived (R), resight between primary occasions given the animal died (R`), site fidelity (F), reimmigration after emigration (F`). Top fifteen candidate models are shown. Model covariates are described in Table 3.2.

Model	Deviance	K[a]	ΔAIC$_c$	Model Likelihood	w_i
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM)F'(~1)	3560.05	23	0.000	1.000	0.36
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM + Time)F'(~1)	3558.14	24	0.145	0.930	0.33
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + a:AHYF + a:AHYM + e:AHYF + e:AHYM)F'(~1)	3558.18	25	2.245	0.325	0.12

Model	Deviance	K^a	ΔAIC_c	Model Likelihood	w_i
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + a:AHYF + a:AHYM + e:AHYF + e:AHYM + Time)F'(~1)	3556.57	26	2.705	0.259	0.09
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a)F'(~1)	3558.15	26	4.282	0.118	0.04
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + Time)F'(~1)	3556.51	27	4.708	0.095	0.03
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)F'(~1)	3546.43	32	4.991	0.082	0.03
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~1)F'(~1)	3581.66	19	13.403	0.001	0.00

Model	Deviance	K[a]	ΔAIC$_c$	Model Likelihood	w$_i$
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM)F'(~1)	3577.78	21	13.628	0.001	0.00
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + Time)F'(~1)	3576.60	22	14.497	0.001	0.00
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + a:AHYF + a:AHYM)F'(~1)	3576.37	23	16.320	0.000	0.00
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + time)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + a:AHYF + a:AHYM + Time)F'(~1)	3575.38	24	17.389	0.000	0.00
S(~AHY + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + cold)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM + Time)F'(~1)	3591.14	17	18.797	0.000	0.00

Model	Deviance	K^a	ΔAIC_c	Model Likelihood	w_i
S(~AHYF + AHYM + a:AHYF + a:AHYM + cold)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM + Time)F'(~1)	3595.37	15	18.949	0.000	0.00
S(~AHYF + AHYM + e:AHYF + e:AHYM + a:AHYF + a:AHYM + e:AHY:a + cold)p(~1)r(~1)R(~1)R'(~1)F(~AHYF + AHYM + e:AHYF + e:AHYM + Time)F'(~1)	3590.69	18	20.394	0.000	0.00

aNumber of parameters

Table 3.3. Summary statistics for posterior distributions of parameter estimates for model of within season dispersal distances (distance between first and second nest attempts within a season) for male and female piping plovers with abandoned nests and nests lost to any other cause in New Jersey, 2012–2019.

Regression Parameter	Mean	SD	Quantile	
			2.5%	97.5%
Intercept	0.45	2.60	-4.54	5.61
Sex coefficient	3.41	3.76	-4.11	10.77
Abandonment coefficient	1.60	5.48	-9.32	12.16
Interaction coefficient	28.07	8.53	11.13	45.24
Individual random effect SD	17.81	1.90	13.97	21.27

Table 3.4. Summary statistics for posterior distributions of parameter estimates for model of between season dispersal distances (distance between the last nest attempt of year t and the first nest attempt of year $t+1$) for male and female piping plovers whose last nest attempt of year t was abandoned or not abandoned in New Jersey, 2012–2019.

Regression Parameter	Mean	SD	Quantile	
			2.5%	97.5%
Intercept	1.29	3.09	-4.42	7.35
Sex coefficient	12.83	4.30	4.49	21.51
Abandonment coefficient	34.23	13.10	8.15	59.55
Interaction coefficient	-14.11	16.33	-45.81	17.54
Individual random effect SD	17.05	4.34	8.24	24.66

Table 3.5. Summary statistics for posterior distributions of parameter estimates for model of natal dispersal distances (distance between nest a chick hatched from in year t and their first nest attempt of year t+1) for male and female piping plovers in New Jersey, 2012–2019.

			Quantile	
Regression Parameter	Mean	SD	2.5%	97.5%
Intercept	22.49	11.16	1.25	43.75
Sex coefficient	20.63	14.85	-9.58	50.01
Individual random effect SD	74.49	14.82	39.74	94.74
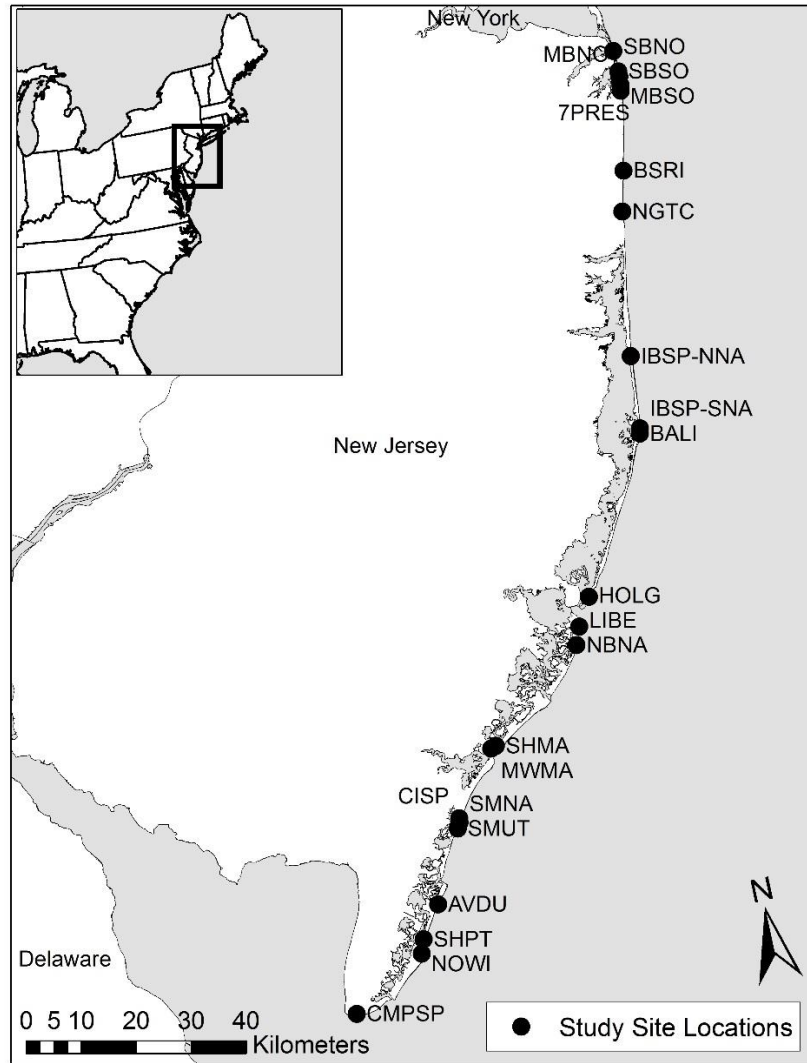
Figure 3.1.Figure 1. Study area for piping plover chick demographic studies in New Jersey,
2012–2019. Site abbreviations are as follows: Seven Presidents Oceanfront Park, 7PRES;
Avalon-Dunes, AVDU; Barnegat Lighthouse State Park, BALI; Belmar-Shark River Inlet, BSRI;
Corson's Inlet State Park, CISP; Holgate Unit, E. B. Forsythe NWR, HOLG; Island Beach State
Park-NNA, IBSP-NNA; Island Beach State Park-SNA, IBSP-SNA; Little Beach Unit, E.B.
Forsythe NWR, LIBE; North Brigantine Natural Area, NBNA; North Wildwood, NOWI; Malibu
Beach Wildlife Management Area, MWMA; Monmouth Beach-North, MBNO; Monmouth
Beach-South, MBSO.
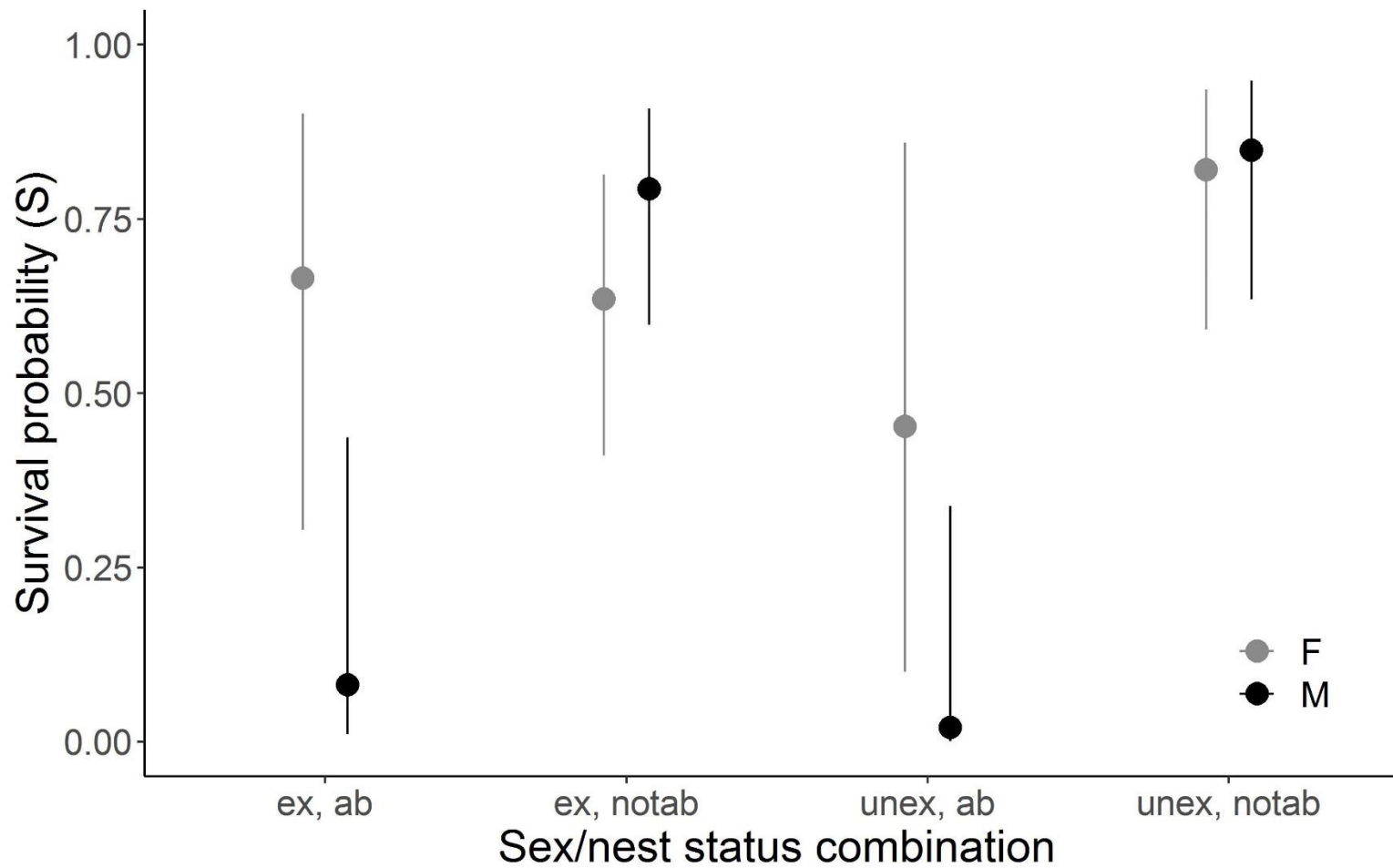
Figure 3.2. Model-averaged true survival (S) predictions for male (M) and female (F) adult piping plovers at exclosed (ex), unexclosed (unex), abandoned (ab) and not abandoned (notab) nests in New Jersey, 2012–2019. Dots represent means and bars represent 95% confidence intervals.
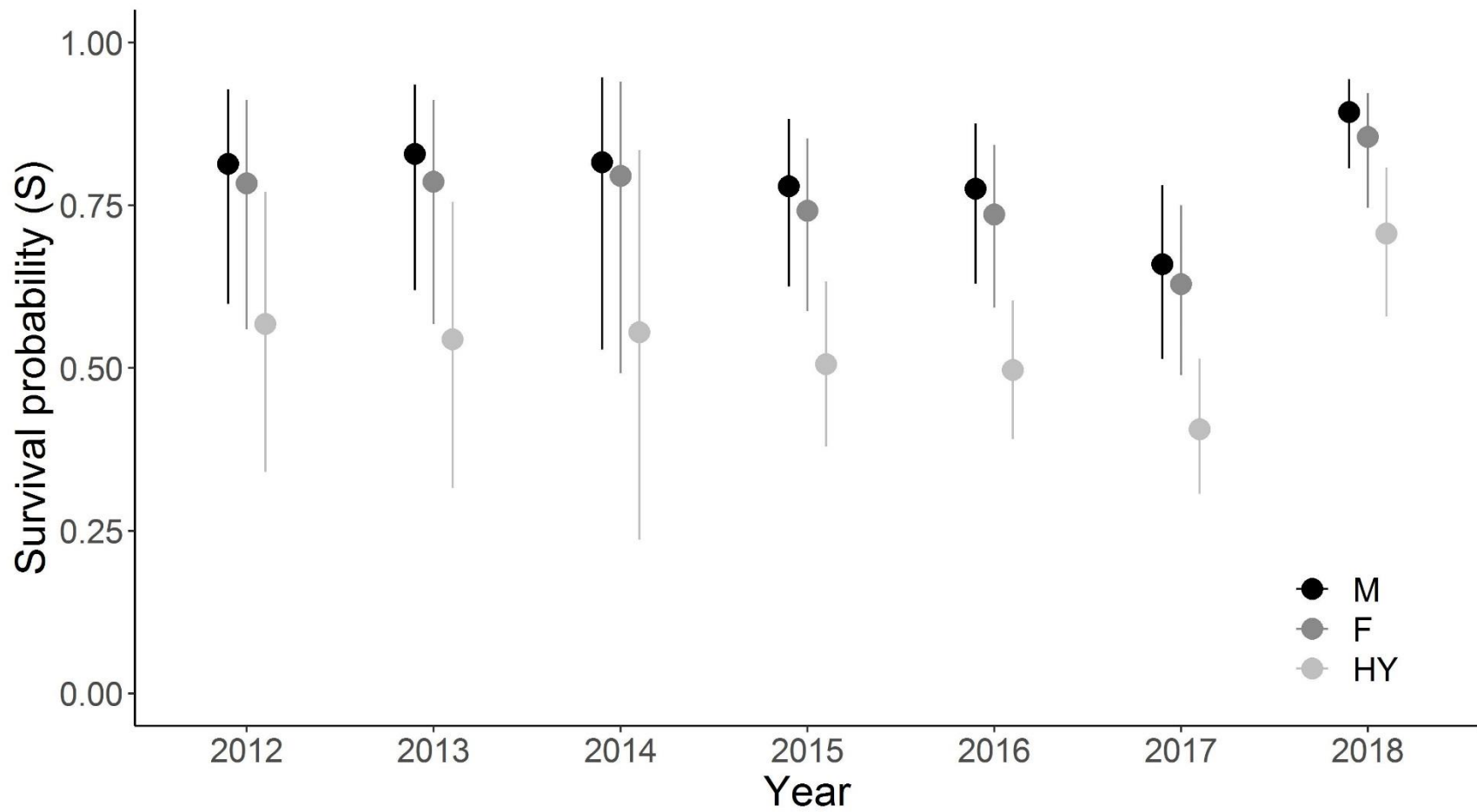
Figure 3.3. Model-averaged yearly true survival (S) predictions for adult piping plover males (M), females (F), and juveniles (HY) in New Jersey, 2012–2019. Dots represent means and bars represent 95% confidence intervals.
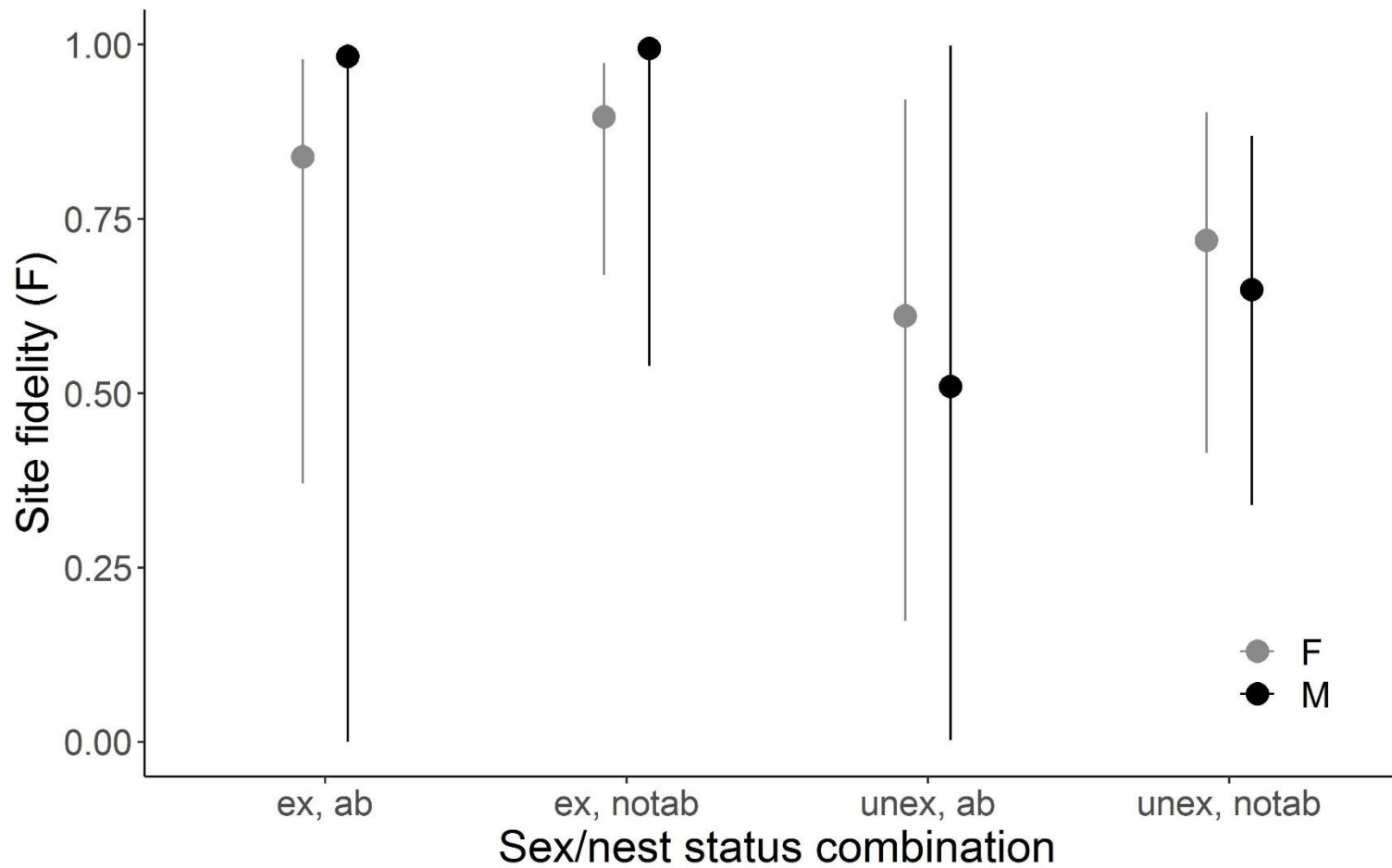
Figure 3.4. Model-averaged site fidelity predictions for male (M) and female (F) adult piping plovers at exclosed (ex), unexclosed (unex), abandoned (ab) and not abandoned (notab) nests in New Jersey, 2012–2019. Dots represent means and bars represent 95% confidence intervals.
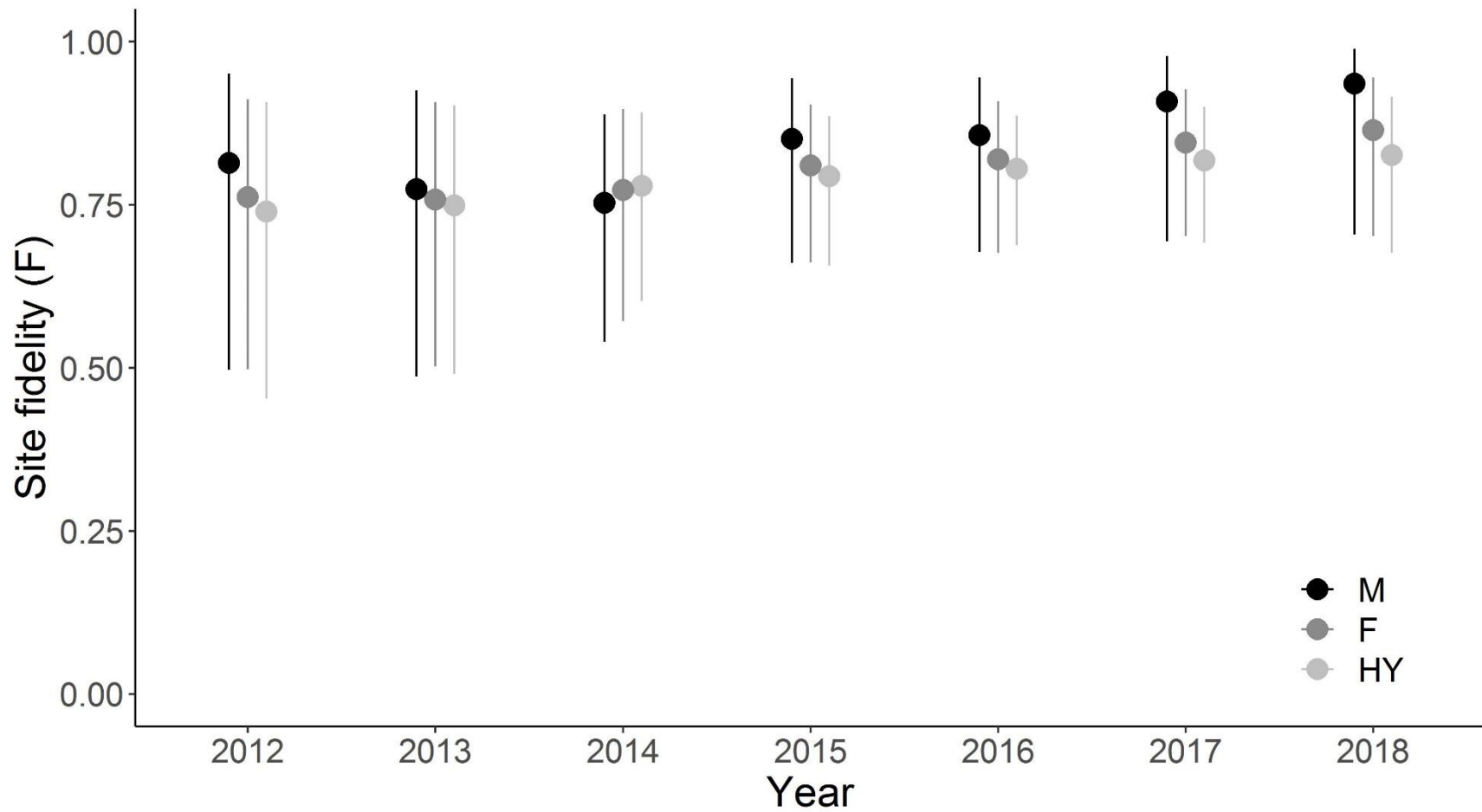
Figure 3.5.Model-averaged yearly site fidelity predictions for adult piping plover males (M), females (F), and juveniles (HY) in New Jersey, 2012–2019. Dots represent means and bars represent 95% confidence intervals.
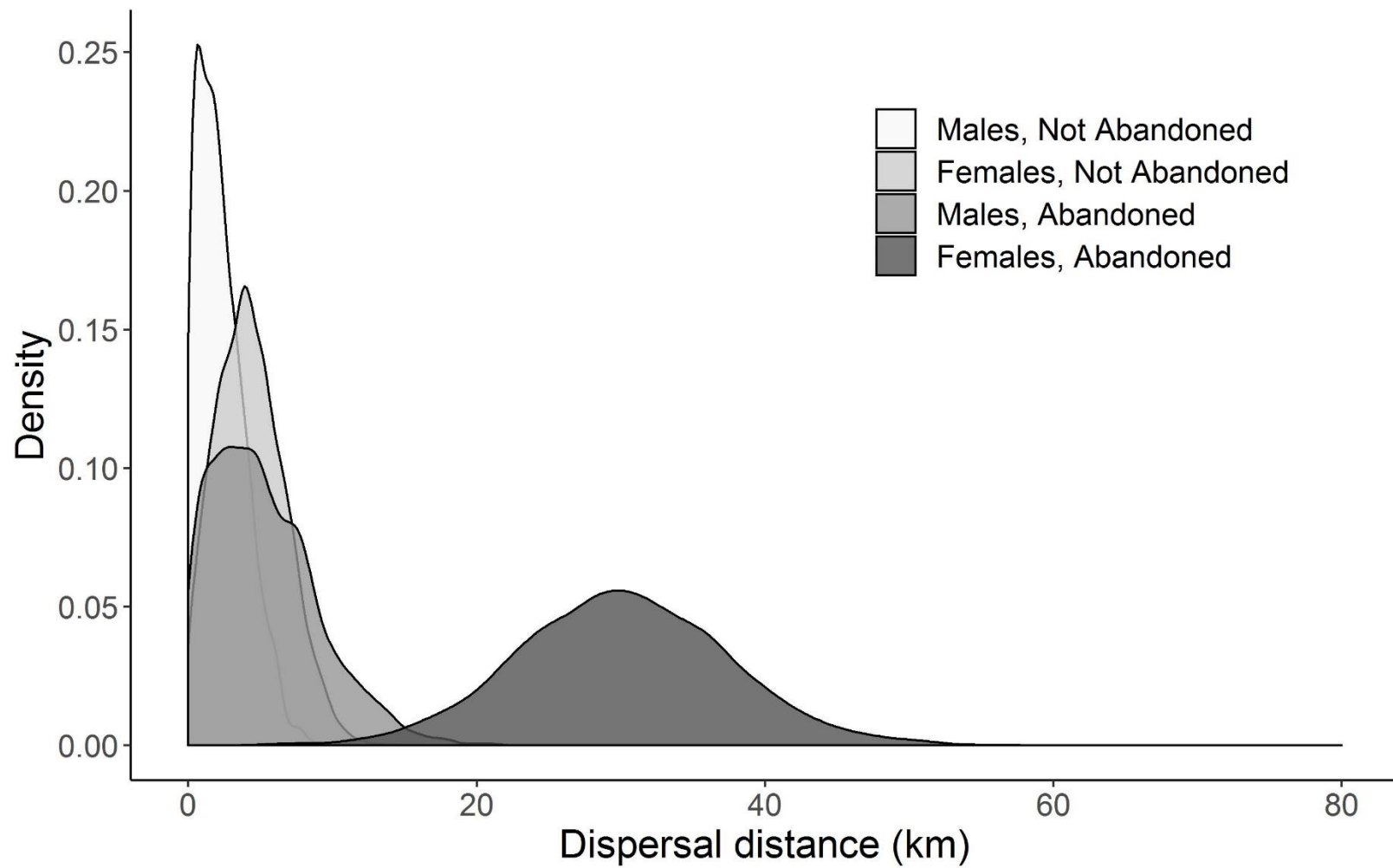
Figure 3.6. Distributions of within season dispersal distance (distance between first and second nest attempts within a season) for male and female piping plovers with abandoned nests and nests lost to any other cause in New Jersey, 2012–2019.
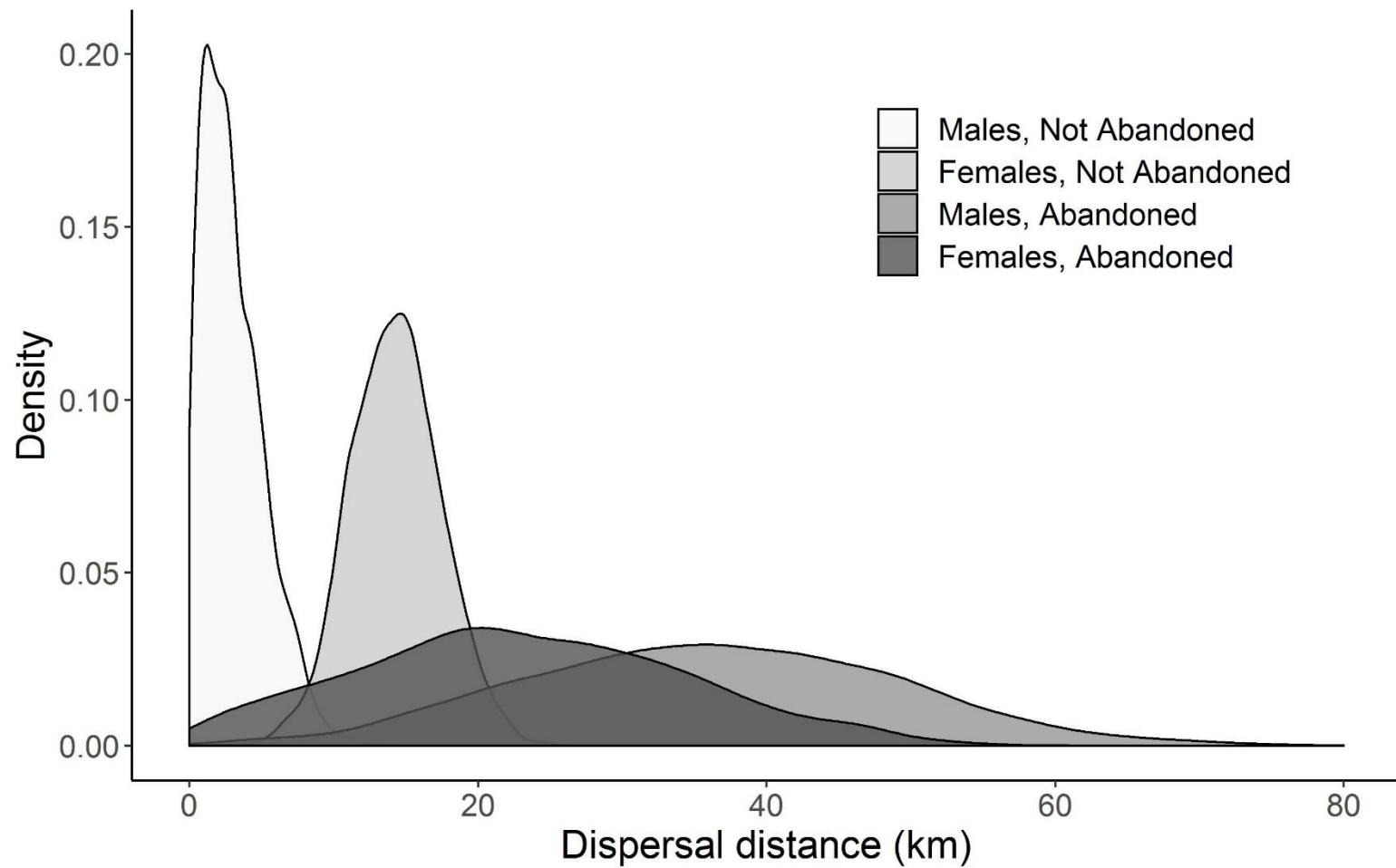
Figure 3.7. Distributions of between season dispersal distance (distance between the last nest attempt of year t and the first nest attempt of year $t+1$) for male and female piping plovers whose last nest attempt of year t was abandoned or not abandoned in New Jersey, 2012–2019.

APPENDIX 3.A. STANDARDIZED EFFECT SIZES WITH 95% CONFIDENCE INTERVALS

Standardized effect sizes (±95% CIs) for top two survival models for piping plovers in New Jersey, 2012–2018. The model parameters are true survival (S), detection (p), recovery of dead animal between primary occasions (r), resight between primary occasions given the animal survived (R), resight between primary occasions given the animal died (RPrime), site fidelity (F). Covariates include year (2012–2018), nest exclosure (e), nest abandonment (a), age (AHY), and sex (M or F).
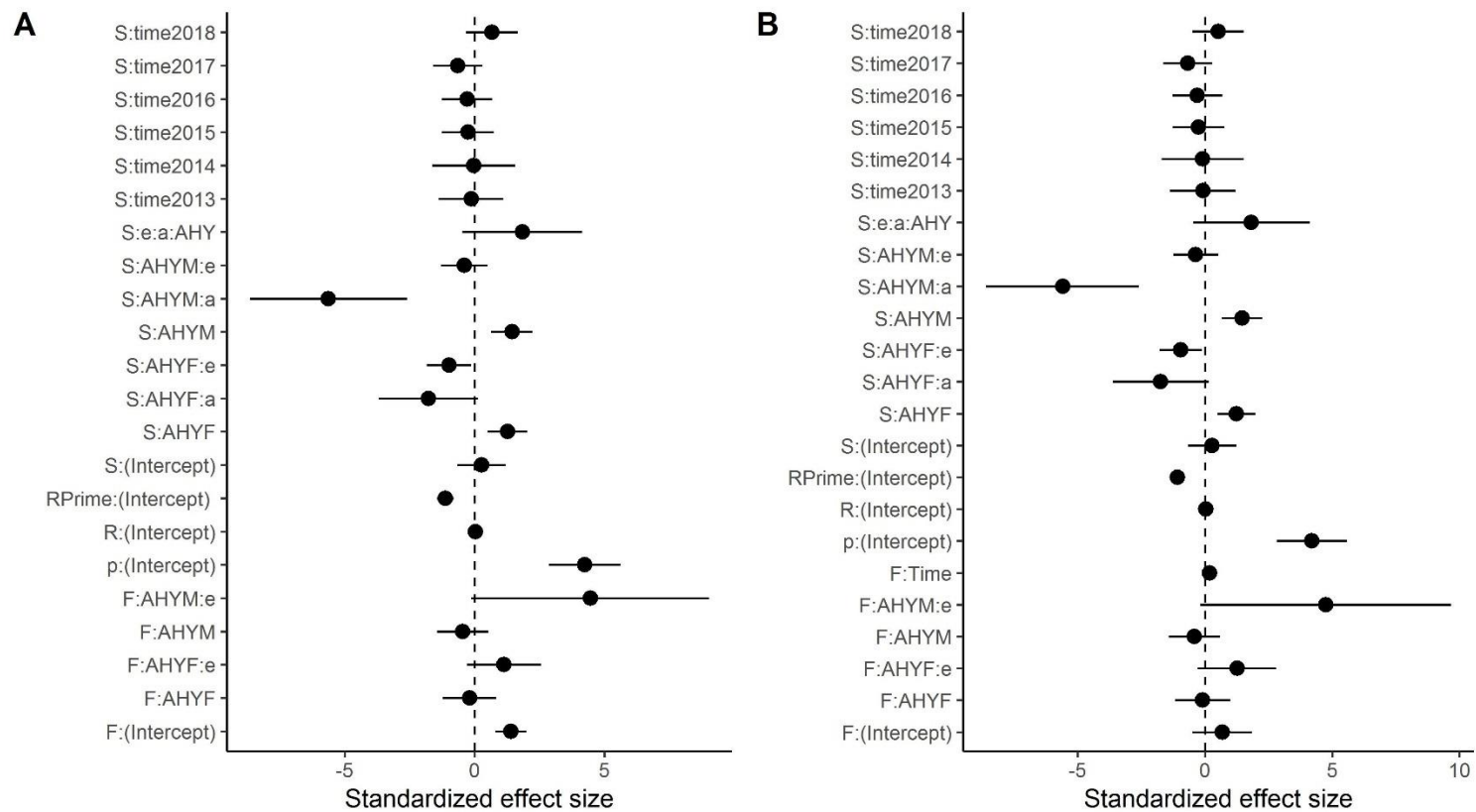
CHAPTER 4 HABITAT SPECIFIC ANTHROPOGENIC DISTURBANCE, GROWTH, AND SURVIVAL OF PIPING PLOVER CHICKS: IMPLICATIONS FOR MANAGEMENT

ABSTRACT When a population of conservation concern is not recovering, it is important to investigate potential limiting factors. For the federally threatened Atlantic Coast piping plover, which has failed to increase in some parts of its range despite over 30 years of conservation, factors affecting survival of precocial chicks may differ greatly among sites and years. Thus, local studies are needed to provide decision support for potential conservation interventions, such as habitat restoration or predation management. We studied the influence of site characteristics and human disturbance on the behavior, habitat use, growth rate, and survival of piping plover chicks in coastal New Jersey, a portion of the Atlantic Coast population that continues to demonstrate poor demographic output, from 2012–2019. Sites varied in levels of human disturbance and access to high-quality foraging habitat, which are two critical components of fledging success. We found that compared to chicks with access to bay beaches, chicks at sites without such access experienced higher rates of anthropogenic disturbance, spent less time in moist-substrate habitats such as ephemeral and tidal pools, and spent more time in upland dunes. Foraging rates were greatest for chicks foraging in moist substrate habitat with bayside foraging access (24.68 pecks/min [95% CBI = 21.4, 28.0]) and for chicks foraging in the oceanside intertidal zone without bayside foraging access (23.49 pecks/min [13.2, 33.4]). Further, overall chick growth rates were higher for chicks reared at sites with bayside foraging access (bay = 1.5 g/day [95% CBI = 1.4, 1.7]; no bay = 1.2 [1.1, 1.4]). In our models, chick survival was heavily influenced by age, precipitation, and foraging habitat. However, it is likely that human disturbance was limiting chick access to foraging opportunities — particularly in the

oceanside intertidal zone — at sites open to the public, with an apparent effect on growth rate. In other studies, chick survival was directly affected by human disturbance; therefore, maintaining access to high quality brood-rearing habitat separate from human activity through restoration, preservation of newly created habitat, supplementary food or beach closures can help to ensure higher reproductive success in New Jersey.

KEY WORDS *Charadrius melodus*, chick survival, endangered species, foraging rates, growth rates, New Jersey, Piping plover

Food availability is an important factor regulating populations as it influences growth, reproductive success and survival of vertebrates ranging from amphibians to bears (Martin 1987, Graeb et al. 2004, Jones and Geupel 2007, Lamb et al. 2017). Moreover, as human development continues to influence ecosystems, anthropogenic changes in habitat may further influence food availability leading to decreases in body condition and survival (Whittingham and Robertson 1994, Amara et al. 2007, Coon et al. 2019). As habitat quality affects food availability, and food availability influences demographic rates, it is important to understand the relationships between habitat quality, food availability, and habitat use for developing informed conservation actions for species of concern.

In birds, precocial chicks represent a particularly vulnerable life stage that is sensitive to habitat quality and a variety of threats. Such chicks are self-feeding from the time of hatching, and habitat selection is usually determined by the attending adults that lead their young away from the nest to forage and grow to be self-sufficient. Precocial development is associated with high energy requirements due to thermoregulation and the cost of activities associated with foraging (Schekkerman et al. 2001, Tjørve et al. 2009), which can leave chicks vulnerable to the quality of the foraging habitat. Failure to acquire enough energy may impede growth and lead to starvation. When precocial chicks exploit areas of high prey density, they can maximize their encounter rate with prey (Courbin et al. 2014) and thereby maximize their rate of energy intake (Kosztolányi et al. 2007, Kentie et al. 2013).

Although high quality foraging habitat may be inaccessible due to poor connectivity between nesting and foraging habitat, human disturbance may also prevent chicks from accessing desirable foraging habitat (Burger 1994, DeRose-Wilson et al. 2018). When the availability of food resources becomes limited for precocial chicks, either physically due to

habitat limitations or functionally due to human disturbance, growth may be slower, leading to a prolonged period of susceptibility to predators and lower chick survival rates. Further, if chicks reared in poor quality habitat survive, they may become poor quality breeders that contribute only marginally to overall population growth rates (Reid et al. 2003, van de Pol et al. 2006).

The Atlantic Coast piping plover (*Charadrius melodus*) is a migratory shorebird that raises its chicks in areas of substantial human activity from recreation, but which has demonstrated steady but geographically and temporally uneven recovery following intensive research into limiting factors and consequent management actions. The species breeds in coastal ecosystems in the United States that have been highly fragmented due to human development, with remaining patches subject to several anthropogenic stressors and with varying degrees of connectivity. They nest on sparsely vegetated beaches on the Atlantic Coast in the United States and Canada (Elliott-Smith and Haig 2004). Regulatory protection and management interventions for piping plovers have been largely successful in recovering populations throughout the breeding range via intensive management of site-specific stressors such as predation and human disturbance, without addressing habitat loss and fragmentation directly (Melvin et al. 1991, USFWS 2009). However, some subpopulations have not recovered, including the New York-New Jersey Recovery Unit where the piping plover population in New Jersey has seen no increase in abundance since the time of listing (USFWS 2016). Approximately 96% of the New Jersey coastline is managed for human recreation (Maslo et al. 2018), and the remaining coastline offers a fragmented landscape of remnant habitat available for nesting and foraging. It will be difficult for the species to meet all recovery goals without improved reproductive success in this geographic region.

Piping plover productivity in these remnant patches depends on a mosaic of foraging and nesting habitat. Piping plover nest site selection is primarily driven by proximity to adequate moist substrate habitat for foraging (Cohen 2005) typically located on the bayside of a barrier island, which provides more arthropod prey items than any other habitat cover types (Loegering and Fraser 1995, DeRose-Wilson et al. 2018). This foraging habitat provides such a reliable food source that adult piping plovers will select nest sites adjacent to moist substrate despite physical barriers such as houses or dunes that may affect their chicks' ability to also access this habitat (Fraser et al. 2005, Cohen et al. 2009). Furthermore, human recreation may serve as a functional barrier for chicks to access high quality foraging habitat on oceanside beaches (Flemming et al. 1988, DeRose-Wilson et al. 2018), and chick growth rates and survival have been linked to their ability to access adequate moist substrate habitat for foraging (Le Fer et al. 2008, Anteau et al. 2012, Hunt et al. 2017). Conservation of piping plovers thus depends on protecting and restoring very specific habitat conditions. Furthermore, if access to moist-substrate foraging habitat is a limiting factor for chicks in New Jersey, whether it is physically or functionally unavailable, we would expect to see differences in chick behavior, growth and survival rates between sites with and without access to moist-substrate habitat on the bayside of a barrier island.

The objectives of this study were to 1) compare chick behavior and habitat use among sites with different available resources and levels of human disturbance, and 2) determine factors that are limiting chick growth rate and chick survival in New Jersey. Given that human disturbance has been shown to influence habitat use which can then influence energy intake and, therefore, the growth rate and survival of chicks, we compared habitat use, activity budgets, the number of foraging attempts per minute, growth rate, and survival at sites with bayside foraging access and without bayside foraging access. We hypothesized that chicks without bayside

foraging access would have lower growth and survival rates than chicks with bayside foraging access which could be attributed to differences in activity budgets, habitat use patterns, and decreased foraging attempts per minute.

METHODS

Study Area

We studied piping plover demographics at study sites in southern New Jersey between 2012–2019 (Fig. 4.1). Our study area spanned from Monmouth Beach-North (MBNO; latitude 40.33°N, longitude -73.97°W) located at the southern border of Gateway National Seashore to Cape May Point State Park (CMPSP; latitude 38.93°N, longitude -74.95°W) located north of the mouth of the Delaware Bay. The barrier islands of the New Jersey coast run north-south and are located in the temperate zone. During the breeding season (Apr–Aug) the temperature averaged 22.14°C ±0.15 SE (range = 8.90–32.60°C) and precipitation averaged 3.79 cm ±0.34 SE (range = 0.00–137.40 cm) (Atlantic City International Airport; National Oceanic and Atmospheric Administration 2019).

Coastal beaches on New Jersey barrier islands are characterized by open, sandy areas with sparse vegetation and both natural and human-modified sand dunes. Piping plover nesting areas are often characterized by storm-created habitat whereby vegetation is scoured by tidal flooding and bayside intertidal sand flats are created (USFWS 1996). Coastal sand dunes are dominated by American beachgrass (*Ammophila breviligulata*), and other beach-adapted plants including seaside goldenrod (*Solidago sempervirens*), beach pea (*Lathyrus japonicus*), and trailing wild bean (*Strophostyles helvola*). Many study areas were inhabited by other beach-nesting birds that were federally and/or state listed such as American oystercatcher (*Haematopus palliatus*), least tern (*Sternula antillarum*), and black skimmer (*Rynchops niger*).

Study sites included Barnegat Lighthouse State Park in Barnegat Light (BALI, 2015–2019); Holgate Unit of E.B. Forsythe National Wildlife Refuge, in Long Beach Township (HOLG, 2015–2019); Little Beach Unit of E.B. Forsythe National Wildlife Refuge in Long Beach Township (LIBE, 2017–2019); North Brigantine Natural Area in Brigantine (NBNA, 2015–2019); Malibu Wildlife Management Area and Seaview Harbor Marina in Longport (MWMA, 2015); Avalon-Dunes in Avalon (AVDU, 2012–2018); Stone Harbor Point in Stone Harbor (SHPT, 2012–2019); North Wildwood Beach in North Wildwood (NOWI, 2015); Island Beach State Park in Berkely Township, NJ (IBSP, 2017–2019); Seabright Beach in Seabright (SBNO, 2018–2019; SBSO, 2018–2019), Monmouth Beach in Monmouth (MBNO, 2018–2019; MBSO, 2018–2019), Seven Presidents Oceanfront Park in Long Brach (7PRES, 2018–2019), and the National Guard Training Center in Sea Girt (NGTC, 2019; Appendix 4.A).

Field Methods

To locate breeding pairs, trained observers visited current and potential nesting sites within New Jersey. Most sites were surveyed daily to weekly, although locations without recent breeding activity may only have been visited during the piping plover breeding seasons from 1–9 June which is the coastwide census window. From 2012–2019, chicks were captured by hand and uniquely marked with two colored Darvic leg bands (model XCLD, internal diameter 3.1mm, AVINET, Dryden, New York) on each tibiotarsus. To evaluate chick growth rates, we recaptured chicks every 5–7 days. At each capture, chicks were weighed to the nearest 0.1 g.

To evaluate habitat use, we conducted behavioral observations on a subset of chicks from Avalon-Dunes, Barnegat Light, Holgate, North Brigantine Natural Area, and Stone Harbor Point from 2016–2017. Prior to each field day, we randomly selected the individual (>3 days old) to be observed, without replacement, and if the selected individual could not be found, we would

move to the next individual. Once all individuals had been observed, we replaced them into the

sampling pool and started over. Behavioral observations were conducted between 06:00 and

18:00 from 27 May–3 August. Observations were conducted within 10 min periods where every

10 seconds the cover type and behavior of the chick was recorded (one

observation/individual/day). Cover types included moist substrate habitat (such as sandflats,

mudflats, tidal pools, or ephemeral pools), berm, wrack, dunes, and oceanside intertidal zone

(Table 4.1). Behaviors included foraging, brooding, resting (sitting, preening), disturbed

(pedestrian, dog, predator, or vehicle) or locomotion (walking or flying; Table 4.2). Additionally,

we recorded each time a chick actively pecked at the substrate to capture a prey item. If a chick

walked out of view during an observation period, we recorded that the chick was out of view

every 10 seconds until the chick was relocated, and the out of view instances were not used in

calculating activity budgets or foraging rates.

Trained observers assigned to each beach attempted to determine brood fate within

established territories or proximity of banded parents every 1–7 days until all chicks had fledged

or were assumed dead based on the absence of the chicks and parents. Because pairs were

monitored at a high frequency (5–7 days/week), we were able to confidently track individual

broods. For unmarked pairs, we identified broods based on location and age.

Analytical Methods

We used Multi-Response Permutation Procedure (MRPP) in Blossom Statistical Software

(Talbert and Cade 2005) to determine whether behavior and habitat use differed between sites

where bayside habitat was or was not available. A nonparametric analog to multivariate analysis

of variance (MANOVA), MRPP is used to test whether there is a significant difference between

the within-group distances of two or more groups (McCune et al. 2002). In contrast to

MANOVA, MRPP does not require distributional assumptions such as normality or homogeneity of variances (McCune et al. 2002). MRPP calculates the mean distance within each group and generates a weighted mean of the distances (McCune et al. 2002). The procedure then shuffles the class variables within the data and recalculates the weighted mean of distances within random groups, and this permutation procedure is repeated until a distribution of mean distances is achieved (McCune et al. 2002). The test statistic describes the separation between the groups, and the larger the negative value of the test statistic, the stronger the separation (McCune et al. 2002). A *P*-value is also associated with the test statistic which is the probability that an observed difference of the within group distances is due to chance (McCune et al. 2002). Due to testing multiple hypotheses, we used the Bonferroni correction to compensate for the increase in the likelihood of incorrectly rejecting the null hypothesis, when performing pairwise comparisons (Armstrong 2014).

We modeled foraging rates using a linear mixed effects model (McCulloch et al. 2011) with individual as a random effect. We modeled the number of pecks/minute from the 10 min behavioral observations as a function of cover type (Table 4.1) and bayside foraging accessibility (binary variable). We fit the model in a Bayesian framework by specifying models in the BUGS language, with posterior distributions for parameters of interest estimated using Markov Chain Monte Carlo (MCMC) simulation with Gibbs sampling as implemented in JAGS v. 3.4.0 (Plummer 2013), run from program R v. 3.5.1 (www.r-project.org, accessed 7 Feb 2018, R Core Team 2018) via the package jagsUI (Kellner 2017). We used wide non-informative priors for all parameters: a normal distribution with mean 0 and variance 1000 for all coefficients in the linear predictors, and a uniform distribution between 0–50 for all variance parameters. We checked for convergence of 3 parallel MCMC chains per model by visually inspecting the trace plots and by

using the Gelman-Rubin diagnostic ($\hat{R}$; Gelman 2004) and considered convergence to be

achieved at $\hat{R} < 1.05$ for all parameters. We considered covariates to be important predictors if

the 95% credible intervals on the regression parameter did not overlap zero (Kuo and Mallick

1998, Link and Barker 2006).

Using data from 2015 and 2016 only, we tested several different growth curves for body

mass including a Richards function, Gompertz function, and Weibull function and determined

that the best fitting growth curve was the four-parameter logistic growth model. We therefore

modeled the change in mass of chicks from 2015-2017 and 2019 with age using a four-parameter

logistic growth model (Crawley 2007) in Bayesian framework with separate parameter estimates

for sites with and without bayside access using a means parameterization (Kéry 2010). A major

strength of the four-parameter logistic growth model is that each of the four parameters has an

intuitive meaning which enhances the interpretability of the fitted model. We used the following

parameterization for the four-parameter logistic model:

$$mass = \Phi_1 + \frac{(\Phi_2 - \Phi_1)}{1 + e^{\frac{\Phi_3 - age}{\Phi_4}}}$$

where Φ_1 parameter represents the lower asymptotic mass, Φ_2 represents the upper asymptote, Φ_3

represents the inflection point (or the age at which the chick is halfway between the lower and

upper asymptote), and Φ_4 represents the slope (or growth rate parameter) at the inflection point.

Using the predicted values for each of the four parameters, we derived the mass at the inflection

point, Φ_3, then calculated the rate of change from day 0 to the inflection point. Further, we

calculated the overall rate of change from day 0 to day 25 when chicks typically fledge. We used

wide non-informative priors for all parameters: a normal distribution with mean 0 and variance

1000. We checked for convergence of 3 parallel MCMC chains per model by visually inspecting

the trace plots and by using the Gelman-Rubin diagnostic ($\hat{R}$; Gelman 2004) and considered

convergence to be achieved at $\hat{R} < 1.05$ for all parameters. We determined whether bayside

foraging access was an important predictor for any of the four parameters by whether 95%

credible intervals overlapped between categories for each parameter (Kuo and Mallick 1998,

Link and Barker 2006).

We analyzed piping plover chick survival rates using a Young survival model (Lukacs et

al. 2004) with the random effect of site nested within the random effect year. Young survival

models correct for imperfect detection of chicks and non-independence among brood mates

using periodic chick counts and a unique identifier for broods (i.e. via leg bands on a parent or

territorial location) rather than individual chicks. We tested for correlation among ecological and

management-related covariates that may influence daily survival probability (Table 4.3) using

the Pearson's pairwise correlation (Soper et al. 1917) in program R using the GGally package

(Schloerke et al. 2018), and we did not use variables that were highly correlated in our models (-

$0.5 < r < 0.5$, Appendix 4.B; Mukaka 2012, Schober et al. 2018). We could not include body

mass or chick growth rate parameters in the survival model, because the sample size of broods

that we repeatedly weighed was much smaller than the number of broods for which we had

survival data. We conducted Bayesian model selection using the indicator variable approach

(Kuo and Mallick 1998, Link and Barker 2006), where each regression parameter k is multiplied

by an indicator variable w_k that follows a Bernoulli distribution with a prior probability of 0.5.

Using this approach, during each MCMC sample the indicator variables were given a value of

one if the covariate occurred in the model and zero if it did not. We used the estimated w_k to

calculate the Bayes' factor (BF) for each covariate, where the BF represents the odds ratio of

inclusion (Smith et al. 2011). Following the recommendations of Link and Barker (2006), to

maintain constant total model variance regardless of the number of parameters entering the

model, we scaled the prior variances for each of the fixed-effect covariates by dividing the prior variance by the number of covariates entering the model at each iteration, with a gamma-distributed prior with parameters 3.29 and 7.8 assigned to the total model variance. We checked for convergence of 3 parallel MCMC chains per model by visually inspecting the trace plots and by using the Gelman-Rubin diagnostic ($\hat{R}$; Gelman et al. 2004) and considered convergence to be achieved at $\hat{R} < 1.05$ for all parameters. We then incorporated the random effects and all standardized covariates with a BF > 1 into a final model and considered covariates to be useful predictors if the 95% credible intervals on the regression parameter did not overlap zero (Kuo and Mallick 1998, Link and Barker 2006).

RESULTS

The time-activity budget of chicks differed between sites with and without bayside foraging access (MRPP, Test statistic = -5.7, $P < 0.001$). Specifically, piping plover chicks spent similar amounts of time resting, walking/flying, and foraging at sites with and without bayside foraging access; however, chicks without bayside foraging access were disturbed 86.7% more than chicks with bayside foraging access (MRPP, Test statistic = -17.1, $P < 0.001$, Fig. 4.2). The amount of time that chicks spent in various cover types differed between sites with and without bayside foraging access (MRPP, Test statistic = -25.8, $P < 0.001$). Chicks with bayside foraging access spent more time in moist substrate foraging habitat than chicks without bayside foraging access (MRPP, Test statistic = -34.6, $P < 0.001$; Fig. 4.3); chicks with bayside foraging access spent half as much time in wrack as chicks without bayside foraging access (MRPP, Test statistic = -5.6, $P < 0.001$; Fig. 4.3). Chicks with bayside foraging access spent very little time in the oceanside intertidal zone compared to chicks without bayside foraging access (MRPP, Test statistic = -4.430, $P = 0.005$; Fig. 4.3). Chicks without bayside foraging access spent more time

on the oceanside berm than chicks without bayside foraging access; (MRPP, Test statistic = -8.6, $P < 0.001$; Fig. 4.3). Chicks without bayside foraging access spent more than twice as much time in the dunes as chicks with bayside foraging access (MRPP, Test statistic = -28.5, $P < 0.001$; Fig. 4.3).

We found a significant interaction between the effects of bayside access and the wrack cover type on foraging rate (Table 4.4). Foraging rate was greater in the wrack for chicks without access to bayside foraging habitat than chicks with access (Fig. 4.4). The number of foraging pecks/minute spent foraging in moist-substrate habitat for chicks with bayside foraging access was over twice the number of foraging pecks/minute spent foraging in dunes (Fig. 4.4). The greatest mean foraging rate was for chicks with bay access foraging in moist-substrate habitat, although the variance within cover types was too large for statistical inference of differences between most pairs of cover types, and foraging rates in wrack and the ocean ITZ for chicks with no bay access were close to foraging rates in moist-substrate habitat for chicks with access (Fig. 4.4).

There were no differences in the Φ_1, Φ_3, or Φ_4 parameters between chicks that were reared at sites with bayside foraging access and chicks that were reared at sites without bayside foraging access (Table 4.5). However, chicks reared at sites with bayside foraging access had greater upper body mass asymptotes (Φ_2) than chicks reared at sites without bayside foraging access (Fig 4.5). The rate of body mass change from day 0 to the inflection point was greater at sites with bay access (mean = 0.76 g/day [95% CBI=0.69, 0.83]) than at sites without (0.61 [0.54, 0.69]), and the rate of change from day 0 to day 25 was also greater at sites with bay access (1.52 [1.39, 1.66]) than at sites without (1.22 [1.09, 1.38]).

From 2012–2019, we monitored 472 nest attempts, 226 of which successfully hatched at least one chick. There was a high degree of correlation between whether or not bayside foraging access was available, the amount of time chicks spent in moist-substrate habitat, and sites that were closed to the public (Appendix 4.B). Similarly, there was a high degree of correlation between the amount of time chicks spent in moist-substrate habitat, the amount of time chicks spent in dunes, sites with ORV use, and sites with high levels of public use (Appendix 4.B). Because bayside foraging availability was of interest in our growth rate model, we chose to use this covariate in our Young survival models. We also included whether or not the site was considered a "high use" site (Appendix 4.A) to examine the impact of human disturbance on daily chick survival. However, because there were no "high use" sites that also had bayside foraging access, we did not interact these two variables. Daily minimum temperature and daily maximum temperature were also correlated, and because we predicted that daily minimum temperature might affect survival and daily maximum temperature might affect detection, we included these covariates in the respective models only.

The effects of chick age, daily precipitation, and bayside foraging access on chick survival as well as the effects of daily maximum temperature and high public use on detection were well supported ($w_k \geq 0.95$) by the model selection procedure (Appendix 4.C). Adult age and high public use on chick survival received moderate support ($w_k \geq 0.50$) by the model selection procedure but the 95% credible intervals overlapped zero. However, the effects of daily minimum temperature, density, the interaction between precipitation and age, and the interaction between bayside foraging access and age on daily chick survival received low support. The final model (Table 4.6) indicated that daily chick survival rates increased with age (Fig. 4.6A), decreased with daily precipitation (Fig. 4.6B), and was lower when bayside foraging access was

not available (Fig. 4.6A). As daily maximum temperature increased, detection of chicks also increased and sites with high levels of human use had higher chick detection rates (Fig. 4.7).

DISCUSSION

Our results suggest that foraging habitat access for chicks is a limiting factor for piping plover productivity in New Jersey, as sites with high levels of human use did not have an impact (positive or negative) on daily chick survival, yet chicks with bayside foraging access had higher daily survival rates. However, we cannot completely separate the effects of food abundance and human disturbance because the cover types with the highest foraging rates were also those of the least disturbance. We found that chicks at sites without bayside foraging spent less time in moist-substrate habitats such as ephemeral or tidal pools and spent more time in dunes than chicks with bayside foraging access. Further, we found that foraging rates for piping plover chicks without bayside foraging access were lowest on the berm and in dunes suggesting that these cover types likely do not provide adequate food resources for chicks, and disturbed chicks are likely spending more time searching for food than successfully capturing prey items. On average, chicks without bayside foraging access had lower foraging rates in moist-substrate habitat than chicks with bayside foraging access, suggesting that when chicks are able to access moist-substrate foraging habitat, they likely experience increased vigilance due to the threat of human disturbance because this foraging habitat is typically found outside of symbolically fenced areas on the oceanside beach, in the form of ephemeral pools formed during extreme high tides or storms.

The relationship we observed between energy intake from foraging rates, growth rate and survival has been documented in studies of other bird species. McKinnon et al. (2012) found that shorebird chicks in the Canadian Arctic that had access to more prey had higher growth rates

than chicks with lower prey availability. Through simulations, Chapman et al. (2010) found that the timing of Antarctic krill spawning can influence the availability of high-energy prey resulting in lower growth rates and survival of Adelie penguin (*Pygoscelis adeliae*) chicks exposed to lower energy densities of Antarctic krill (*Euphausia superba*). Similarly, Cairns (1982) found that piping plover chicks failing to reach 60 percent of the mean weight at day 12 were less likely to survive than chicks heavier than the mean weight at day 12. Loegering and Fraser (1995) found that piping plover chick survival rates were lower for broods reared on ocean beaches when compared to broods reared on bayside beaches, further demonstrating that poor food supply contributes to chick mortality.

A shortage of food availability during early development can lead to long-term effects on fitness, in addition to the immediate effects on chick growth rates and survival (Metcalfe and Monaghan 2001). Several studies suggest these long-term consequences on fitness include adult survival before recruitment (Harris et al. 1994, Cam et al. 2003) and recruitment probability (Reid et al. 2003, Noguera et al. 2012). For example, van de Pol et al. (2006) found both short-term and long-term effects for Eurasian oystercatchers (*Haematopus ostralegus*) reared in high-quality habitat – the short term benefits included higher juvenile survival rates, and the long-term consequences included higher pre-breeder survival rates, lifetime reproductive success, and a probability of nesting in high-quality habitat. Therefore, the long-term consequences for piping plover chicks reared in poor quality habitat may include poor quality breeders that contribute only marginally to overall population growth rates.

Factors such as precipitation and brood age that affect piping plover chick survival rates have been documented in other ground nesting bird species. Schulte and Simons (2015) found that American oystercatchers (*Haematopus palliatus*) chicks were most vulnerable during the

first week of hatching, Knopf and Rupert (1996) documented lower survival rates for mountain plover (*Charadrius montanus*) chicks within the first 10 days of hatching, and Colwell et al. (2007) found that snowy plover (*Charadrius nivosus*) chicks were most likely to die within the first 3 days after hatching. Both age and precipitation may influence thermoregulation such that during adverse weather conditions, younger chicks may be more susceptible to direct exposure via hypothermia (Beintema and Visser 1989, Schekkerman et al. 2001). Further, severe weather events may decrease a chick's ability to forage, leading to decreasing in survival at any age (Erikstad and Andersen 1983). Very similar to our findings, Terhune et al. (2019) found that chick survival rates for Northern bobwhite decreased with total amount of daily precipitation. It has been documented that gadwall duckling survival from age 8-30 days decreases with precipitation (Pietz et al. 2003). Brudney et al. (2013) also documented that piping plover chicks were vulnerable to increased precipitation in the Great Lakes where survival of chicks was reduced by heavy rain during the first 3 days of life. The age-related increase in piping plover chick survival in New Jersey suggests that older chicks are more capable of thermoregulation and evading predators, whereas the negative effect of precipitation on survival suggests that chicks may experience limited foraging opportunities during periods of poor weather, which may be important for chicks without access to adequate foraging habitat or that experience high levels of human disturbance.

While understanding the factors affecting chick survival are valuable, mitigating the impacts of environmental factors on reproductive success are often impractical. However, with increased protections and restored habitat, factors such as a lack of bayside foraging access and high recreational beach use can potentially be mitigated. Restoring habitat for piping plovers has successfully increased foraging rates for both adults and chicks in New Jersey (Maslo et al.

2012). Similar to our findings, Elias et al. (2000) found that foraging rates were highest for piping plover chicks foraging in moist-substrate habitats, suggesting that if access to this type of foraging habitat is increased, fledge success may also increase. Further, piping plover chicks have been documented to spend less time in foraging habitat, make fewer foraging attempts per minute and experience lower daily survival rates on weekends when recreational beach use is high (DeRose-Wilson et al. 2018). Ruhlen et al. (2003) also documented higher rates of snowy plover chick loss in Point Reyes National Seashore, California on busy weekends and holidays as compared to weekdays. Unfortunately, cover types such as bayside sand flats and ephemeral pools are relatively rare in New Jersey due to coastal management projects such as dune building and beach renourishment, relegating chicks to the oceanside beach for foraging. Restoring moist substrate foraging habitat for piping plover chicks as well as reducing human disturbance to foraging chicks may lead to increases in chick survival rates in New Jersey.

Habitat restoration may not be an option for many New Jersey nesting sites such as Avalon-Dunes or Monmouth County beaches which are linear nesting sites backed by areas of heavy human development. However, because these beaches also experience high levels of human disturbance, it is important to develop creative ways for chicks to access adequate foraging. Restoring access to intertidal areas during times of high human activity by extending beach closures to the waterline may help to improve growth and survival for sites where creation of new bayside foraging habitat is not an option. However, closing intertidal zones to walking traffic could have legal barriers or political consequences and might not be possible. Supplementary feeding has also been demonstrated to increase nesting success in both songbirds and ground-nesting birds (Castro et al. 2003, Draycott et al. 2005, Robb et al. 2008, Freeman et al. 2020). Additionally, Rooney et al. (2015) found that supplementary feeding of adult common

buzzards (*Buteo buteo*) nesting in low-quality habitats had the ability to neutralize the effects of the poor quality habitat on hatching and fledging success such that there was no difference between poor and high quality habitat on reproductive success. For piping plovers, supplementary feeding might be accomplished by simply collecting freshly accumulated wrack and regularly placing it strategically inside of symbolically fenced areas to provide a higher quality food resource than dune-dwelling invertebrates when chicks cannot reach the intertidal zone or wrack line. This approach has been shown to substantially increase the abundance of important prey items for plovers (Schlacher et al. 2017) and may be a practicable management tool to help improve reproductive success. Our study has demonstrated that food availability can be a major constraint for growth and survival of piping plover chicks, and creating foraging habitat within protected areas for chicks to readily access during periods of high human activity may help to improve growth and survival for sites where bayside habitat restoration might not be an option.

Moderate support from our chick survival model suggests that second year adults are less successful parents than after second year adults. Of the known age piping plovers that return to nest on New Jersey beaches each year, as many as 45% are second year birds (Stantial, unpublished data). Robinson (2020) found that the population of piping plovers nesting in Fire Island on Long Island, NY was primarily composed of returning adults and immigrants and that a low proportion of the population was made up of natal recruits (5–19%). Furthermore, Roche et al. (2010) found that of the 31 Great Lakes piping plover adults that disappeared from 1993–2007, only 3 of them were second year adults. It is possible that the reason a larger proportion of the New Jersey population is made up of natal recruits is due to the higher rates of adult mortality for after second year birds at exclosed nests (see Chapter 3). Further, if second year

adults are less apt at rearing chicks than after second year adults, then the New Jersey population

may be experiencing lower than average chick survival rates, regardless of habitat or human

disturbance.

The increase in detection rate for chicks as the daily maximum temperature increased was

contrary to our hypothesis. We had hypothesized that chicks would be more difficult to detect as

the daily maximum temperature increased because we often observed chicks hiding under

vegetation during behavioral observations during times of extreme heat. It is also possible,

however, that younger chicks are being brooded by adults and more difficult to detect during

colder temperatures, then as temperatures increase and chicks are more active on the beach, they

are easier to detect. Beintema and Visser (1989) found that the amount of time that chicks spent

brooding and foraging were temperature dependent, where chicks spent less time foraging and

more time brooding during colder temperatures. The increase in chick detection rates on beaches

with high human use may be related to chicks being easier to locate because they have fewer

places hide but may also be related to the amount of time that monitors spend searching for

chicks. Roche et al. (2014) found that when monitors spend more time searching for chicks,

detection probabilities increased. On beaches such as HOLG with many pairs, monitors often

spend less time searching for chicks as they need to move on to the next nest or brood.

However, at beaches with only one or two pairs, monitors may be less constrained by time and

therefore spend more time searching for chicks.

Understanding how anthropogenic disturbances and food availability are affecting chick

behavior and chick growth rates is important for developing management plans as human

recreation encroaches further into piping plover habitat. The functional decrease in available

foraging habitat due to recreational beach use can result in demographic consequences for piping

plovers. Further, management actions that affect chick survival generally have positive impacts on overall productivity. Therefore, maintaining access to high quality brood-rearing habitat through restoration, preservation of newly created habitat, or beach closures will help to ensure the reproductive success required to contribute to the recovery of the New Jersey piping plover population. The combined efforts of increasing adult survival rates, improving reproductive success, and refining predator removal strategies in New Jersey will help to increase abundance for the New York-New Jersey Recovery Unit to ensure the long-term viability of the Atlantic Coast piping plover population.

Table 4.1. Descriptions of cover types used to evaluate habitat use during behavioral observations of piping plover chicks in New Jersey, 2016–2017.

Cover type	Description
Berm	Flat open area of the beach above the high tide line
Dune	Vegetated ridge of sand that forms behind the berm of the beach; dominant vegetation is typically American beachgrass (*Ammophila breviligulata*)
Moist substrate habitats (MOSH)	-
Sandflats	Extended, flat area of sand nearshore that is typically exposed during low tide events; often occur on the low-wave energy side of the beach
Mudflats	Extended, flat area of mud/sand mix nearshore that is typically exposed during low tide events; occur on the low-wave energy side of the beach, typically along saltmarshes
Tidal pool	Shallow pools of water that form following outgoing tides; can occur on the high or low-wave energy side of the beach
Ephemeral pool	Shallow pools of water that form following large storm events that bring water higher onto the beach; typically lasting for days to weeks; can occur on the high or low-wave energy side of the beach

Oceanside intertidal zone (ITZ)	Part of the beach that is fully saturated following an incoming wave; also known as the swash zone; occurs on the high-wave energy side of the beach
Wrack	-
Fresh wrack	The fresh line of seaweed that accumulates on the beach following a high tide or large storm event
Old wrack	Aged fresh wrack

Table 4.2. Definitions and interpretations of behaviors observed during observations of piping plover chicks in New Jersey, 2016–2017.

Behavior	Description
Brooding	Chick underneath adult being brooded to maintain constant body temperature
Disturbed	Chick either crouched or actively displaced (running) in response to presence of a dog, ORV, pedestrian, predator, boat, or a combination of these disturbances; the cause of disturbance was noted in each case, and had to be identified in order to classify a chick as disturbed; adult behavior was also considered which typically included moving chicks away from the source of disturbance
Foraging	Chick in foraging habitat actively searching and attempting to capture prey items
Locomotion	Chick moving due to an unknown reason; this category was used only in circumstances when a chick was not disturbed and was not actively foraging; examples include when a chick transitioned between cover types to return to foraging following a disturbance or a chick was approaching an adult to be brooded or a chick was returning to a shaded, grassy area to rest
Resting	Chick loafing, sitting, or preening in a relaxed and restful state; adults typically nearby also loafing or preening

Table 4.3. Variables names, descriptions, and expected effects on detection (p) and survival (Φ) parameters in Young survival models of piping plover chicks in New Jersey, 2012–2019.

Parameter	Variable	Description	Expected Effect
p	Daily maximum temperature	The maximum temperature over the 24 hr period (°C)	-
	Daily maximum temperature^2	The maximum temperature over the 24 hr period (°C)	convex
Φ, p	Chick age	Number of days since hatching (d)	+ (Φ), - (p)
	Bayside access	Bayside access available (1) or bayside not accessible (0)	+ (Φ), - (p)
	High public use	Beach experience high levels of public recreational use (1) or does not experience high levels of use (0)	- (Φ), - (p)
Φ	Second year adult	At least one adult was a known second year (1) or both adults are known after second years (0)	-
	Pair density	Number of piping plover pairs per hectare of dry-sand beach monitored	-
	Daily precipitation	The total amount of precipitation that has accumulated within the last 24 hrs (cm)	-
	Daily minimum temperature	The minimum temperature over the 24-hr period (°C)	-
	Hatch date	Julian day of the year the chick hatched	-

Table 4.4. Summary statistics for posterior distributions of regression parameter estimates for the model of number of foraging pecks/minute of observation made by piping plover chicks in New Jersey, 2015–2017.

Regression parameter	Mean	SD	Quantile	
			2.5%	97.5%
Intercept[a]	17.71	4.89	6.97	27.06
Coefficients				
Dune	-1.32	5.26	-11.20	9.44
Wrack	2.56	5.20	-7.39	13.48
Berm	-3.58	5.81	-14.69	8.25
ITZ	4.92	6.97	-8.38	18.22
Bay access	6.97	5.12	-2.74	17.84
Dune*bay access	-12.79	6.86	-26.18	0.75
Wrack*bay access	-13.67	6.46	-26.62	-1.57
Berm*bay access	-4.36	7.08	-18.70	9.38
ITZ*bay access	-13.86	10.49	-34.40	5.98
Individual random effect SD	7.19	1.63	3.51	10.14

[a]Random effect hyperparameter

Table 4.5. Summary statistics for posterior distributions of parameter estimates for the means parameterization of the four-parameter logistic growth model for piping plover chicks in New Jersey, 2015–2017.

Parameter[a]	Mean	SD	Quantile	
			2.5%	97.5%
$\Phi_{1,\text{ no bay}}$	5.38	0.65	4.03	6.60
$\Phi_{1,\text{ bay}}$	4.50	0.64	3.01	5.62
$\Phi_{2,\text{ no bay}}$	35.46	1.45	33.02	38.84
$\Phi_{2,\text{ bay}}$	42.14	1.26	39.86	44.86
$\Phi_{3,\text{ no bay}}$	14.17	0.52	13.21	15.31
$\Phi_{3,\text{ bay}}$	14.13	0.33	13.52	14.83
$\Phi_{4,\text{ no bay}}$	4.33	0.47	3.49	5.39
$\Phi_{4,\text{ bay}}$	4.84	0.36	4.20	5.67

[a]Φ_1 represents the lower asymptotic mass, Φ_2 represents the upper asymptote, Φ_3 represents the inflection point (or the age at which the chick is halfway between the weight at hatch and the upper asymptote), and Φ_4 represents the slope (or growth rate parameter) at the inflection point.

Table 4.6. Standardized parameter estimates and 95% Bayesian credible intervals for Young survival model after Bayesian model selection for Atlantic Coast piping plover chicks in New Jersey, 2012–2019.

Regression parameter	Mean	SD	Quantile	
			2.50%	97.50%
Intercepts				
Chick survival[a]	2.74	0.26	2.19	3.18
Detection	2.19	0.04	2.11	2.27
Fixed effects on chick survival				
Age	0.06	0.01	0.04	0.07
Bay access	0.43	0.14	0.16	0.71
Second year adult	-0.30	0.16	-0.62	0.02
Daily precipitation	-0.17	0.05	-0.25	-0.07
High public use	0.02	0.21	-0.38	0.45
Fixed effects on detection				
Daily maximum temperature	0.14	0.03	0.09	0.20
High public use	0.52	0.13	0.27	0.77
Random effects SD				
Year	0.41	0.27	0.03	1.05
Site	4.98	2.89	0.24	9.73

[a]Random effects hyperparameter
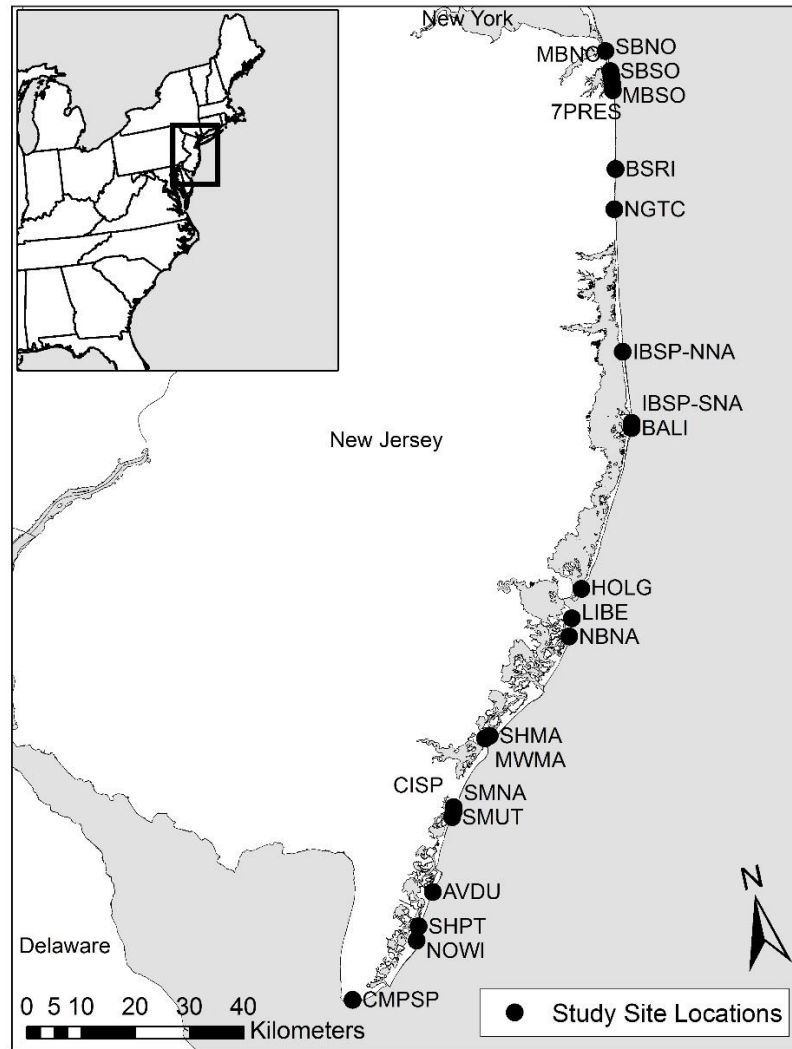
Figure 4.1. Study area for piping plover chick demographic studies in New Jersey, 2012–2019. Site abbreviations are as follows: Seven Presidents Oceanfront Park, 7PRES; Avalon-Dunes, AVDU; Barnegat Lighthouse State Park, BALI; Belmar-Shark River Inlet, BSRI; Corson's Inlet State Park, CISP; Holgate Unit, E. B. Forsythe NWR, HOLG; Island Beach State Park-NNA, IBSP-NNA; Island Beach State Park-SNA, IBSP-SNA; Little Beach Unit, E.B. Forsythe NWR, LIBE; North Brigantine Natural Area, NBNA; North Wildwood, NOWI; Malibu Beach Wildlife Management Area, MWMA; Monmouth Beach-North, MBNO; Monmouth Beach-South, MBSO.
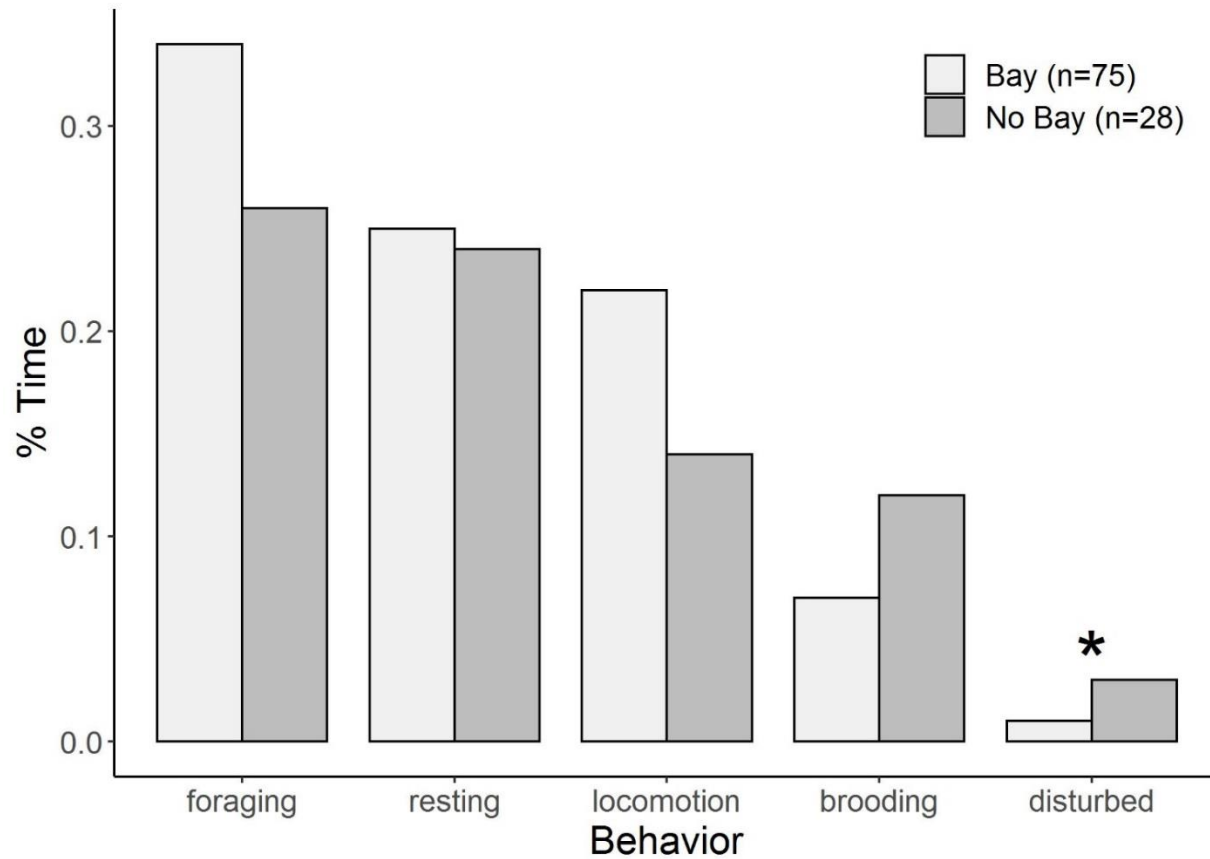
Figure 4.2. Median percent time piping plover chicks spent foraging, resting, locomoting, or disturbed at sites with and without

bayside foraging access in New Jersey, 2016–2017. Median time spent disturbed was greater at sites without bayside foraging access

than at sites with bayside foraging access (MRPP, Test statistic = -17.1, $P < 0.001$). Within behaviors, medians with an asterisk (*) are

significantly different, based on Bonferonni-corrected α levels.
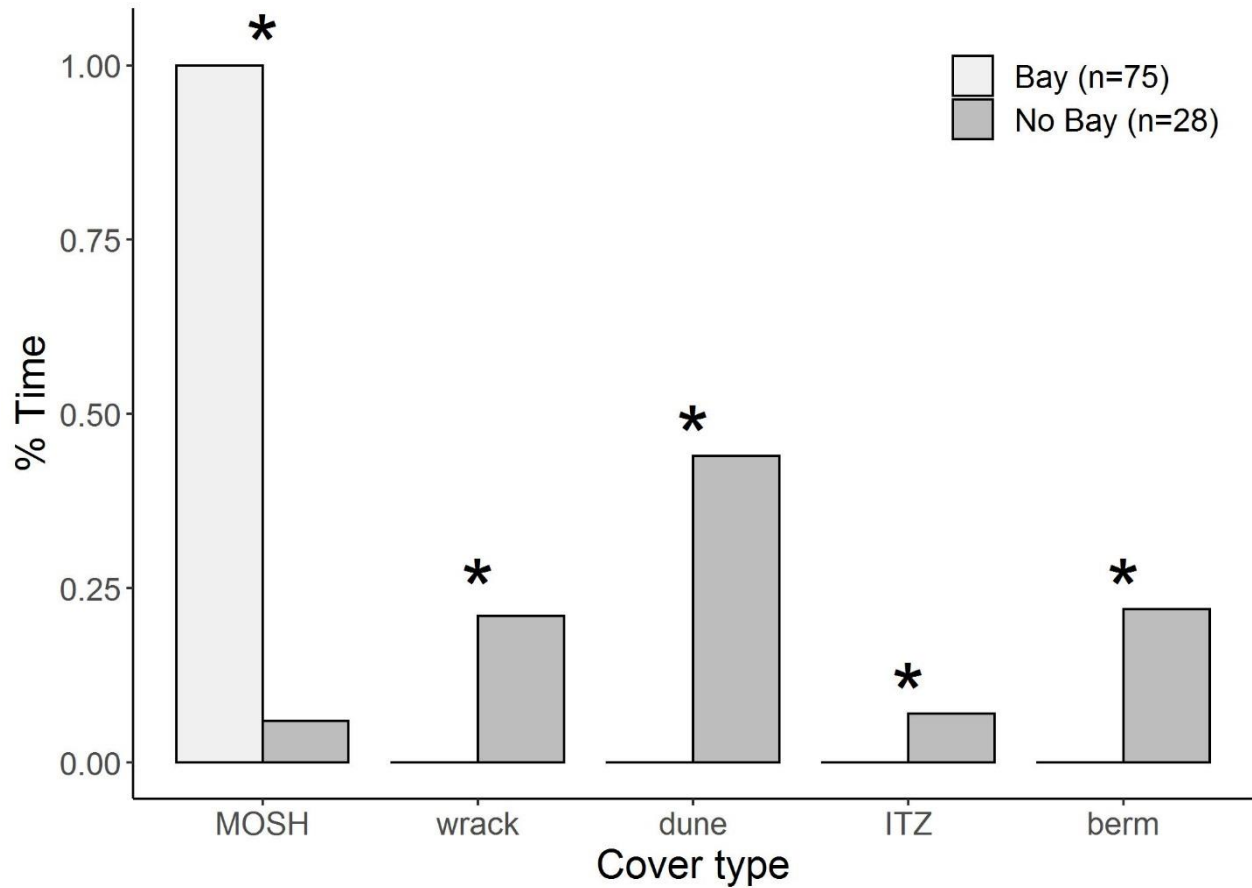
Figure 4.3. Median percent time piping plover chicks spent in moist substrate (MOSH), wrack, dunes, oceanside intertidal zone (ITZ) or berm habitats at sites with and without bayside foraging access in New Jersey, 2016–2017. Within cover types, medians with an asterisk (*) are significantly different, based on Bonferonni-corrected α levels.
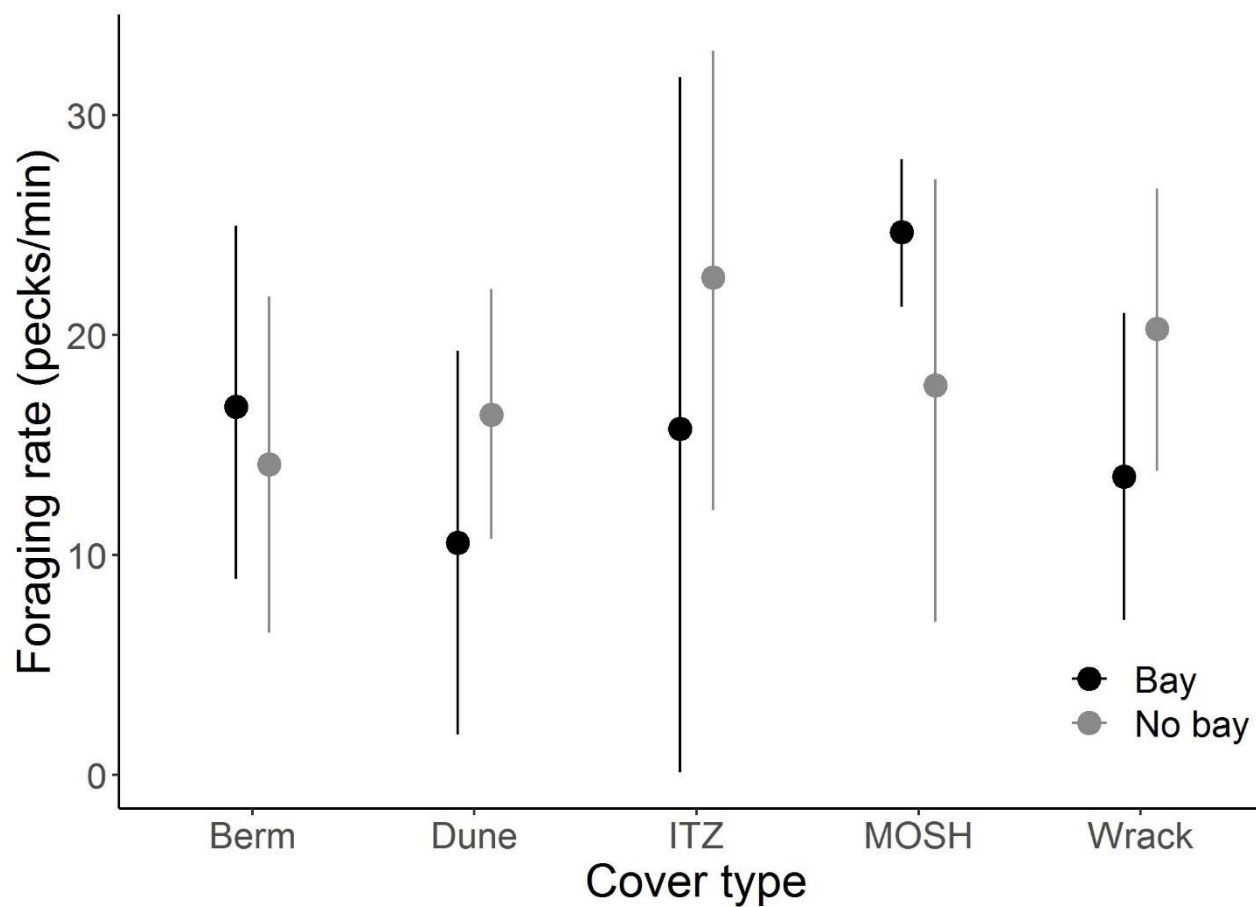
Figure 4.4. Number of foraging attempts per minute observed for piping plover chicks in New Jersey, 2016–2017. Solid dots represent means, bars represent 95% Bayesian Credible Intervals. Cover types include moist substrate (MOSH), dunes, wrack, berm, and oceanside intertidal zone (ITZ; Table 4.1), and black dots represent whether bayside foraging habitat was available (Bay) and gray dots represent whether bayside foraging habitat was not available (No Bay).
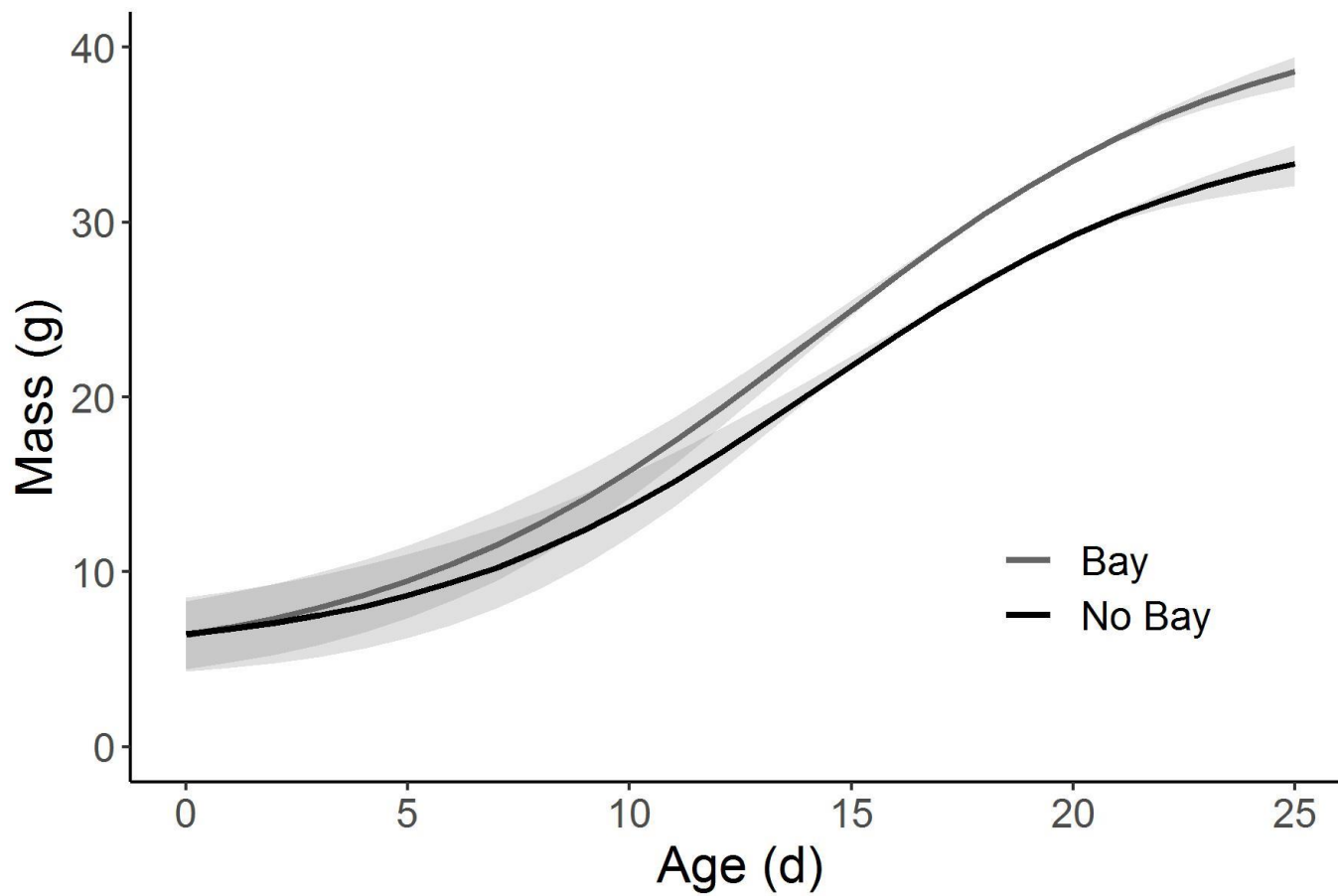
Figure 4.5. Average body mass by age for piping plover chicks at sites with bayside access (Bay) and without (No Bay) in New Jersey, 2012–2019. Bold lines represent mean growth rates, gray polygons represent 95% Bayesian Credible Intervals.
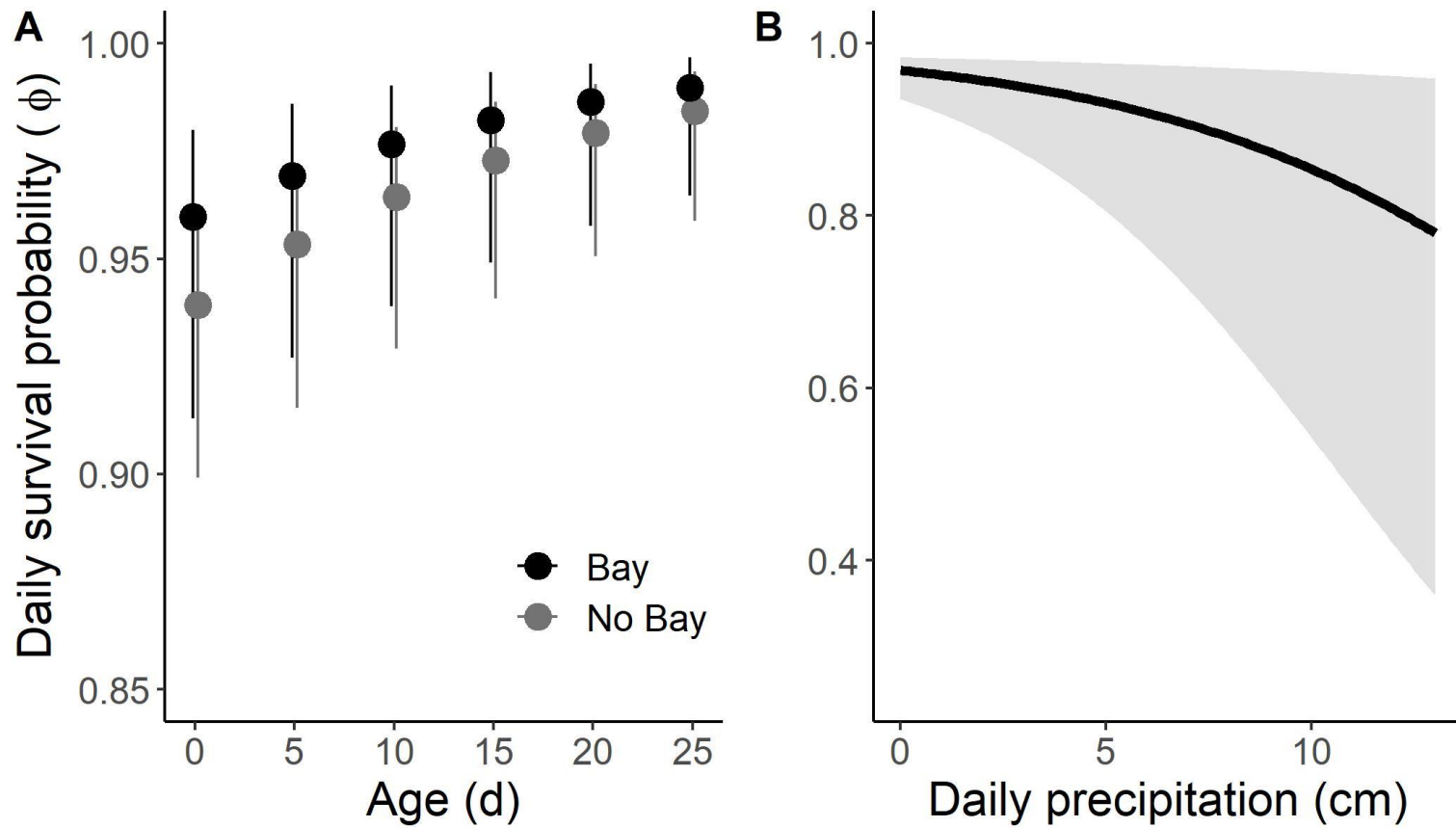
Figure 4.6. Daily chick survival probabilities vs. A) age in days and access to a bay side (Bay) or not (No Bay) and B) daily

precipitation for Atlantic Coast piping plovers in New Jersey, 2012–2019. Bold lines represent mean survival, gray polygons represent

95% Bayesian Credible Intervals.
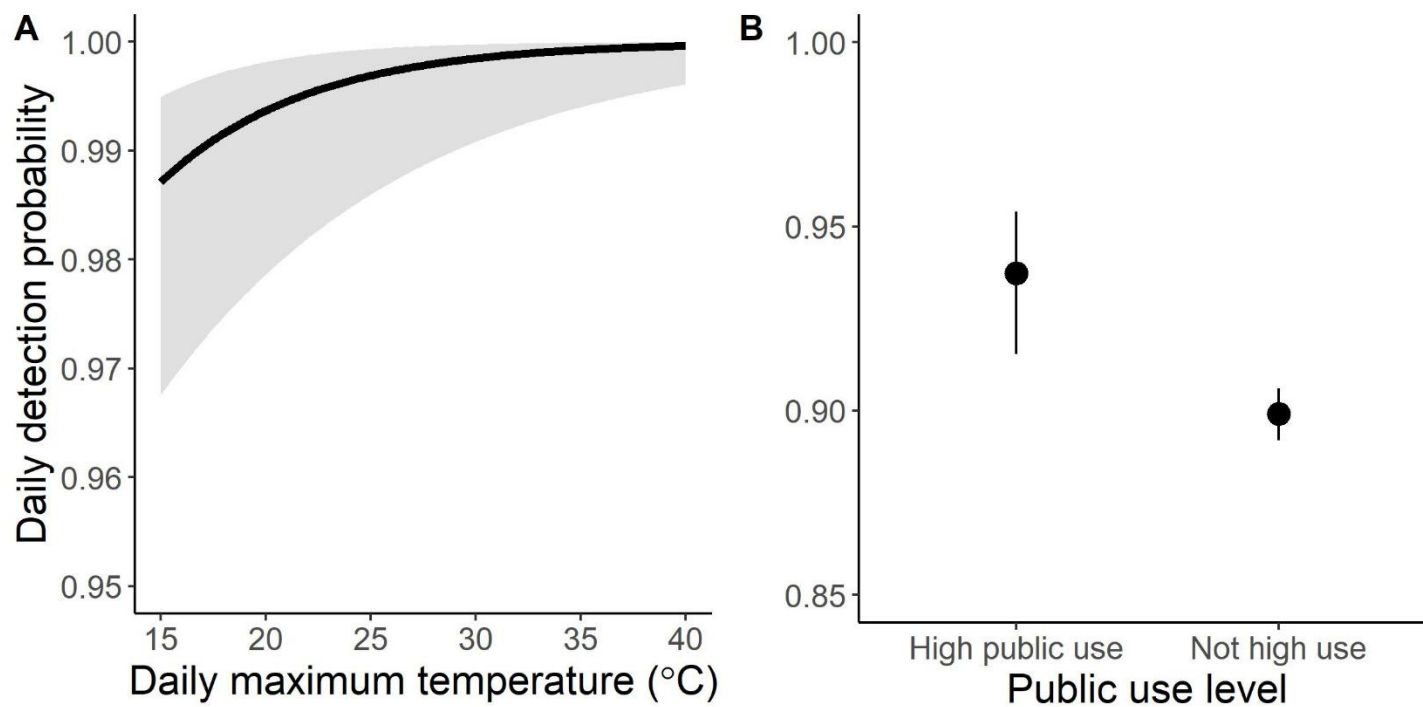
Figure 4.7. Daily chick survival detection for Atlantic Coast piping plovers in New Jersey, 2012–2019. A) Chick detection probability vs. daily maximum temperature where bold lines represent mean survival, gray polygons represent 95% Bayesian Credible Intervals. B) Chick detection probability vs. public use level where dots represent mean daily survival and bars represent 95% Bayesian Credible Intervals.

APPENDIX 4.A. STUDY SITES

Locations, abbreviations, and site characteristics of piping plover study sites in New Jersey, 2012–2019.

Site	Site ID	Latitude	Longitude	Public Use Level[a]	Bayside
Seven Presidents Oceanfront Park	7PRES	40.31494	-73.97696	High	No
Avalon-Dunes	AVDU	39.07918	-74.73201	High	No
Barnegat Lighthouse State Park	BALI-I	39.76032	-74.09947	Moderate	No[b]
Barnegat Light Town Beach	BALI-FB	39.76032	-74.09947	High	No
Belmar-Shark River Inlet	BSRI	40.18625	-74.00898	High	No
Corson's Inlet State Park	CISP	39.20935	-74.64968	High	Yes
Holgate Unit, E. B. Forsythe NWR	HOLG	39.51765	-74.28113	None	Yes
Island Beach State Park-NNA	IBSP-NNA	39.88717	-74.08176	Low	No
Island Beach State Park-SNA	IBSP-SNA	39.76858	-74.09664	Moderate	No
Little Beach Unit, E.B. Forsythe NWR	LIBE	39.47332	-74.31493	None	Yes
North Brigantine Natural Area	NBNA	39.44482	-74.32929	Low	Yes
North Wildwood	NOWI	39.00583	-74.78819	High	Yes
Malibu Beach Wildlife Management Area	MWMA	39.30972	-74.55247	Moderate[c]	Yes
Monmouth Beach-North	MBNO	40.33814	-73.97333	High	No

Monmouth Beach-South	MBSO	40.32401	-73.97503	High	No
National Guard Training Center	NGTC	40.12137	-74.03106	Moderate	No
Seabright Beach-North	SBNO	40.38115	-73.97354	Moderate	No
Seabright Beach-South	SBSO	40.34677	-73.97301	High	No
Seaview Harbor Marina	SHMA	39.31241	-74.54177	Low	No
Stone Harbor Point	SHPT	39.02831	-74.77754	Moderate	Yes
Strathmere Natural Area	SMNA	39.20254	-74.65117	High	Yes
Strathmere Town Beach	SMUT	39.19356	-74.65746	High	No
Cape May Point State Park	CMPSP	38.93228	-74.94828	Moderate	No

[a]Public use levels were categorized with the assistance of NJENSP staff and were considered only for the chick-rearing phase.

[b]Bayside foraging access created in 2019 due to restoration project at Barnegat Lighthouse State Park.

[c]This site is closed to the public yet is adjacent to a highly used dog beach and receives frequent trespassers.

APPENDIX 4.B. CORRELATION COEFFICIENTS

Pearson correlation coefficients for covariates of interest for Young survival models in New Jersey, 2012–2019. Covariates include: ORV use during chick rearing (ORV), bayside foraging accessiblity (Bay), pairs/hectare of dry sand (Density), proportion of time spent in moist-substrate habitat (TimeMOSH), proportion of time spent in dunes (TimeDUNE), daily total precipitation (PRCP), daily maximum temperature (TMAX), daily minimum temperature (TMIN), low public use (LowUse), moderate public use (ModUse), high public use (HighUse), closed to public (Closed), day of year hatched (HatchDay), and whether one or both adults were a second year (SY).

	ORV	BaysideHab	Density	TimeDune	TimeMOSH	PRCP	TMAX	TMIN	LowUse	HighUse	ModUse	Closed	HatchDay	SY
SY														
HatchDay														0.31
Closed													0.14	0.02
ModUse												-0.59	-0.08	-0.11
HighUse											-0.25	-0.51	-0.08	0.05
LowUse										-0.11	-0.13	-0.27	-0.02	0.07
TMIN									0.04	-0.04	-0.05	0.05	0.26	0.12
TMAX								0.66	0.06	-0.01	-0.02	-0.01	0.22	0.1
PRCP							-0.05	0.1	-0.02	-0.03	-0.03	0.05	0.02	0.02
TimeMOSH						0.02	0.07	0.09	0	-0.62	0.09	0.46	0.22	0.13
TimeDune					-0.68	-0.03	-0.07	-0.06	0	0.58	-0.03	-0.47	-0.26	-0.02
Density				-0.43	0.03	0	-0.05	-0.06	0	0.32	-0.13	-0.13	-0.09	0.01
BaysideHab			-0.22	-0.43	0.63	0.03	-0.03	0.01	-0.3	-0.4	-0.17	0.58	0	-0.04
ORV		-0.29	-0.13	0.71	-0.53	-0.02	-0.01	-0.02	-0.06	0.51	-0.13	-0.26	-0.04	-0.06

APPENDIX 4.C. SUMMARY STATISTICS FOR POSTERIOR DISTRIBUTIONS OF
PARAMETER ESTIMATES FOR YOUNG SURVIVAL MODELS

Standardized parameter estimates, 95% Bayesian credible intervals (BCI), inclusion probabilities (w_k) and Bayes' factors (BF) for variables hypothesized to affect daily probabilities of piping plover chick survival in New Jersey, 2012–2019.

Regression parameter	Mean	SD	Quantile		W_k	BF
			2.5%	97.5%		
Intercepts						
Chick survival[a]	2.763	0.225	2.254	3.149		
Detection	2.226	0.067	2.122	2.392		
Fixed effects on chick survival						
Age	0.058	0.010	0.040	0.079	1.000	Inf[b]
Bay access	0.399	0.158	0.120	0.708	0.981	51.631
Second year adult	-0.197	0.309	-0.665	0.606	0.715	2.508
Density	-0.044	0.378	-0.833	0.836	0.421	0.727
Daily precipitation	-0.153	0.122	-0.262	0.134	0.947	17.867
Daily minimum temperature	-0.013	0.428	-0.921	0.875	0.195	0.242
Daily precipitation*age	0.001	0.458	-0.921	0.908	0.043	0.044
Bay access*age	0.003	0.452	-0.913	0.927	0.091	0.100
High public use	0.003	0.185	-0.349	0.372	0.581	1.386
Hatch date	-0.001	0.426	-0.906	0.882	0.182	0.222
Fixed effects on detection						
Age	0.003	0.438	-0.895	0.888	0.120	0.136

Daily maximum temperature	0.135	0.031	0.073	0.196	1.000	Inf
Daily maximum temperature^2	-0.017	0.382	-0.859	0.843	0.367	0.579
High public use	0.479	0.123	0.238	0.723	1.000	Inf
Random effects SD						
Year	0.306	0.241	0.015	0.900		
Site	5.010	2.890	0.260	9.762		

[a]Random effect hyperparameter

[b]Positive infinity

CHAPTER 5 RED FOX HABITAT USE IN LANDSCAPES WITH NESTING ENDANGERED SHOREBIRDS

ABSTRACT Predation of nests and young is one of the limiting factors in the conservation of birds; understanding environmental covariates of predator distribution can inform decisions regarding the best management strategies to reduce predation risk. The habitat of beach-nesting birds is often reshaped by storms in ways that may affect nest predation, such as by flattening vegetated dunes where mammals hunt, but human management of beaches aims to prevent the effects of storms on the landscape with unknown implications for predator distributions. Moreover, human development may affect predator distributions by subsidizing food and shelter. To determine the relationship between predator occupancy and landscape features in beach-nesting bird habitat, we repeated mammalian predator track surveys 8 times per year at 90 plots in southern New Jersey from 2015–2017. We used dynamic occupancy models to estimate the probability of habitat use by red foxes and to document changes in habitat use over the avian breeding season within years. We had 373 red fox (*Vulpes vulpes*) detections with years pooled. Detection probability for red foxes varied by year, and probability of habitat use by red fox decreased as the distance to the nearest primary dune increased. However, we found no evidence that red fox habitat use depended on distance to human development. Our results suggest that conserving nesting habitat that includes open areas (i.e., storm overwash) may reduce predation risk, because ground-nesting birds would not be forced into nesting close to dunes, which are typically used for hunting by red foxes.

KEY WORDS *Charadrius melodus*, dynamic occupancy, endangered species, habitat use, New Jersey, piping plover, red fox, *Vulpes vulpes*

Predation of nests and young is one of the primary limiting factors in the conservation of endangered birds (Vickery et al. 1992, Berry and Taisacan 2008, Vanderwerf 2012). Human activities have caused changes in the abundance and distribution of potential predators both indirectly (e.g. through landscape alteration and food subsidies) and directly (e.g. through transport of domestic animals; Boarman 2003, Fischer et al. 2012). Understanding the factors that affect the distribution of predators can aid efforts to develop and employ management strategies that reduce predation risk. The interaction of hunting habits and habitat configuration, including size, shape, and arrangement of foraging patches (Irlandi et al. 1995, Hovland et al. 1999), may play an important role in predicting predator distribution.

Predators must make decisions regarding how much time to invest exploiting a foraging patch before moving on, with the overall objective of maximizing energy intake rate. Therefore, to optimize energy gained, animals should choose to leave a patch when the capture rate in the patch drops to the average capture rate for the landscape (Charnov 1976). Where foraging patches are separated by large open spaces with little food and exposure to mortality risks, predators may be inclined to spend more time in one patch because the cost of traveling between patches is too high (Nonacs 2001). Furthermore, linear patches may decrease search time and increase intake rates of prey items such as bird eggs (Major et al. 1999).

Ground-nesting birds are highly vulnerable to local extirpation due to nest predators (Parr 1992, Schmidt 1999, Duncan and Blackburn 2007) because it is relatively easy for a nest predator to deplete a group of nests within a foraging patch. Moreover, predation risk of ground nests has been shown to increase with nest density (Keyser et al. 1998). In the eastern United States, beach-nesting birds lay their eggs in shallow scrapes on the ground in open, sandy areas with little to no vegetation, often concentrated in fragmented habitat on highly developed

coastlines. Within coastal ecosystems, human structures and engineered dune systems, which are manipulated to protect infrastructure through the use of sand fencing, beach-grass planting, and/or beach replenishment, may provide high quality foraging opportunities for many predator species due to the abundance of small mammals such as mice, voles, and rabbits (Rendall et al. 2019). Thus, predator abundance close to beach-nesting bird habitat may be high, and beach-nesting birds may experience higher predation risk as predators exploit eggs and chicks as food resources during the nesting season.

Throughout most of their range in the eastern United States, beach-nesting bird species such as the piping plover (*Charadrius melodus*) nest on barrier island systems, in which most of the landscape features such as dunes and vegetation are relatively linear, and the total area of nesting habitat is constrained to be narrow and may be disjointed. Many barrier islands consist of large areas of human development where the beach, dune system, and sometimes maritime forest run parallel to the shoreline and are often artificially manipulated in response to storm-created shoreline changes and erosion (Speybroeck et al. 2006, Harrington 2008). Major et al. (1999) found that artificial nest predation was significantly higher (62% predation rate) in linear strips of habitat than large, open patches (34% predation rate) suggesting that linear strips of vegetation may provide optimal energy intake rates for predators. In less manipulated systems, the dunes are punctuated by storm-created overwash fans, which are flat areas typically lacking in vegetation where sediment has been deposited by wind and waves (Leatherman 1979, Figlus et al. 2011). Such overwashes are particularly attractive to beach nesting birds because they allow for a large viewshed to observe approaching predators and provide little cover for predators (Burger 1987).

Elevated rates of predation on piping plover eggs, chicks, and adults due to human activity have contributed to the decline of Atlantic coast population of piping plovers (United

States Fish and Wildlife Service; USFWS 1996), which was listed as threatened under the U.S. Endangered Species Act (ESA) in 1986. Predators of piping plover eggs and chicks tend to be generalist species with wide distributions that respond positively to the presence of humans (Marzluff and Neatherlin 2006, Bino et al. 2010). Predator types and abundances tend to vary by location, but include both native and non-native predators such as American crow (*Corvus brachyrhynchos*), common grackle (*Quiscalus quiscula*), eastern coyote (*Canis latrans*), red fox (*Vulpes vulpes*), striped skunk (*Mephitis mephitis*), raccoon (*Procyon lotor*), Virginia opossum (*Didelphis virginiana*), large gull species (*Larus* spp.), great-horned owl (Bubo virginianus), feral cat (*Felis catus*), and Atlantic ghost crab (*Ocypode quadrata;* (Patterson et al. 1991, Watts and Bradshaw 1995, USFWS 1996). Predation was the primary cause of nest loss in the Cape Cod National Seashore, Massachusetts in 1993 and 1996, accounting for more than half of the nest failures (Hoopes 1996b, a); nest predators at Assateague Island National Seashore accounted for 91 percent of nest losses from 1986–1987 (Patterson et al. 1991); approximately 30% of nest losses in West Hampton Dunes, NY from 1993–2004 were due to red fox alone (Cohen et al. 2009); and from 2012–2016 nest predators in New Jersey accounted for 23.3 to 52.1 percent of nest losses (Pover and Davis 2012, 2013, 2014, 2015, 2016). Evidence suggests that human activities may affect the abundance and activity patterns of predators (Nishijima et al. 2014, Taylor et al. 2016), which may exacerbate the effects of predation on piping plover eggs, chicks, and adults.

Regulatory protection and management interventions for piping plovers have been largely successful throughout the breeding range, but population size within the New York-New Jersey region decreased 15% between 2007–2010 (USFWS 2011) and in New Jersey the population has not grown at all since the species was listed in 1986. Although predation has been a contributing

factor, habitat loss due to human development and recreation has also played a significant role in limiting population growth in the region (USFWS 1996, 2009). Piping plovers have highly specialized habitat requirements, yet approximately 96% of the New Jersey coastline is maintained for human recreation (Maslo et al. 2018). The remaining coastline offers a fragmented landscape of remnant habitat available for nesting, potentially amplifying the effects of predation of eggs and chicks. Because piping plover abundance and reproductive success may be limited by human activity and the presence of predators, it is important to gain a better understanding of the factors influencing the distribution of predators within this region.

Given the relatively open landscapes where piping plovers nest, predators that hunt for plover eggs and chicks will find most of their cover within the dunes and near human habitation. A wide-ranging predator such as the red fox, which is one of the most significant sources of loss for piping plover nests in many places (Cohen et al. 2009, Heiser and Davis 2019), must therefore decide whether to stay within a foraging patch and close to shelter as it hunts, or to travel between dune patches and search areas that are more open such as overwash fans. Doncaster et al. (1990) found that the composition of the red fox diet varied seasonally, with bird predation peaking in June, which is the peak nesting season for piping plovers and other beach nesting shorebirds. Additionally, red foxes are highly mobile and can cover distances >10 km/day (Larivière and Pasitschniak-Arts 1996), meaning that a single red fox can potentially impact several pairs of piping plovers in a single day (Cohen et al. 2009). Red foxes may also lead to indirect nest losses. Doherty and Heath (2011) found that the best predictor of nest abandonment by piping plovers was the number of red fox tracks documented on transects near nests. Nest abandonment has been shown to be an indicator of adult mortality (Roche et al.

2010), and therefore red fox predation may have serious population level consequences if red foxes are consuming both nests and adults.

The goal of this study was to understand the roles of landscape features in affecting predator distributions within piping plover breeding areas in a population that is failing to recover from a historic low. Our objectives were to 1) document the prevalence of different potential nest predators of piping plovers, and 2) determine the relationship between predator occupancy and landscape-level variables for the most prevalent species. Our results will lead to more comprehensive recommendations for predator management and habitat restoration that will simultaneously reduce predation pressures and create high quality habitat to begin recovery in New Jersey. We hypothesized that the probability of predator habitat use would be related to habitat configuration, the probability of predator habitat use would fluctuate between years and throughout the nesting season, and the probability of predator habitat use would decrease as the distance to human development increased.

METHODS

Study area

We studied predator distribution from 2015–2017 at 8 sites on barrier islands in southern New Jersey (Fig. 5.1). Our study area spanned from Barnegat Lighthouse State Park (BALI; latitude 39.75°N, longitude -74.09°W) located on the south side of Barnegat Inlet to Cape May Point State Park (CMPSP; latitude 38.93°, longitude -74.95°) located north of the mouth of the Delaware Bay. The barrier islands of the New Jersey coast run north-south and are located in the temperate zone. During the breeding season (Apr–Aug) the temperature averages 22.14°C ±0.15 (SE; range = 8.90-32.60°C) with and precipitation averaged 3.79 cm ±0.34 (SE; range = 0.00-

137.40 cm; Atlantic City International Airport; National Oceanic and Atmospheric

Administration 2019).

Coastal beaches on New Jersey barrier islands are characterized by open, sandy areas

with sparse vegetation and both natural and human-modified sand dunes. Piping plover nesting

areas are often characterized by storm-created habitat whereby vegetation is scoured by tidal

flooding and bayside intertidal sand flats are created. However, coastal storms often do not form

overwashes in areas that are backed by human development. Coastal sand dunes are dominated

by American beachgrass (*Ammophila breviligulata*), and other beach-adapted plants including

seaside goldenrod (*Solidago sempervirens*), beach pea (*Lathyrus japonicus*), and trailing wild

bean (*Strophostyles helvola*). Many study areas were inhabited by other beach-nesting birds that

were federally and/or state listed such as American oystercatcher (*Haematopus palliatus*), least

tern (*Sternula antillarum*), and black skimmer (*Rynchops niger*).

Study sites included Barnegat Lighthouse State Park, Barnegat Light (BALI); Holgate

Unit, E.B. Forsythe National Wildlife Refuge, Long Beach Township (HOLG); North Brigantine

Natural Area, Brigantine (NBNA); Malibu Wildlife Management Area and Seaview Harbor

Marina, Longport (MWMA); Avalon-Dunes, Avalon (AVDU); Stone Harbor Point, Stone

Harbor (SHPT); North Wildwood Beach, North Wildwood (NOWI); and Cape May Point State

Park and South Cape May Meadows, Cape May Point (CMPSP). We chose study sites to

represent a variety of habitat configurations that consisted of differing arrangements of nesting

habitat and foraging habitat for piping plovers and various levels of human use (Table 5.1,

Appendix 5.A). For example, study sites such as North Brigantine Natural Area (NBNA), the

Holgate Unit of E.B. Forsythe NWR (HOLG), and Stone Harbor Point (SHPT) occurred at the

ends of barrier islands further from human development with large overwash fans for beach-

nesting birds whereas sites such as Avalon-Dunes (AVDU), North Wildwood (NOWI), and

Barnegat Light (BALI) were areas with high levels of human development and linear dune

systems.

Field Methods

We used occupancy models based on repeated predator track surveys to determine the

spatial and temporal distribution of mammalian predators in piping plover nesting habitat. To

generate predator tracking plots, we downloaded the 2012 Land Use/Land Cover Map for New

Jersey (NJDEP/OIRM/BGIS 2015), then uploaded the GIS data into ArcMap (ArcGIS 10.1) and

selected the dune and beach polygons, assuming these would best represent piping plover

habitat. We used the random point generator in ArcMap to place random points 50-200 m apart

(Fig. 5.2). We chose 50 m as our minimum distance to prevent overlapping of survey plots, and

200 m as the maximum distance, which represented half the distance of the widest stretch of

open, sandy beach at our study sites. During the first survey period of the study, we ground-

truthed each plot location to validate the land cover and vegetation types and marked the plot

with a wooden stake for ease of navigation in future surveys. We removed points that were in

cover types such as forested areas, thick vegetation, or saltmarsh where predator tracking would

not be feasible. Any points that remained contained substrates such as sand, sand/mud, mud,

sand/shell, sand/cobble, or bare soil where predator tracking would be practicable

We recorded detections of mammalian predator tracks (i.e. footprints) at each plot

biweekly between 15 April–15 August to ensure tracks would not persist between survey periods

and following at least 24 hr of good weather (i.e. wind <10 kph, no rain within 24 hr) to optimize

tracking conditions. Predator tracks were identified by experienced surveyors who were also

trained specifically to identify predator tracks by an expert tracker. Further, surveyors were able

to reference a field guide in circumstances where tracks might have been difficult to identify (Elbroch 2003).

To estimate seasonal changes in predator occupancy, we grouped our surveys within four periods for analysis, based on plover breeding phenology. The 4 survey periods and their date ranges included: pre-nesting, 15 April–3 May; incubation, 4 May–31 May; chick rearing, 1 June–28 June; and chick fledging, 29 June–26 July. We counted the number of track trails by each species present within a 10 m radius of the plot center. We tied a 10 m long string to the wooden stake marking the center point, then walked a circle around the wooden stake to provide an outline for the 10 m radius. Because beach features can change between seasons, we downloaded the 2015 New Jersey High Resolution Orthoimagery (NJOIT/OGIS 2016) to visually classify the anthropogenic and geomorphic features for the 2015 and 2016 field seasons. We then downloaded the 2017 New Jersey High Resolution Orthoimagery (NJOIT/OGIS 2018) to visually classify the anthropogenic and geomorphic features for the 2017 field season. We then used the "Near" tool in the ArcMap (ArcGIS 10.5.1) Toolbox (located under "Proximity") to digitize and calculate covariates that may affect the presence of predators including the distance to dunes (nearest m), distance to forest, distance to wetland (fresh or saltwater), distance to human development, and distance to roads. We digitized areas of human development that included static, stable features such as houses or other buildings, and we digitized roads to include only paved roads and parking lots (Appendix 5.B).

Given that a plot was within the home range of a predator, our detection of its tracks depended on 1) whether the predator used that part of its home range just prior to our survey and 2) if it did, whether we were able to discern and correctly identify its tracks. There were few tracks that we were unable to identify (Fig. 5.3), however, if we were unable to identify a track

within a plot with 100% certainty, we recorded the track as unknown mammal, and these tracks were not included in the models. Because we attempted to complete surveys only during periods of good weather, we did not include weather covariates in our detection models; however, because observers varied by year, we did include year as a covariate for detection.

Analytical Methods

We used dynamic occupancy models (MacKenzie et al. 2005, Kéry and Schaub 2012) to estimate the probability of habitat use by predators and to document changes in habitat use throughout the course of the nesting season at site i in time t. We fit models of the form $logit(\Psi) = X^{\Psi}\beta^{\Psi}$, $logit(\varepsilon) = X^{\varepsilon}\beta^{\varepsilon}$, $logit(\gamma) = X^{\gamma}\beta^{\gamma}$, and $logit(p) = X^{p}\beta^{p}$, where Ψ is the vector of length i of occupancy probabilities in the first survey, ε and γ are vectors of length $i \times$ t-1 of extinction and colonization probabilities between surveys, p is the vector of length $i \times t$ of detection probability on each survey, X represents the design matrix of explanatory variables for each occupancy model parameter, and β represents the vector of regression parameter estimates for each occupancy model parameter.

We tested for correlation among land cover covariates using the Pearson's pairwise correlation (Soper et al. 1917) in R (R Version 3.5.1, www.r-project.org, accessed 7 Feb 2018) using GGally (Schloerke et al. 2018), and we did not use variables that were highly correlated in our models (r < -0.5 or r > 0.5; Mukaka 2012, Schober et al. 2018). Standardized covariates were tested in separate submodels investigating survey-level effects on detection (p) and plot-level effects on occupancy (Ψ), colonization (γ), and extinction rates (ε). We identified the top supported variables for Ψ, ε, γ, and p (Table 5.2) sequentially in R using unmarked (Chandler and Fiske 2011), using a null model for the non-focal parameters while fitting all subsets of the most complex model for the focal parameter (43 subsets for each focal parameter; Doherty et al.

2012). For all models of the focal parameter, we compared model fit using Akaike's Information Criterion adjusted for small sample size (AIC$_c$) and considered models with a relative likelihood of 0.125 to have some support (Burnham and Anderson 2002). After identifying the top supported models for each parameter, we combined them into a single occupancy model, then performed further model selection by fitting all subsets of the top models (Doherty et al. 2012). Furthermore, if the addition of a parameter yielded a similar AIC$_c$ to a reduced model but did not reduce deviance, we considered that parameter to be uninformative and kept only the reduced model in our set (Arnold 2010). We generated predicted values for ψ, ε, γ, and p using the top model or model-averaging if there was ambiguous evidence for a top model (Burnham and Anderson 2002).

RESULTS

We conducted 24 mammalian predator track surveys at 80 plots among 7 study sites, 15 April−15 August 2015–2017. Of the 6 mammalian predator species of focus, red foxes were detected the most frequently (Fig. 5.3). We had a total of 373 red fox detections across years and study sites. Red fox tracks were counted in higher numbers at North Brigantine Natural Area than any other sites in all years (Table 5.3). Because data from the remaining 5 mammalian predator species were scarce, dynamic occupancy models would not converge. Given the scarcity of records for other predators and because red foxes have been the top predator of piping plover eggs in New Jersey, we focused our modeling efforts on estimating occupancy rates for red foxes only.

We found a high degree of correlation between the distance to dune and distance to forest covariates, presumably because most primary dunes are backed by maritime forest on barrier islands (Appendix 5.C). Additionally, we also found a high degree of correlation between the

distance to human development and distance to road covariates, likely because all human development is accessed by roads on New Jersey barrier islands (Appendix 5.C). While red foxes may be present in forests in New Jersey because forests provide denning sites, piping plovers are not found in forests, and because we were interested in how red foxes were using piping plover habitat, we chose to use distance to dune in our models rather than distance to forest. Because roads were associated only with human development at all our study sites except Malibu Wildlife Management Area, we chose to remove distance to road from our models and use distance to human development as the feature that may be most representative of cover areas or sources of human-subsidized food for red foxes.

We found support for an effect of distance to dune on occupancy, an effect of distance to dune on extinction, an effect of distance to human development and year on extinction, an effect of year on colonization, and an effect of year on detection, as these effects appeared in the top two models (Table 5.3). We also found support for an effect of year on first-survey occupancy, as the second ranked model's relative likelihood was ≥ 0.125 and the model weight was 0.240, although the addition of year did not reduce deviance (Table 5.3). Because we found some support for an effect of year on occupancy and a single top model was not clear, we model-averaged predictions for ψ, ε, γ, and p (model-averaged estimates, Appendix 5.D).

Red fox probability of habitat use (estimated by first-survey ψ) decreased as the distance to the nearest primary dune increased (Fig. 5.4) and the mean probability of habitat use was greater in 2015 than subsequent years (Fig. 5.5). Habitat use remained constant throughout the course of the nesting season (Fig. 5.6). Probability of red fox colonization of survey plots was lower in 2016 than in 2015 and 2017 (Fig. 5.7). Probability of extinction of red foxes at a survey plot increased as the distance from the nearest primary dune increased (Fig. 5.8A) and decreased

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as the distance from the nearest area of human development increased (Fig. 5.8B). In the former case, the 95% confidence intervals were so wide that although distance to dune was supported in our model selection, it may have low predictive capability. Detection rates for red foxes varied by year and were highest in 2015 (Fig. 5.9).

DISCUSSION

The decreasing relationship between habitat use probability (estimated by first-survey ψ) and distance to dunes and the increasing relationship between extinction probability and distance to dunes suggest that red foxes may be attracted to these dune systems which both provide cover and high-quality foraging opportunities. Dune systems can host an abundance of small mammals such as mice, voles, and rabbits (Rendall et al. 2019) that provide prey for red foxes. Moreover, dunes in our study area occur in long, linear ridges that may be easy for red foxes to search for prey. For instance, Major et al. (1999) found that artificial nest predation was significantly higher (62% predation rate) in linear strips of habitat than large, open patches (34% predation rate) suggesting that linear strips of vegetation may provide optimal energy intake rates for predators. While red foxes are attracted to vegetated dunes, piping plovers select nest sites far from such topography and cover, in flat areas created between and among dunes by wind and wave action (USFWS 1996). This mosaic of landscape features tends to be temporary and is primarily created by large storm events that lead to waves overwashing barrier islands. Because barrier islands in New Jersey often consist of large areas of human development with artificially manipulated shorelines and long, linear dune systems, beach-nesting birds at these locations have few flat, open areas to choose from and must nest close to dunes. Thus, plovers in New Jersey may experience higher rates of predation than beaches where natural processes continue to shape the habitat.

Within coastal ecosystems, artificially manipulated dune systems are created to protect infrastructure, often with fencing to capture sand and stabilize dunes. Fences can act as artificial barriers which can have considerable effects on animal movements (Crist et al. 1992, McDonald and St. Clair 2004, Vanak et al. 2010). Moreover, fences can be used by some predators to increase hunting success (van Dyk and Slotow 2003). Both Avalon-Dunes and the municipal areas of Barnegat Light contain dune systems that have been stabilized by sand fencing. The decreasing relationship between habitat use probability and distance to dunes may therefore also suggest that red foxes are attracted to these dune systems not only because they provide high-quality foraging opportunities but sand fencing within artificially manipulated dune systems may also increase hunting success for red foxes.

Several studies have demonstrated a positive relationship between anthropogenic features on the landscape and red fox occupancy (Bino et al. 2010, Lesmeister et al. 2015), yet we found little evidence to suggest that red fox habitat use was related to the proximity to human development. Although we did find that plot extinction probability slightly decreased as the distance to human development increased, this pattern was the inverse of what we had hypothesized. It is possible that the scale of our study was too small to detect whether red foxes on barrier islands in New Jersey are using areas close to human development because each site was small enough to be within the potential home range of a single red fox (Trewhella et al. 1988, Henry et al. 2005). It is also possible that human presence influences red fox habitat use differently than static anthropogenic features (Nickel et al. 2020). However, if human presence were influencing habitat use by red foxes, we would have expected to see an increase in red fox habitat use as the nesting season progressed, as human presence on New Jersey barrier islands steadily increases throughout the nesting season. It is also possible that red foxes in our study

area are not influenced by anthropogenic features or human presence. Maslo et al. (2016) found that predation of nests was not stronger on human dominated beaches suggesting that habitat use by predators may not be strongly influenced by human activity.

Because predators of piping plovers are not often observable during daylight hours, track surveys can be an effective tool for estimating the probability of presence of animals at a site (Silveira et al. 2003). One benefit is that surveys can be repeated across a large area or region with little effort. Another benefit is that the cost required to conduct a track survey is minimal compared to the cost of conducing camera trap surveys in terms of the number of hours required to identify predators from photos compared to the amount of time required to count and identify tracks in a plot. However, there are several limitations to using this method including the requirement that individual observers have the ability accurately identify tracks to species-level, the tendency of tracks to disappear or become unidentifiable on sandy substrates within hours due to human activity or weather, and poor tracking conditions in many cover types of interest (such as forests, marshes, and cobble beaches). We do not feel that these tracking limitations affected our results as our observers were well-trained, our plots were generally within symbolically fenced areas where the public were restricted from entering, and our surveys were conducted after periods of good weather to maximize our tracking abilities. Furthermore, we feel as though predator track surveys can be an effective tool for wildlife managers to determine which predator species are present on their beaches in order to monitor predator occurrence at piping plover nesting sites.

The between-year temporal variation that we found in occupancy, colonization, and detection may demonstrate that red fox habitat use is dependent upon annual fluctuations in predator abundance. The number of red foxes on the landscape can change both seasonally and

between years as a result of changes in prey abundance (Sidorovich et al. 2006, Henden et al. 2010), winter severity (Bartoń and Zalewski 2007), or mange outbreaks (Jarnemo and Liberg 2005). It is likely that changes in red fox abundance are also related to the effort to remove red foxes from the landscape through targeted predator removal programs aimed to increase piping plover reproductive success in New Jersey. Because occupancy is related to abundance, we would expect to see yearly changes in red fox habitat use related to both natural fluctuations in abundance and changes due to predator removal by management agencies. However, it is unlikely that all red foxes are removed from a study site each year, and we do not believe that red fox removal influenced habitat use or the results of this study.

Previous studies have suggested that predator exclosures around piping plover nests serve as cues that attract predators (Neuman et al. 2004, Beaulieu et al. 2014). Additionally, it is thought that mammalian predators may be attracted to piping plover nests with pipping eggs as it has been shown that predators key into songbird nests with begging nestlings (Leech and Leonard 1997, Haff and Magrath 2011). While mean habitat use by red foxes varied across years, we did not find evidence of period temporal variation between the various phases of the nesting cycle. If red foxes were attracted to predator exclosures, we would have expected to see an increase in red fox habitat use between the pre-nesting period and nesting period. Further, if red foxes were attracted to the sound of piping plover chicks inside pipping eggs at hatching, we would expect to see an increase in red fox habitat use from the nesting period to the chick rearing period. These results suggest that red foxes may not be changing their habitat use as a result of piping plover presence on New Jersey beaches.

Selective predator removal programs have been implemented to increase nesting success of waterfowl and other game birds (Balser et al. 1968). More recently, wildlife managers have

used predator removal to increase nesting success of non-game and endangered bird species where predation has become a serious impediment to recovery (Balser et al. 1968, Neuman et al. 2004). Harding et al. (2001) found that red fox predator removal in California was effective in the short-term, but changes in red fox adult survival had little effect on population growth indicating that predator removal efforts would be unsuccessful in the long-term. However, Saunders et al. (2014) suggest red fox predator control programs in Australia are often ineffective at improving nesting success. Habitat restoration and habitat management may also be used to increase nesting success (Maslo et al. 2011, Catlin et al. 2016). Identifying habitat features that may be less attractive to predators combined with information regarding the biology of the target predator species may help to inform plans for habitat creation at piping plover nesting areas.

Management Implications

Our results suggest that conserving nesting habitat that includes both overwash fans and sparsely vegetated areas may improve nest success of piping plovers, because birds are not forced into nesting in areas typically used for hunting by red foxes, which are close to primary dunes. Nesting sites with patchy dunes that are separated by open overwash areas are often among the highest-quality breeding areas for piping plovers, as they tend to be adjacent to low-wave energy tidal flats for foraging. Piping plovers are highly dependent on this dynamic beach system for successful breeding, and management that maintains the heterogeneity created by coastal storms and eliminates beach manipulation projects that reduce the frequency of overwash may be important for successful nesting of piping plovers in terms of predation risk, in addition to foraging quality.

Table 5.1. Locations, study site area, and number of survey plots at piping plover nesting sites for red fox occupancy modeling in New Jersey, USA, 2015-2017.

Site	Site ID	Latitude	Longitude	Landscape	Area of sandy substrate (ha)	Number of survey plots
Barnegat Lighthouse State Park	BALI	39.76032	-74.09947	Barrier Island/Inlet	58.05	8
Holgate Unit, E.B. Forsythe NWR	HOLG	39.51765	-74.28113	Barrier Island/Inlet	101.25	24
North Brigantine Natural Area	NBNA	39.44482	-74.32929	Barrier Island/Inlet	56.85	16
Malibu Beach Wildlife Management Area	MWMA	39.31070	-74.55052	Barrier Island	7.58	9
Avalon-Dunes	AVDU	39.07918	-74.73201	Barrier Island	25.14	6
Stone Harbor Point	SHPT	39.02831	-74.77754	Inlet	61.20	18
North Wildwood	NOWI	39.00583	-74.78819	Inlet	7.91	3
Cape May Point State Park	CMPSP	38.93228	-74.94828	Mainland	25.02	6

Table 5.2. List of variables used for detection (p), first-survey occupancy (Ψ), colonization (γ), and extinction (ε) parameters in dynamic occupancy modeling of red foxes in piping plover habitat in New Jersey, USA, 2015-2017.

Parameter	Variable	Description
p	Year	Year the survey was completed
Ψ, γ, ε	Dune	Distance (m) from center of plot to nearest primary dune
	Wetland	Distance (m) from center of plot to nearest saltwater or freshwater wetland
	Develop	Distance (m) from center of plot to nearest area of human development
	Year	Year the survey was completed

Table 5.3. Model parameters, parameter counts, and information theoretic model selection criteria for dynamic occupancy models for red foxes using piping plover habitat in New Jersey, USA, 2015–2017. The model parameters are detection (p), first-survey occupancy (Ψ), colonization (γ), and extinction (ε). All candidate models and the null model are shown. AIC_c is Akaike's information criterion adjusted for small sample size, K is the number of parameters in the model, and w_i is AIC_c model weight.

Model description	Deviance	K	ΔAIC_c	Relative Likelihood	w_i
Ψ(dune) γ(year) ε(dune+develop+year) p(year)	232.64	13	0.00	1.000	0.73
Ψ(dune+year) γ(year) ε(dune+develop+year) p(year)	233.73	15	2.18	0.336	0.25
Ψ(dune) γ(year) ε(develop+year) p(year)	236.32	12	7.35	0.025	0.02
Ψ(dune+year) γ(year) ε(develop+year) p(year)	237.35	14	9.42	0.009	0.01
Ψ(dune) γ(year) ε(dune+develop) p(year)	239.36	11	13.43	0.001	0.00
Ψ(dune+year) γ(year) ε(dune+develop) p(year)	240.95	13	16.61	0.000	0.00
Ψ(dune) γ(year) ε(develop) p(year)	241.39	10	17.50	0.000	0.00
Ψ(dune+year) γ(year) ε(develop) p(year)	242.94	12	20.59	0.000	0.00
Ψ(dune) γ(year) ε(dune+year) p(year)	245.54	12	25.79	0.000	0.00
Ψ(dune) γ(year) ε(year) p(year)	245.69	11	26.09	0.000	0.00
Ψ(dune+year) γ(year) ε(dune+year) p(year)	246.68	14	28.07	0.000	0.00
Ψ(dune+year) γ(year) ε(year) p(year)	246.86	13	28.43	0.000	0.00
Ψ(dune) γ(year) ε(dune) p(year)	249.90	10	34.51	0.000	0.00
Ψ(dune+year) γ(year) ε(dune) p(year)	251.10	12	36.92	0.000	0.00
Ψ(.) γ(.) ε(.) p(.)	263.18	4	61.08	0.000	0.00
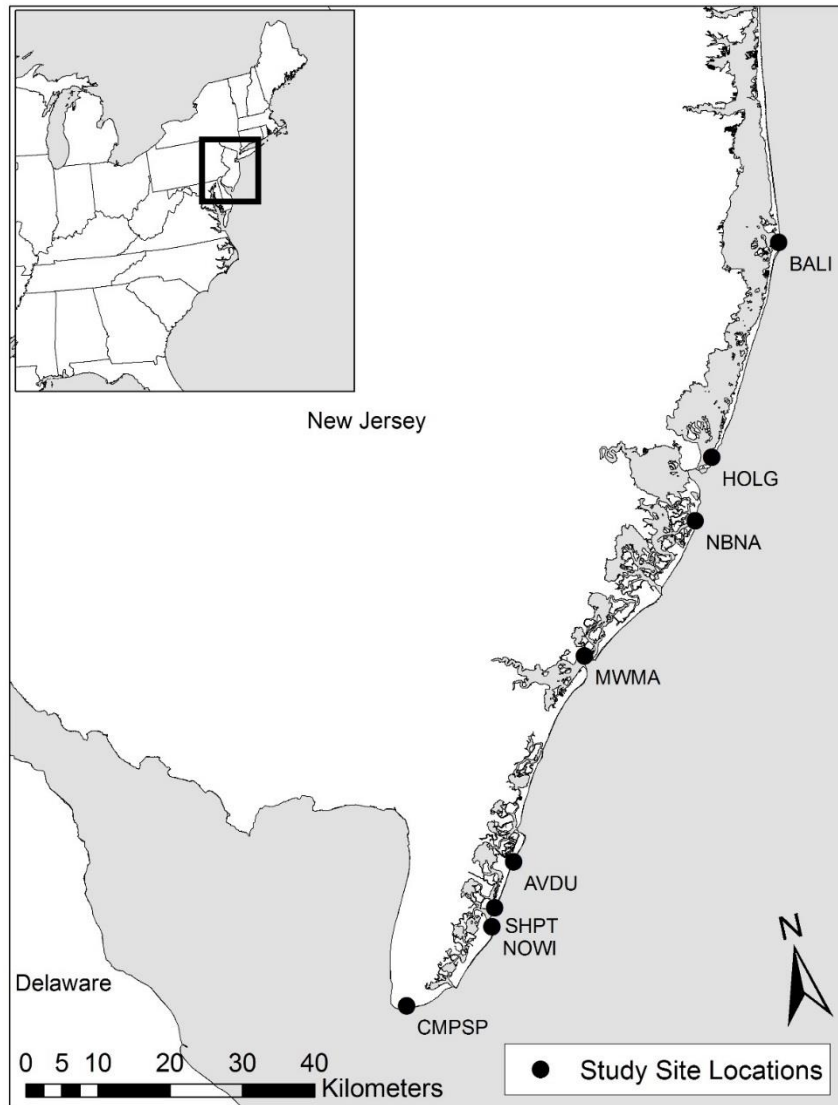
Figure 5.1. Locations of study sites for predator habitat use in piping plover nesting areas in New Jersey, USA, 2015–2017. Study sites are labeled as follows: BALI, Barnegat Lighthouse States Park; HOLG, Holgate Unit, E.B. Forsythe NWR; NBNA, North Brigantine Natural Area; MWMA, Malibu Beach Wildlife Management Area; AVDU, Avalon-Dunes; SHPT, Stone Harbor Point; NOWI, North Wildwood; CMPSP, Cape May Point State Park.
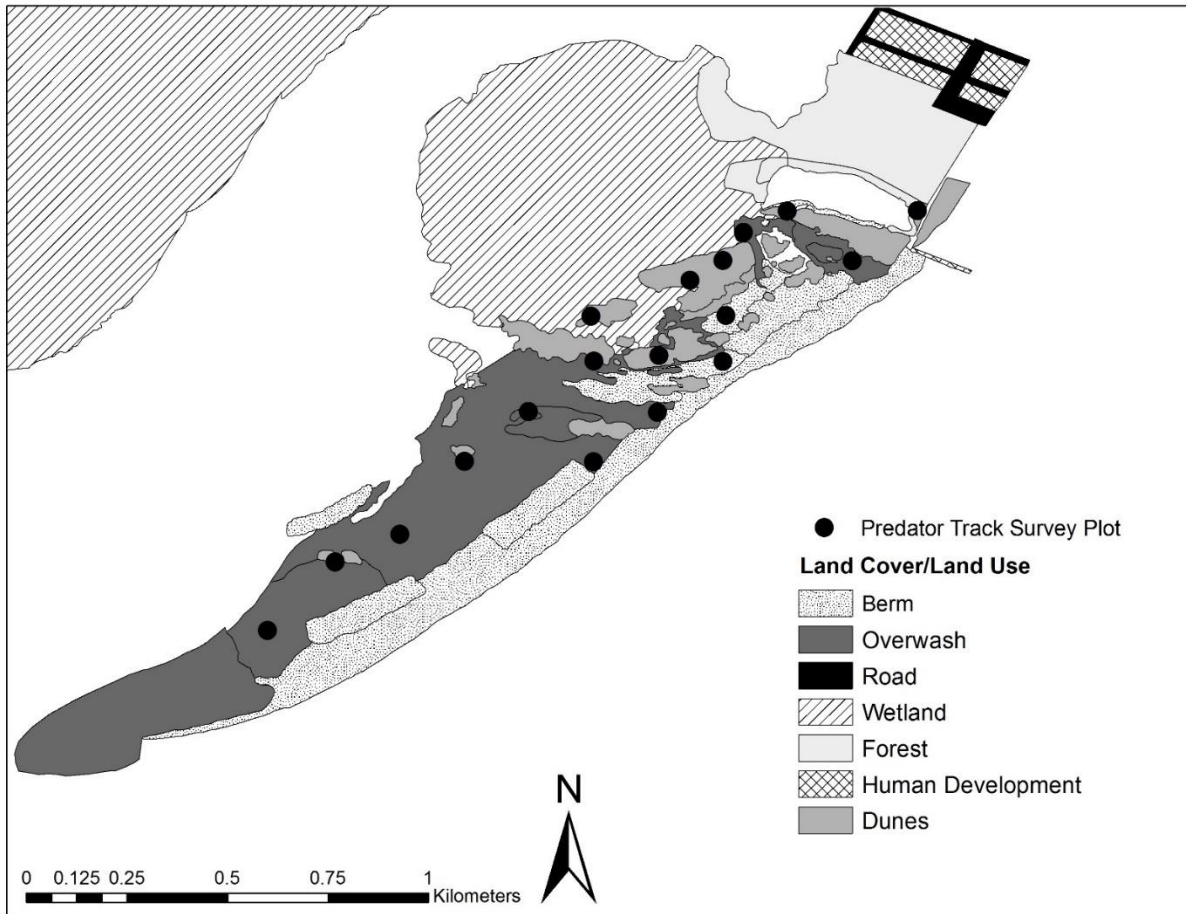
Figure 5.2. Example study site map for New Jersey, USA predator occupancy study (Stone Harbor Point, Stone Harbor, New Jersey; SHPT), 2015–2017. Predator plot locations are represented by dots and visually classified anthropogenic and geomorphic features that were considered for occupancy models are represented by shaded areas.
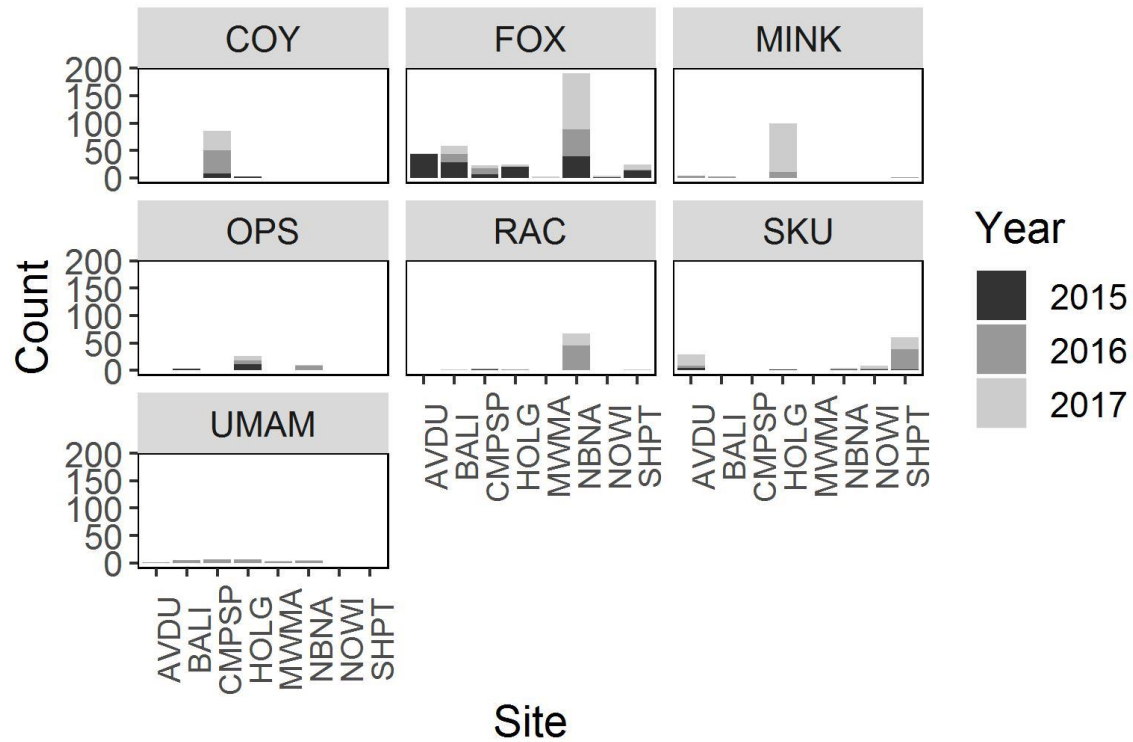
Figure 5.3. Number of detections of each predator species at piping plover breeding sites in New Jersey, USA, 2015–2017. Species codes are as follows: COY, coyote; FOX, red fox; MINK, American mink; OPS, Virginia opossum; RAC, raccoon; SKU, striped skunk; and UMAM, unknown mammal. Study sites are labeled as follows: BALI, Barnegat Lighthouse States Park; HOLG, Holgate Unit, E.B. Forsythe NWR; NBNA, North Brigantine Natural Area; MWMA, Malibu Beach Wildlife Management Area; AVDU, Avalon-Dunes; SHPT, Stone Harbor Point; NOWI, North Wildwood; CMPSP, Cape May Point State Park.
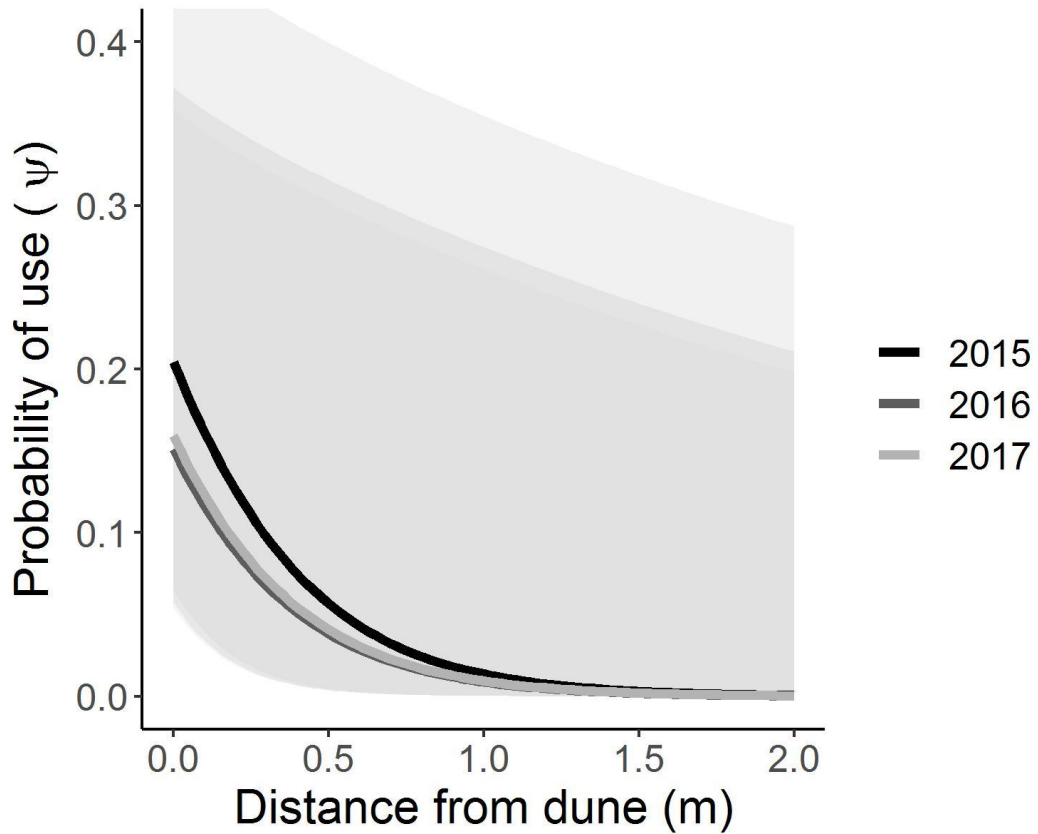
Figure 5.4. First survey occupancy probability (i.e., habitat use) vs. distance of the survey plot from the nearest primary dune for red foxes during the piping plover breeding season in New Jersey, USA, 2015–2017, using model averaged predictions from dynamic occupancy models made from predator track survey data (N = 90 plots, n = 24 surveys). Bold lines represent mean habitat use, gray polygons represent 95% confidence intervals.
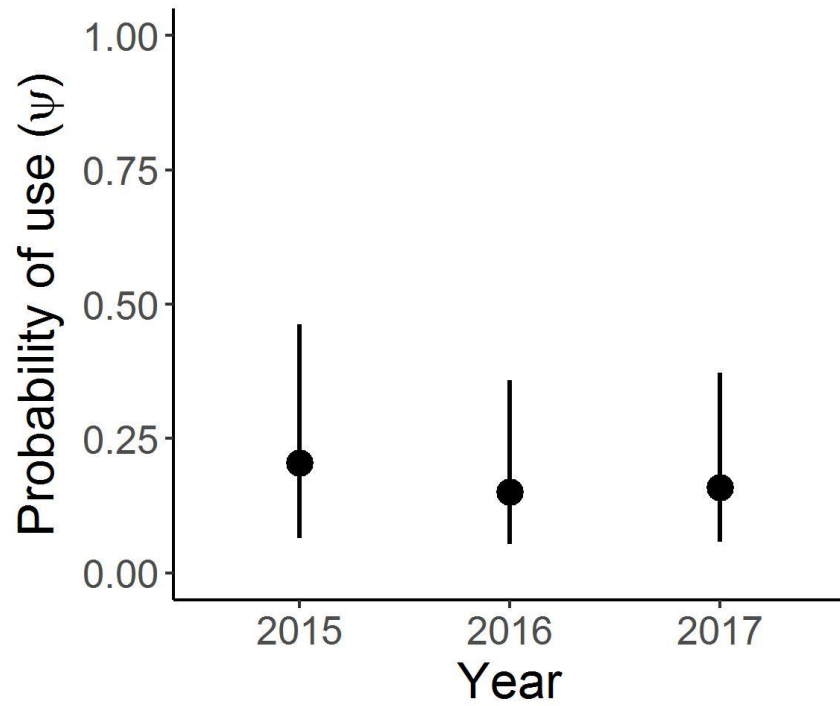
Figure 5.5. First survey occupancy probability (i.e., habitat use) of red foxes during the piping plover breeding season in New Jersey, USA, 2015–2017, using model averaged predictions from dynamic occupancy models made from predator track survey data (N = 90 plots, n = 24 surveys). Means are represented by dots and bars represent 95% confidence intervals.
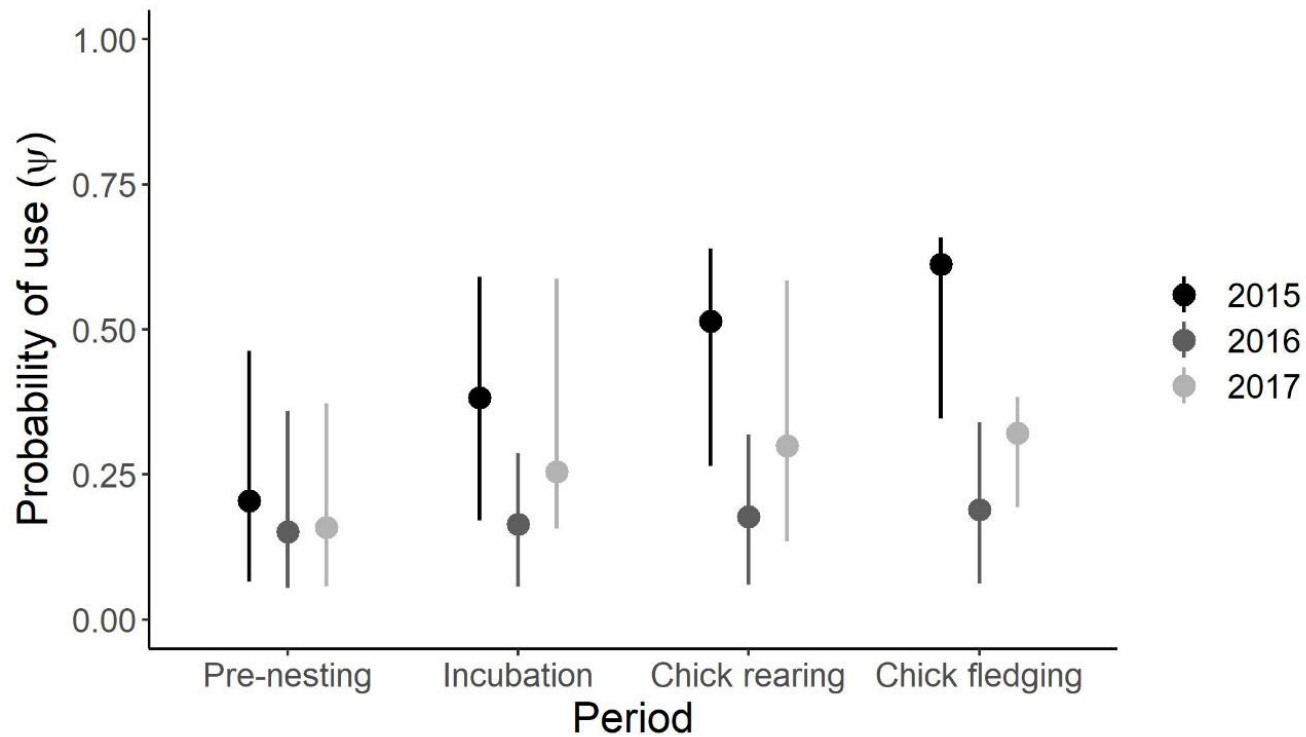
Figure 5.6. Derived occupancy probability of red foxes during the piping plover breeding season in New Jersey, USA, 2015–2017, using model averaged predictions from dynamic occupancy models based on predator track survey data (N = 90 plots, n = 24 surveys). The 4 survey periods and their date ranges include: pre-nesting, 15 April–3 May; incubation, 4 May–31 May; chick rearing, 1 June–28 June; and chick fledging, 29 June–26 July. Means are represented by dots and bars represent 95% confidence intervals.
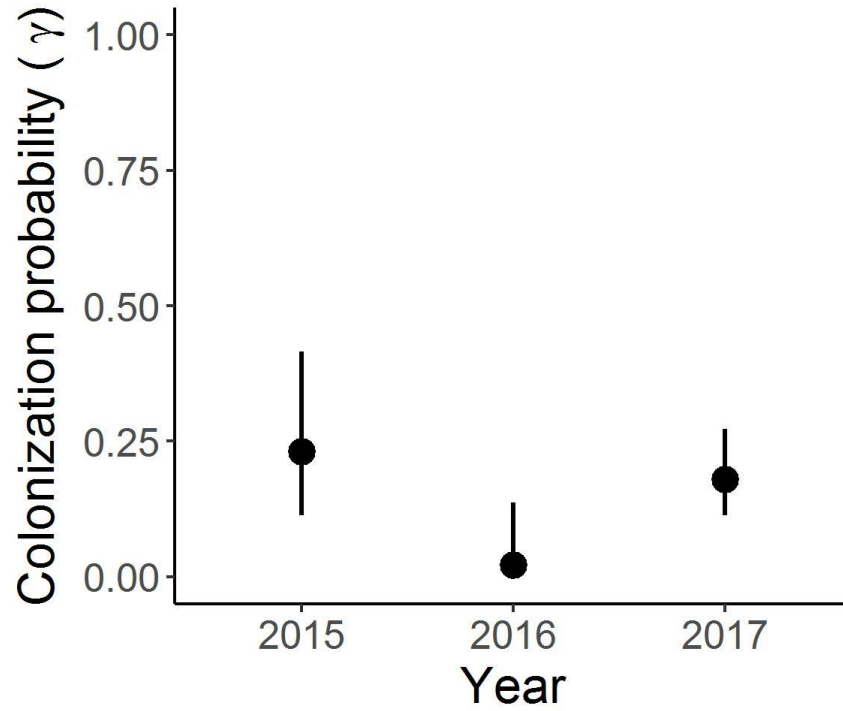
Figure 5.7. Colonization probability of red foxes during the piping plover breeding season in New Jersey, USA, 2015–2017, using model averaged predictions from dynamic occupancy models based on predator track survey data (N = 90 plots, n = 24 surveys). Means are represented by dots and bars represent 95% confidence intervals.
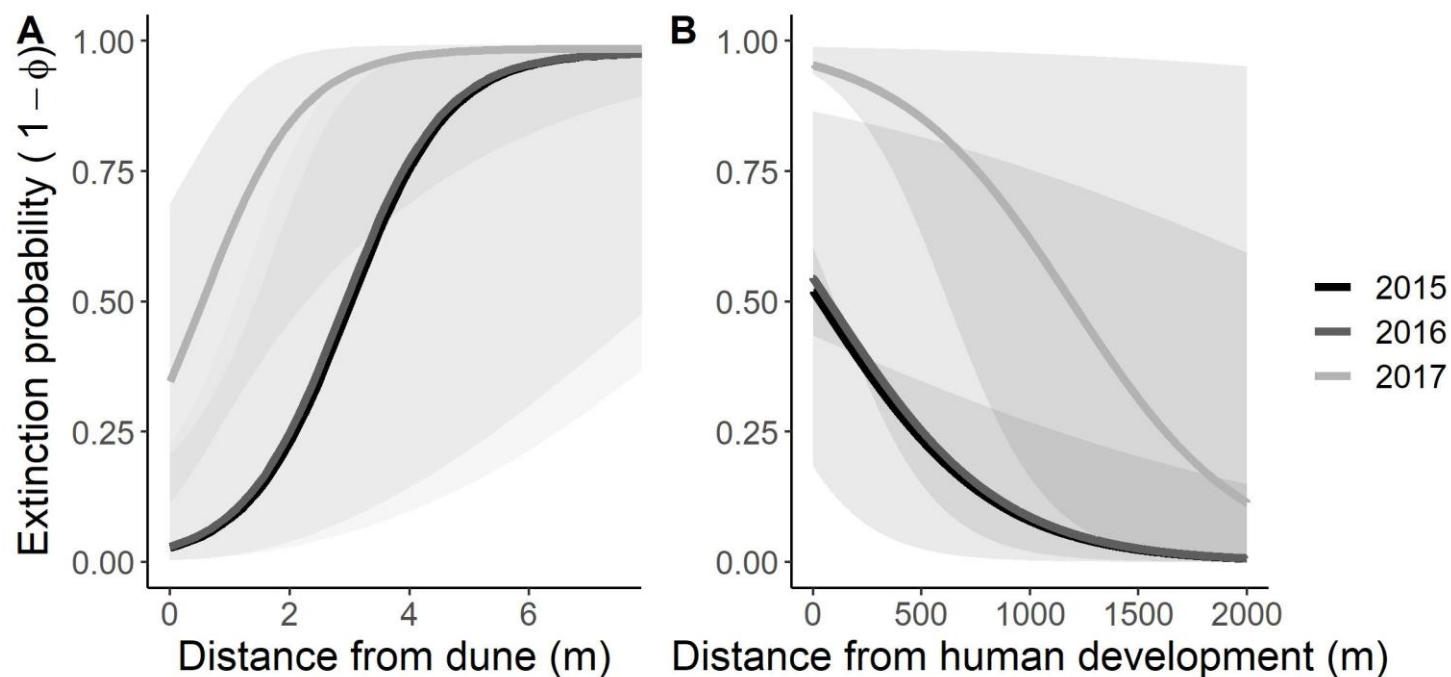
Figure 5.8. A) Extinction probability vs. distance of the survey plot from the nearest primary dune for red foxes during the piping plover breeding season in New Jersey, USA, 2015–2017, using model averaged predictions from dynamic occupancy models based on predator track survey data (N = 90 plots, n = 24 surveys). Bold lines represent mean habitat use, gray polygons represent 95% confidence intervals. B) Extinction probability vs. distance of the survey plot from the nearest area of human development for red foxes during the piping plover breeding season in New Jersey, USA, 2015–2017, using model averaged predictions from dynamic occupancy models made from predator track survey data (N = 90 plots, n = 24 surveys). Bold lines represent mean habitat use, gray polygons represent 95% confidence intervals.
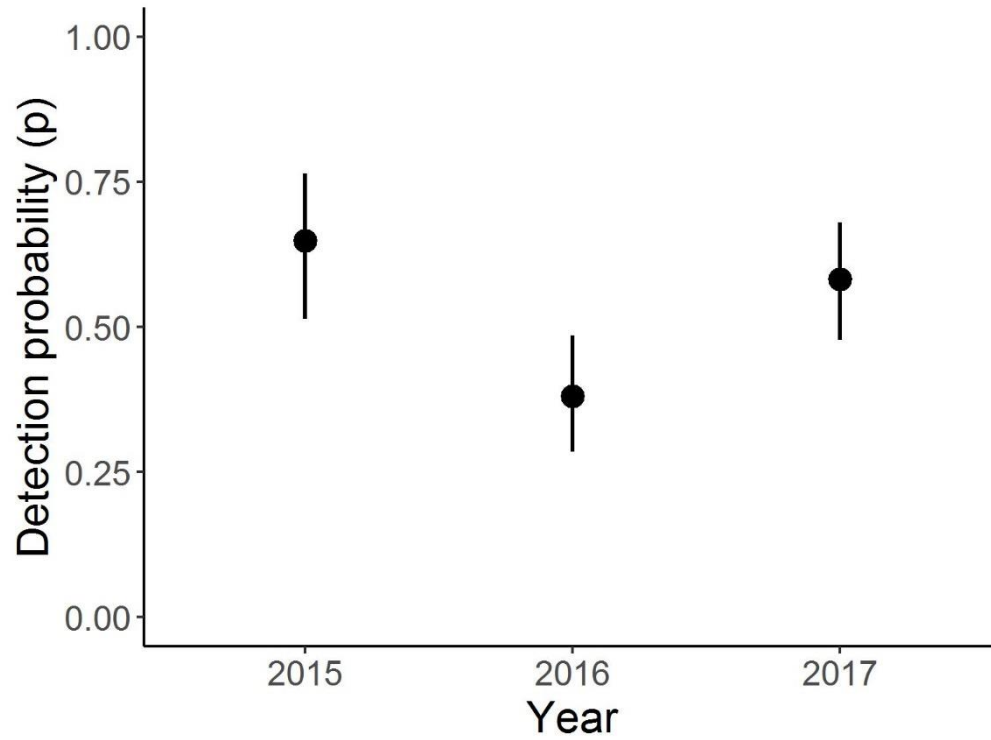
Figure 5.9. Detection probability of red foxes during the piping plover breeding season in New Jersey, USA, 2015–2017, using model averaged predictions from dynamic occupancy models made from predator track survey data (N = 90 plots, n = 24 surveys). Means are represented by dots and bars represent 95% confidence intervals.

APPENDIX 5.A. DESCRIPTION OF STUDY SITES.

Barnegat Lighthouse State Park, Barnegat Light, New Jersey (BALI)

Barnegat Light State Park (39.760323, -74.099465) is located at the northern portion of Long Beach Island on the Atlantic coast of New Jersey. The site consists of open, sandy areas on the berm of the beach, which provide nesting habitat for plovers. Piping plover foraging habitat includes a low-energy tidal pool around the jetty of the inlet as well as abundant oceanside wrack; however, foraging access may be limited due to anthropogenic activity. The site experiences relatively high levels of human disturbance from beach visitors; however, off-road vehicle use and dogs are not permitted. Red foxes were removed from this study site in 2015, but not in 2016 or 2017.

In 2015, Rutgers University and the Conserve Wildlife Foundation of New Jersey (CWFNJ) partnered to begin a restoration project at Barnegat Lighthouse State Park. This project is currently underway and aims to remove vegetation to establish new nesting areas and create a tidally-fed, low-wave energy pond for foraging.

Edwin B. Forsythe National Wildlife Refuge, Holgate Unit, Beach Haven, New Jersey (HOLG)

The Holgate Unit of E. B. Forsythe NWR (39.517654, -74.281131) is located at the southern end of Long Beach Island on the Atlantic coast of New Jersey. The site is approximately 5 km of piping plover nesting and foraging habitat. Natural processes are unhindered, and piping plovers experience no human disturbance during the nesting season. The north end of the site experiences regular overwash due to storm surge, with small dune patches and expansive bayside mudflats for foraging; however, the southern portion of the site comprises wide berms, large dunes, and very little moist substrate foraging habitat. Red foxes were removed from this study site during all 3 years of this study.

North Brigantine Natural Area, Brigantine, New Jersey (NBNA)

North Brigantine Natural Area (39.444821, -74.329292) is located at the northern end of Brigantine Island on the Atlantic coast of New Jersey. This site is approximately 4.5 km long; however, piping plovers tend to nest in open, low-lying areas at the northernmost portion of the site. Depending on nest location and territory size, foraging areas contiguous with nesting habitat may be limited to the oceanside intertidal zone and wrack line or may include areas of low-energy bayside foraging access. The northernmost part of the site experiences relatively low-levels of human disturbance; however, off-road vehicles are permitted the length of the site until chick-hatching occurs. Dogs are not permitted. Red foxes were removed from this study site during all 3 years of this study.

Malibu Wildlife Management Area/ Seaview Harbor Marina, Longport, New Jersey (MWMA)

Malibu Wildlife Management Area/ Seaview Harbor Marina (39.310698, -74.550517) is located in the inlet between Ocean City Island and Absecon Island. The site consists of the largest tern and skimmer colony in the state of New Jersey, which typically forms in mid-May. Sparsely vegetated dune communities are available for piping plover nesting. Foraging access is limited to oceanside intertidal zone where peat banks are exposed during low tide and an ephemeral pond on the bayside that is created during overwash events. The site experiences very low levels of anthropogenic disturbance; however, it is located adjacent to a popular and heavily used off-leash dog beach. The dog beach and nesting areas are delineated by sand or snow fencing, to prevent dog owners from crossing into the Wildlife Management Area. Red foxes were removed from this study site during all 3 years of this study.

Avalon-Dunes, Avalon, New Jersey (AVDU)

Avalon-Dunes (39.079176, -74.732010) is located in the northern portion of Seven Mile Island, an Atlantic barrier island. The site consists of sparsely vegetated areas and open, sandy areas on the berm of the beach below the dune, which provide nesting habitat for piping plovers. Piping plover access to foraging is restricted to the oceanside intertidal zone and wrackline given that access to bayside foraging is obstructed by coastal development. The site experiences relatively high levels of anthropogenic disturbance from beach visitors; however, off-road vehicle use and dogs are not permitted. Red foxes were removed from this study site during all 3 years of this study.

Stone Harbor Point, Stone Harbor, New Jersey (SHPT)

Stone Harbor Point (39.028307, -74.777536) is located at the southern-most end of Seven Mile Island. The site consists of low-lying, open sand and cobble areas and sparsely vegetated dunes, which provide suitable nesting habitat for piping plovers. Ample bayside and oceanside foraging exists and corridors between bayside and oceanside are maintained by frequent washover events that occur during strong storms and monthly high tides. An additional foraging area for piping plovers has been artificially created on the northern end of the site and includes a pond (contained dredge facility) that is tidally influenced. The site experiences relatively low levels of anthropogenic disturbance from beach visitors, and off-road vehicles and dogs are not permitted. In 2015, New Jersey Audubon, the Wetlands Institute, and the Conserve Wildlife Foundation of New Jersey partnered to restore nesting habitat at Stone Harbor Point for beach nesting

shorebirds including piping plovers, American oystercatchers, terns, and black skimmers. Red foxes were removed from this study site during all 3 years of this study.

North Wildwood Beach, North Wildlife, New Jersey (NOWI)

North Wildwood Beach (39.005833, -74.788189) is located at the northern end of a barrier island referred to locally as "the Wildwoods." The site consists of sparsely vegetated areas and open, sandy areas on the berm of the beach below the dune, which provide suitable nesting habitat for piping plovers. Depending on nest location and territory size, foraging areas contiguous with nesting habitat may be limited to the oceanside intertidal zone and wrack line or may contain flight corridors between ephemeral pond foraging and oceanside nesting habitats. The site experiences extremely high levels of anthropogenic disturbances from beach visitors and off-road vehicle use. Dogs are not permitted. Red foxes were not removed from this study site during any years of this study.

Cape May Point State Park/South Cape May Meadows, Cape May, New Jersey (CMPSP)

Cape May Point State Park and South Cape May Meadows (38.932281, -74.948278) make up the southernmost study site, located at the southern point of the state. The site consists of sparsely vegetated areas on the berm of the beach below the dune, however, this site does not currently support nesting piping plovers. The site experiences moderate levels of anthropogenic disturbance from beach visitors, but off-road vehicle use and dogs are not permitted.

Plans are underway to begin removing vegetation from low-lying areas to restore nesting habitat and to remove vegetation throughout the dunes to encourage access to bayside ponds for

foraging piping plovers at Cape May Point State Park. Red foxes were not removed from this study site during any years of this study.

Inlet beach

Linear beach

Land Cover Type
- Berm
- Overwash
- Road
- Wetland
- Forest
- Human Development
- Dunes
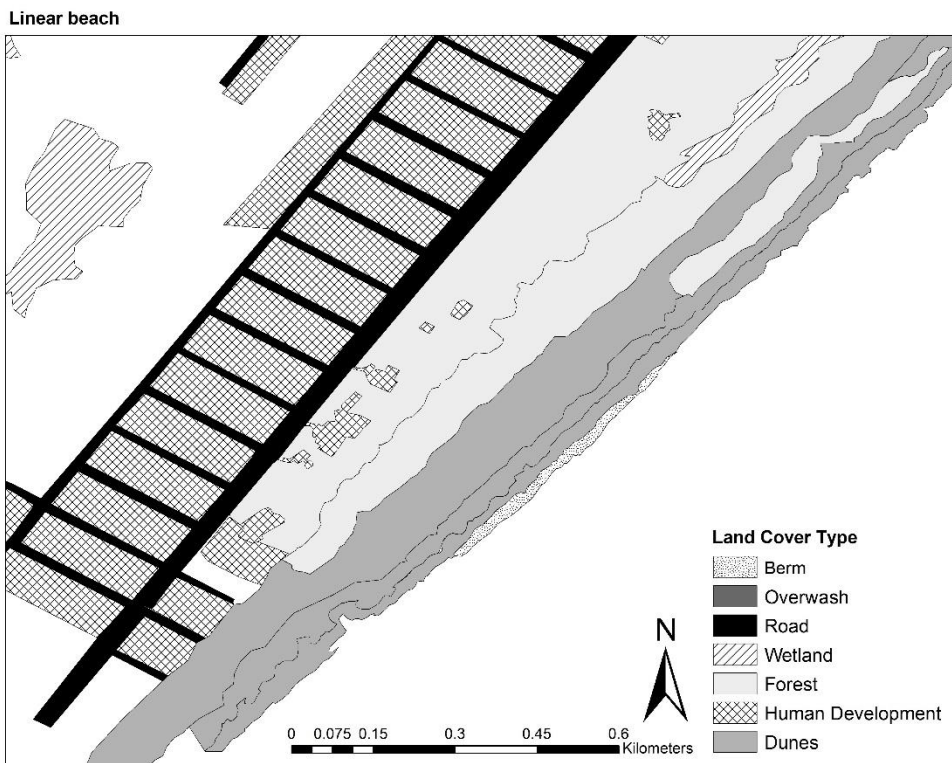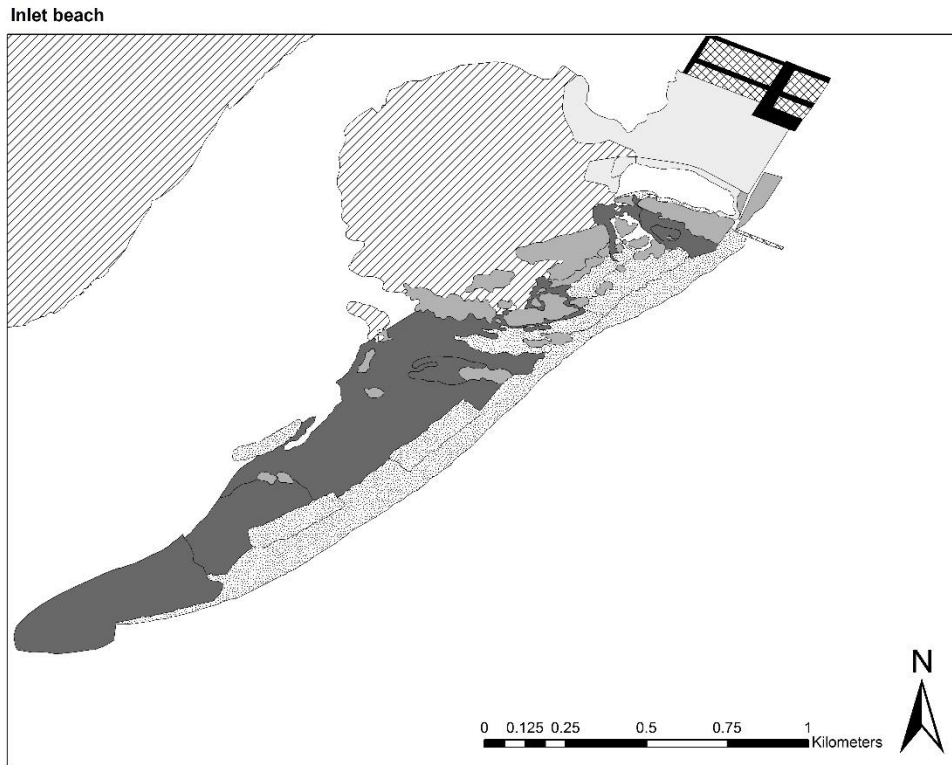
APPENDIX 5.B. CORRELATION COEFFICIENTS

Pearson correlation coefficients for covariates of interest for dynamic occupancy models made from predator track survey data in New Jersey, 2015-2017. Covariates include distance each of the following features (m): roads (ROAD), fresh or saltwater wetland (WETLAND), primary dune (DUNE), human development (DEVELOP), and maritime forest (FOREST).
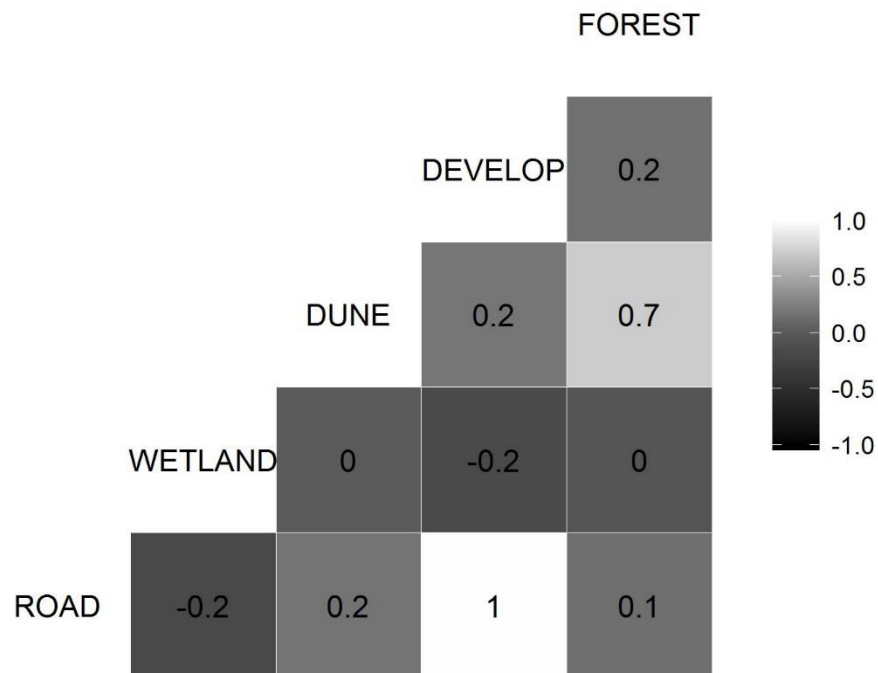
APPENDIX 5.C. DISTRIBUTION OF PLOT DISTANCE VARIABLES

Density of plot distances for covariates of interest for dynamic occupancy models made from

predator track survey data in New Jersey, 2015-2017. Dotted lines are means.
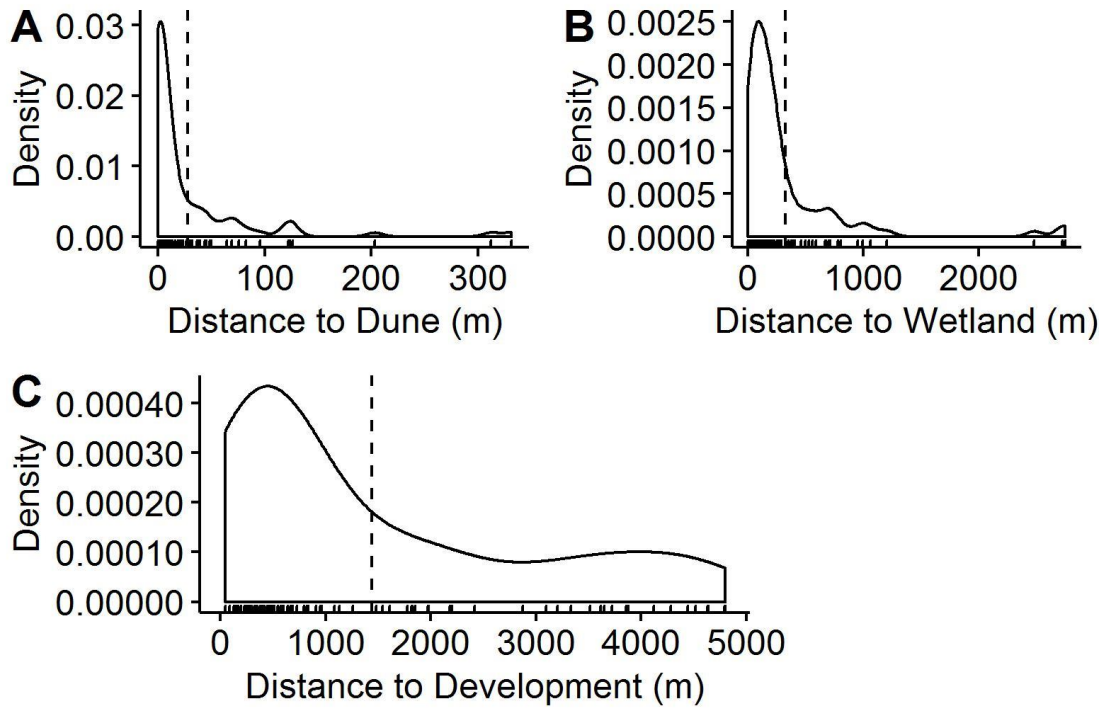
APPENDIX 5.D. STANDARDIZED EFFECT SIZES WITH 95% CONFIDENCE INTERVALS

Standardized effect sizes (±95% CIs) for top two occupancy models for red foxes in southern New Jersey, 2015-2017. The response variable was y_{ijt}, a binary variable denoting whether red foxes were detected at plot i during survey j of nesting period t. The model parameters are detection (p), first-survey occupancy (psi), colonization (col), and extinction (ext). Covariates include distance to primary dune (m; dune), distance to human development (m; development) and year (2015–2017).
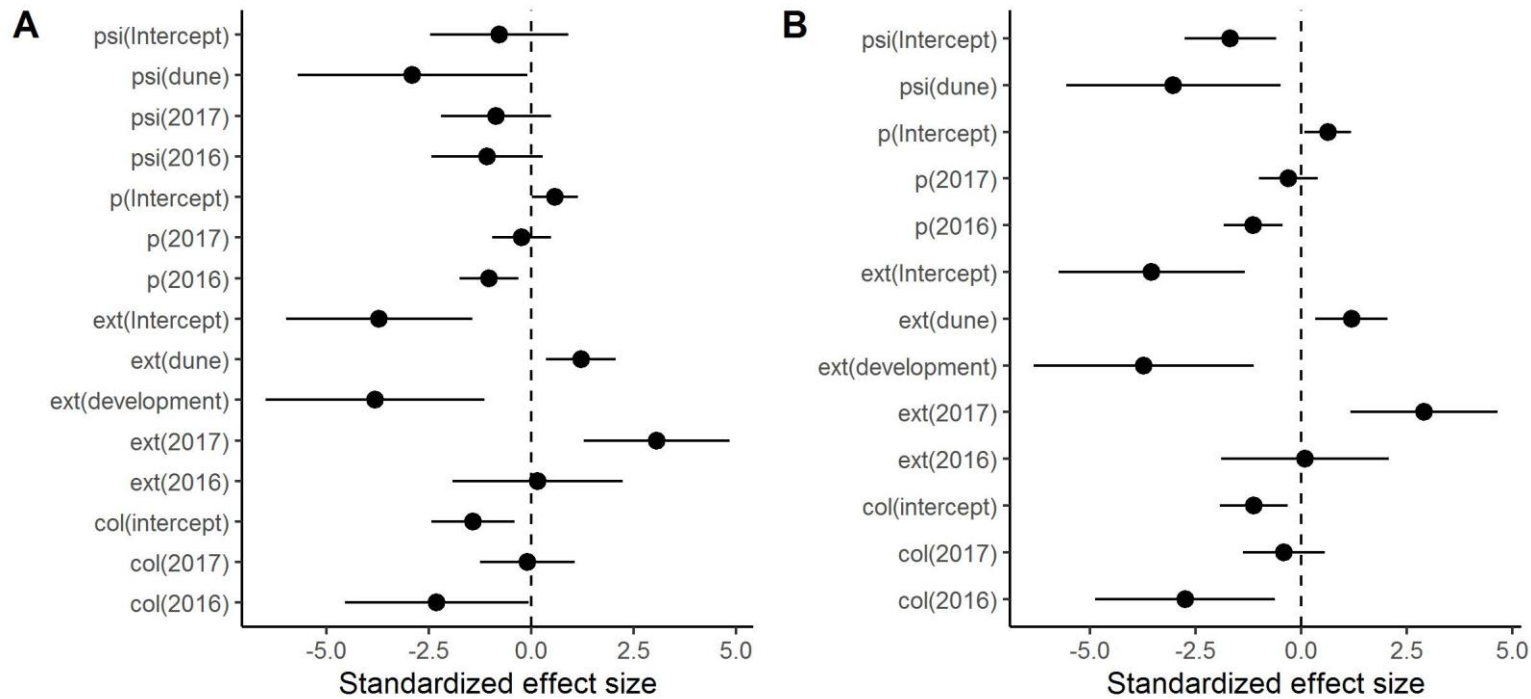
CHAPTER 6 CONCLUSIONS

Unlike game species which provide several instrumental values to society including economic and recreational values that incentivize habitat and population management, non-game and endangered species are valued in less tangible ways, necessitating special protections by federal and state agencies. The goal of these agencies is to actively conserve wildlife populations and their habitats so that they can persist for future generations. Wildlife managers have many tools available to help increase demographic rates or abundance of nongame populations; however, the effectiveness of each of these tools may be situationally dependent and data for nongame species is often sparse which makes evaluation of management challenging. Nonetheless, as anthropogenic stressors intensify it is increasingly important that we use science to evaluate the usefulness of wildlife management tools to make recommendations and guide wildlife managers to make the best possible decisions.

The improvement or maintenance of preferred habitat, selective beach closures, and predation management are all important tools that wildlife managers can use to increase abundance and reproductive success, and wildlife populations typically increase in response to these management actions (Shaughnessy et al. 1988, Bodkin et al. 2002, Watts et al. 2008, Madhusudan 2009, Walters et al. 2010). However, some management actions may have unintended consequences (Chauvenet et al. 2011). The Atlantic coast piping plover population has experienced great recovery success through the protection of the U.S. Endangered Species Act, but the New Jersey population has seen no increase in abundance since the time of listing. A coast-wide effort to summarize data on abundance, distribution, and reproductive success of piping plovers has continued since the species' ESA listing. Recovery actions include procedures to reduce the amount of habitat loss due to human development and management techniques to

protect adults, eggs, and chicks from predators and disturbance (Hecht and Melvin 2009). Management techniques include extensive monitoring of breeding pairs from the time of arrival on the nesting grounds until the time of departure, symbolic fencing to provide buffers around nesting areas preventing human disturbance, predation management including the use of exclosures to protect nests (Melvin et al. 1992), and off-road vehicle restrictions to allow broods to forage without the threat of being crushed by a vehicle. My study aimed to assess the impact of management actions aimed at increasing abundance and productivity for the New Jersey population of piping plovers.

A population viability analysis that was conducted by Melvin and Gibbs (1996) indicated that the Atlantic Coast population of piping plovers is highly sensitive to changes in productivity and adult survival, and my study has demonstrated that the use of exclosures may be leading to an increase in adult mortality, specifically for males. Coupled with poor chick growth and poor chick survival rates at sites without bayside foraging access that are open to the public, the New Jersey population of piping plovers is likely being supported by only a few sites with high productivity, bayside foraging access, and public beach closures such as E. B. Forsythe NWR.

I have provided information regarding the habitat use of mammalian predators of piping plovers such as red foxes and American mink that have not been previously documented. I have demonstrated that red fox habitat use decreases as the distance to the nearest primary dune increases; however, I found no evidence that red fox habitat use depends on the distance to human development. This suggests that allowing natural processes to restructure beaches with open sandy areas for nesting, or restoring habitat that replicates these natural processes, may lead to reduced predation rates by red foxes using piping plover nesting areas. I have also demonstrated that while predation management has been used as a tool to reduce predation

pressures for beach nesting birds, the removal of red foxes on the landscape can lead to mesopredator release. Consequently, as smaller predators such as American mink move into areas where red foxes have been removed, nest predation rates may increase rather than decrease. Furthermore, mesopredator release may diminish the effectiveness of nest exclosures for piping plovers. Understanding the complicated relationships between predator species and how they are using the landscape is important when considering management tools such as predation management and exclosures for reducing predation pressures for piping plovers.

I have identified limiting factors for all three life stages of piping plovers: adults, eggs, and chicks. Because adult survival is important for regional population growth rates, reducing exclosure use may lead to increases in adult survival and is a relatively easy management action to address. However, if exclosure use is reduced, eggs may be left vulnerable to the effects of predation by human-subsidized predators. Therefore, development of strategic predator removal programs that take into account the predator community and the interactions among predator species will be necessary to increase hatch success for piping plover nests. As hatch success increases, restoring access to adequate foraging habitat for chicks through habitat restoration, beach closures, or supplementary food will be necessary to maximize chick growth rates and survival. All of these actions could lead to increases in productivity and abundance for piping plovers in New Jersey, and it is important that we continue to monitor and track population changes as the population responds to changes in management actions. Understanding how management actions can lead to population level impacts gives wildlife managers a clearer understanding of when to use the various tools available to them to aid in species recovery.

In conclusion, maintaining nesting habitat for piping plovers that includes open, sandy areas created by coastal storms is critical to the conservation of piping plovers. However,

maintaining nesting and foraging habitat for piping plovers can have benefits to other species that rely on barrier islands for at least part of their life cycle including other beach nesting birds such as black skimmers and least terns, marsh nesting birds such as saltmarsh sparrows and black rails, and even plants such as seabeach amaranth and seaside sandwort, many of which are also threatened and endangered species.

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Stantial, M. L., J. B. Cohen, A. J. Darrah, S. Farrell, B. Maslo. In Review. Red fox habitat use in landscapes with nesting endangered shorebirds. Journal of Wildlife Management.

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Evidence for an ecological trap. Ecology 86:1422–1431.

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63:139–150.

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Climatic Change 64:41.

MICHELLE L. STANTIAL

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EDUCATION

Doctor of Philosophy, Candidate
SUNY-ESF, Environment and Forest Biology
Fish and Wildlife Biology and Management
Dissertation: "Factors Limiting Abundance and Reproductive Success of Piping Plovers in New Jersey"

January 2016 to Present (Spring 2020)
Syracuse, New York

Master of Science
SUNY-ESF, Environment and Forest Biology
Fish and Wildlife Biology and Management
Thesis: "Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines"

March 2012 to December 2014
Syracuse, New York

Bachelor of Science
Marietta College
Biology (Minor: Chemistry)
Capstone: "Odonate and Anuran Diversity at the Wilds in Southeast Ohio"

August 2001 to August 2005
Marietta, Ohio

REFEREED JOURNAL ARTICLES

Stantial, M.L, J.B. Cohen, A.J. Darrah, S. Farrel, and B. Maslo. Storm-created Features Detract Predators of an Endangered Beach-nesting Bird. Journal of Wildlife Management. *Submitted November 10, 2019, In Revision.*

Stantial, M.L. and J.B. Cohen. Miniature GPS tags provide high resolution movement data for a small-bodied endangered shorebird. Waterbirds. *Submitted October 14, 2019. In Review.*

Tattoni, D., E. Mordecai, and **M.L. Stantial**. Increase in coexistence among colonial nesting seabirds with 42 years of climate change. Waterbirds. *Submitted October 31, 2019, In Review.*

Stantial, M.L., J.B. Cohen, P.H. Loring, P.W.C. Paton. 2019. Radio transmitters did not affect apparent survival rates of Adult Piping Plovers. Waterbirds, 42(2): 205-209.

Gibson, D., A.D. Hornsby, M.B. Brown, J.B. Cohen, L.R. Dinan, J.D. Fraser, M.J. Friedrich, C.L. Gratto-Trevor, K.L. Hunt, M. Jeffrey, J.G. Jorgensen, P.W.C. Paton, S.G. Robinson, J. Rock, **M.L. Stantial**, C.E. Weithman, and D.H. Catlin. 2019. Migratory shorebird adheres to Bergmann's Rule by responding to environmental conditions through the annual lifecycle. Ecography, 42(9):1482-1493.

Grant, D.M., J.B. Cohen, **M.L. Stantial**, R. Linhart. Substrate-level nest site selection of sympatric Piping Plovers (*Charadrius melodus*) and American Oystercatchers (*Haematopus palliatus*) in New Jersey, USA. Waterbirds, 42(3): 272-281.

Stantial, M.L. and J.B. Cohen. 2018. The influence of habitat, tidal stage, temperature and breeding status on the Flight Behavior of Breeding Piping Plovers (*Charadrius melodus*). Journal of Ornithology, 159: 723.

Stantial, M.L., J.B. Cohen, A.J. Darrah, K.E. Iaquinto, P. H. Loring, P.W. C. Paton. 2018. Radio transmitters did not affect daily nest and chick survival of Piping Plovers. Wilson Journal of Ornithology, 130(2):518-524.

Stantial, M.L. and J.B. Cohen. 2015. Estimating flight height and flight speed of breeding Piping Plovers. Journal of Field Ornithology, 86: 369–377.

OTHER PUBLICATIONS

Stantial, M.L., R. Katz, J.B. Cohen, K. Amaral, J. Denoncour, A. Hecht, P. Loring, K. O'Brien, K. Parsons, C. Spiegel, A. Wilke. 2018. Structured Decision Making for Predator Removal to Benefit Piping Plovers and Other Beach Nesting Birds. In Best management

practices for coordinated predation monitoring and management for the Atlantic Flyway Shorebird Initiative. U.S. Fish and Wildlife Service and National Fish and Wildlife Foundation.

Stantial, M.L. 2014. Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Wind Turbines. M.S. Thesis, State University of New York - College of Environmental Science and Forestry, Syracuse, NY.

USFWS. 2012a. Summary of field season activities in 2009. Monomoy National Wildlife, USFWS. February 2012. Chatham, MA.

USFWS. 2012b. Summary of field season activities in 2010. Monomoy National Wildlife Refuge, USFWS. February 2012. Chatham, MA.

GRANTS

M.L. Stantial, J.B. Cohen, K. Clark, C. Davis. $401,138 (pending). Assessing the relationship of Peregrine Falcons (*Falco peregrinus*) and nesting Piping Plovers (*Charadrius melodus*) in New Jersey: Does an endangered species conflict exist? New Jersey Department of Environmental Protection, Non-Game and Endangered Species Program. 1/2020 – 12/2021.

Cohen J.B., **Stantial M.L.** $22,667. Monitoring Piping Plover Populations in Response to Management. U.S. Fish and Wildlife Service. 7/2019 – 12/2019.

Cohen J.B., **Stantial M.L.** $7,959. Statewide Piping Plover HCP Implementation Assistance. Massachusetts Division of Fisheries and Wildlife. 4/2019 – 6/2019.

Cohen J.B., **Stantial M.L.** $12,000. Statewide Piping Plover HCP Implementation Assistance. Massachusetts Division of Fisheries and Wildlife. 1/2018 – 6/2018.

Cohen J.B., **Stantial M.L.** $6,000. Structured Decision Making for Predator Management to Benefit Piping Plovers. U.S. Fish and Wildlife Service. 5/2018 – 9/2018.

Cohen J.B., **Stantial M.L.** $59,811. Factors Affecting Productivity of Piping Plovers on the Edwin B. Forsythe National Wildlife Refuge. U.S. Fish and Wildlife Service. 1/2016 – 6/2017.

Cohen J.B., **Stantial M.L.** $50,000. Factors Affecting Productivity of Piping Plovers in Southern New Jersey. U.S. Fish and Wildlife Service. 1/2016 – 6/2017.

AWARDS

43rd Annual Meeting, Waterbird Society, Best Student Paper	*Princess Anne, MD*	November 2019	$200
2019 Wilford A. Dence Fellowship Award	*Syracuse, NY*	April 2019	$2600
2019 Burgess Award, Outstanding Doctoral Scholar	*Syracuse, NY*	April 2019	-
Office of Instruction and Graduate Studies (OIGS) Travel Award	*Jamnagar, India*	January 2019	$500
42nd Annual Meeting, Waterbird Society Student Travel Award	*Vancouver, Canada*	August 2018	$400
American Ornithological Society Student Travel Award	*Vancouver, Canada*	August 2018	$300
Waterbird Society Research Grant	*Waco, TX*	March 2018	$1950
Scott Melvin Memorial Award	*Westboro, MA*	March 2018	$1000
Edna Bailey Sussman Foundation Award	*Syracuse, NY*	May 2016	$6370
6th North American Ornithological Conference Travel Award	*Washington, DC*	August 2016	$210
Betty Moore Chamberlaine Memorial Award	*Syracuse, NY*	May 2015	$1500
38th Annual Meeting, Waterbird Society Student Travel Award	*La Paz, Mexico*	November 2014	$200
26th International Ornithological Congress, Student Travel Award	*Tokyo, Japan*	August 2014	$1000
37th Annual Meeting, Waterbird Society, Best Student Paper	*Wilhelmshaven, Germany*	September 2013	-
37th Annual Meeting, Waterbird Society Student Travel Award	*Wilhelmshaven, Germany*	September 2013	$100
Garden Club of American, Francis M. Peacock Scholarship	*New York, NY*	April 2013	$4500
Goldenrod Foundation, Small Equipment Grant	*Plymouth, MA*	February 2013	$1500
Bird Conservation Conference of the Northeast Student Travel Award	*Plymouth, MA*	October 2012	$80

PROFESSIONAL WORK EXPERIENCE

Little Egg Foundation   Ithaca, New York
Co-Founder and Executive Director   January 2019 to Present
- Produced a data collection smartphone app and data management platform called NestStory using piping plovers as a test-species
- The platform is now being used for 10 additional species including: bald eagles, osprey, peregrine falcons, Northern goshawks, American kestrels, least terns, common terns, black skimmers, burrowing owls, and American Oystercatchers
- https://www.little-egg.org/

SUNY-ESF, Environment and Forest Biology   Syracuse, New York
Senior Research Support Specialist   January 2015 to January 2016
- Defined research objectives for the project entitled, "Factors Limiting Reproductive Success of Piping Plovers in New Jersey"
- Planned and coordinated field activities with partners in southern New Jersey
- Trapped and banded adult piping plovers using exclosure funnel traps (40 individuals)
- Captured and banded 0-3 d old hatch year piping plovers using hand capture (62 individuals)
- Analyzed data collected during the field season
- Produced technical annual reports for SUNY-ESF, NFWF, USFWS, and NJDEP
- Prepared manuscripts for publication

Toxicology Consultants & Assessment Specialists, LLC   Skaneateles, New York
Assistant Toxicologist   May 2014 to March 2015
- Research effects of various chemicals and drugs on the environment, wildlife, and humans
- Prepare summaries of research and data analysis for supplemental information to various toxicology reports
- Assist in developing human and ecological risk assessments from data acquired from sampling efforts for various toxicology cases throughout the United States

Monomoy National Wildlife Refuge   Chatham, Massachusetts
USFWS Biological Science Technician – GS 0404-05   April 2011 to March 2012
- Piping Plover (41 pairs), American Oystercatcher (23 pairs), Black Skimmer (5 pairs), and Least Tern (100 pairs) nest searching and productivity monitoring
- Roseate Tern nest searching, adult trapping (Potter traps), adult and chick banding, productivity monitoring, and post-breeding resighting (13 pairs)
- Common Tern (7000 pairs) productivity monitoring, adult trapping (Potter traps), adult and chick banding, and Laughing Gull kleptoparasitism monitoring
- Participated in Red Knot Migration Study involving cannon netting and banding of shorebirds (REKN, SBDO, BBPL, SAND – 500+ individuals captured and 300+ banded)
- Supervised crew of 2 Seasonal Biological Technicians and 4 Seasonal Biological Interns
- Managed all data collected during the field season into Excel spreadsheets and analyzed data for state census forms and 2011 Annual Field Season Report
- Assisted with grant proposal development and submission for Roseate Tern, American Oystercatcher, and Northeastern Beach Tiger Beetle projects occurring at the refuge
- Acquired wildlife permits for 2012 field season
- Tracked 12 rabbits with radio telemetry units trapped at Mashpee NWR– mixed sampling of New England Cottontail and Eastern Cottontail for home range analysis
- Tagged and processed 500+ spawning Horseshoe Crabs
- Finalized 2009 and 2010 Annual Field Season Reports for internal publication

Tufts University   Wellfleet, Massachusetts
Common Eider Technician   November 2009 to March 2012
- Conducted weekly/monthly counts of dead, moribund, and healthy Common Eiders
- Collected wing samples and newly deceased specimens for aging, sexing, and necropsy
- Surveyed adjacent waters for all healthy species of waterfowl

Virginia Tech   Dauphin Island, Alabama
Research Crew Leader   August 2010 to April 2011

- Conducted surveys of wintering Piping Plovers on Gulf Coast barrier islands
- Trapped and banded wintering Piping Plovers using drop and whoosh nets (38 individuals)
- Resighted uniquely marked adult Piping Plovers for winter survival analysis
- Supervised field crew and coordinated daily activities with boat captain
- Managed collected data into Access database

Massachusetts Audubon Society   Wellfleet, Massachusetts
Beach Nesting Bird Field Coordinator   March 2009 to August 2010
- Piping Plover (23-30 pairs), American Oystercatcher (2 pairs), and Least Tern (100-300 pairs) nest searching and productivity monitoring on Cape Cod Bay beaches from Brewster to Provincetown
- Trapped and banded adult American Oystercatchers using whoosh nets (4 individuals); hand captured and banded hatch year American Oystercatchers (2 individuals)
- Supervised, coordinated, and communicated with 3 staff members and 20+ volunteers
- Made recommendations to landowners regarding management of nesting shorebirds
- Managed data collected during field season into an Access database for state census forms
- Assisted in the development of new educational materials and curriculum

Sea Turtle Field Technician
- Retrieved cold-stunned sea turtles identified by volunteers on local Cape Cod Bay beaches
- Recorded measurements of recovered turtles such as straight carapace length, curved carapace length, straight carapace width, curved carapace width, weight, and body condition
- Managed data on recovered turtles into Excel spreadsheets
- Updated NOAA about stranding numbers, locations, and mortalities on a weekly basis

Roseate Tern Field Technician
- Conducted counts of staging Common and Roseate Tern flocks at outer Cape Cod beaches from Chatham to Provincetown
- Resighted color banded adult Roseate Terns for post-breeding dispersal study
- Managed data collected during the field season into spreadsheets for analysis and report

Tuckernuck Land Trust   Nantucket, Massachusetts
Coastal Land Steward   May 2008 to September 2008
- Monitored nesting Piping Plovers (5 pairs) and American Oystercatchers (11 pairs)
- Educated beachgoers about important nesting habitats and appropriate beach use
- Led weekly natural history programs for Tuckernuck Island residents
- Assisted with locating nests and banding Northern Harrier chicks

Becket Chimney Corners YMCA   Becket, Massachusetts
Outdoor Education Program Coordinator (Interim Director)   August 2006 to May 2008
- Scheduled, planned, and implemented programs and staff for all visiting groups
- Trained and supervised seasonal staff (up to 40 staff members) in outdoor leadership courses (high ropes, low ropes, and teambuilding) and environmental education programs (forest ecology and pond ecology)
- Completed billing, evaluations, and follow-ups with visiting groups

Outdoor Experiential Educator   August 2005 to August 2006
- Lead visiting groups of various ages from elementary school to adult through outdoor leadership courses such as teambuilding, low ropes, and high ropes
- Taught specialty courses in forest and pond ecology for interested visiting elementary schools

RESEARCH ASSISTANTSHIPS

Graduate Research Assistant (Ph.D.)
- Analyzed data for Dr. Jacqueline Frair from otter tracking surveys across New York State using Bayesian time-to-detection occupancy models with distance substituted for time; provide methods used to be incorporated into reports for NYSDEC
- Led the analysis and preparation of a report to evaluate the efficacy of predator removal in Massachusetts using historic nesting data as a goal of the Massachusetts Habitat Conservation Plan (HCP); made recommendations for approaches to evaluate efficacy moving forward

- Assisted with development of a tool to help beach managers make decision regarding exclosure use for Atlantic coast piping plovers (PiperEx)
- Collected behavioral observations of piping plovers nesting along Lake Ontario in New York

Graduate Research Assistant (M.S.)
- Reviewed and commented on the Massachusetts State-Wide Habitat Conservation Plan (HCP) for piping plovers during the development phase

TEACHING EXPERIENCE

Introduction to Conservation Biology   Spring 2020
Instructor   SUNY-ESF EFB 413
Created course syllabus and prepared teaching materials to facilitate the curriculum
- Lectured and led class discussions two days/week
- Provided relevant assignments for students that demonstrated real-life problems on conservation biology
- Created quizzes and final exams
- Graded final exams, quizzes, and final projects
- Maintained records of scores on assignments

Applied Wildlife Science   Spring 2019
Graduate Teaching Assistant   SUNY-ESF EFB 491/796
- Led discussions prior to lab, answer questions and clarify materials
- Completed lab projects prior to assigning them to students so that any needed modifications could be made
- Graded exams and lab assignments
- Scheduled and maintained regular office hours to work with students one-on-one and learn about problems they may be having with the course material
- Attend lectures given by the instructor (Dr. Jacqui Frair) and lead lectures in the instructor's absence

Global Status, Trends, and Threats to Coastal Birds   January 13-18, 2018
Workshop Presenter and Field Assistant   Jamnagar, India
Lecture: "Ecology and Conservation of Beach-Nesting Birds"
Lecture: "Multi-response Permutation Procedure (MRPP) for Analyzing Behavioral Data"
Field Demonstration: "Shorebird Capture and Handling Techniques"
Field Demonstration: "Behavioral Observations and Habitat Data Collection Techniques"

Structured Decision-Making Workshop   October 2-6, 2017
Assistant Coach   Newbury, Massachusetts
"Structured Decision Making for Predator Removal to Benefit Piping Plovers and Least Terns in Maine and Massachusetts"

SUNY-ESF   August 2015 to Present
Graduate Student Mentor   Syracuse, New York
- Trained 25+ undergraduates how to review continuous camera footage on piping plover nests, record data effectively, and enter data into a database
- Advised 3 students through honors projects where they created their own study and carried it out using existing data or collecting data in the field
- Mentored 10 student interns during field work to help generate an understanding of how field work is coordinated and executed, the importance of collecting good data, and the value of entering and properly auditing data for analyses

The Wildlife Society at SUNY ESF   Spring 2018
Guest Lecturer   1-hour lecture
"MOTUS Wildlife Tracking System"

Ornithology (EFB 482)   Fall 2017
Guest Lecturer   1-hour lecture
"Field Techniques for Piping Plover Research"

The Wildlife Society at SUNY ESF   Fall 2017
Guest Lecturer   1-hour lecture
"Understanding Spatial and Temporal Distribution of Red Foxes (*Vulpes vulpes*) in Piping Plover (*Charadrius melodus*) Nesting Habitat in Southern New Jersey"

Ph.D. Candidacy Exam Preparation   Fall 2017
Graduate Student Panel   1-hour lecture

SUNY ESF Bird Club   Fall 2016
Guest Lecturer   1-hour lecture
"Understanding Spatial and Temporal Distribution of Red Foxes (*Vulpes vulpes*) in Piping Plover (*Charadrius melodus*) Nesting Habitat in Southern New Jersey"

NJENSP Piping Plover Monitor Trainer   Spring 2016
Guest Trainer   1-hour lecture
"Predator Tracking: Tips for Identifying Tracks of Nest Predators"

SERVICE

Journal Reviewer
Wilson Journal of Ornithology (1)   2018
Ibis (1)   2017
Waterbirds (3)   2015, 2016, 2017

Onondaga Audubon   Syracuse, New York
Secretary   July 2018 to Present
Board Member   July 2016 to Present
- Attend monthly meetings to help advance the organization's mission of encouraging the conservation of birds and other wildlife native that are to central New York
- Write and review grant proposals for projects of interest to the organization
- Organize and coordinate weekly bald eagle surveys on Onondaga Lake
- Record notes at monthly meetings and distribute notes to board members

Baltimore Woods Nature Center   Marcellus, New York
MAPS Bird Banding Program   May 2017 to Present
- Reinstated MAPS bird banding station at Baltimore Woods in coordination with Onondaga Audubon and SUNY-ESF
- Extract captured passerines from mist nests and apply metal service bands
- Take measurements of captured birds and record on MAPS datasheets
- Enter data into MAPSProg and Bandit at the end of the season

Mass Audubon   Wellfleet, Massachusetts
Wellfleet Bay Wildlife Sanctuary Volunteer   October 2008 to March 2012
- Conducted stranded sea turtle beach surveys and communicated locations of stranded turtles to staff
- Helped with special event setup, coordination, and breakdown
- Participate in prescribed burns on managed grasslands

Cape Cod Natural History Museum   Brewster, Massachusetts
MAPS Bird Banding Program Volunteer   October 2008 to August 2010
- Extracted captured birds from mist nests (500+ individuals)
- Took measurements of captured birds
- Recorded data for Master Bander

The Wilds   Cumberland, Ohio

Conservation Science Intern   May 2004 to August 2004
- Banded and monitored osprey chick behaviors for reintroduction program
- Assisted naturalists with Conservation Education Programs
- Performed trail maintenance, invasive species eradication, habitat restoration, and other duties

CONFERENCE PRESENTATIONS

Stantial, M.L., J.B. Cohen. 2019. "Effects of Mesopredator Release on an Endangered Shorebird in New Jersey." Waterbird Society, 43rd Annual Meeting, Princess Anne, MD, November 6-9, 2019.

Stantial, M.L., R. Katz, J.B. Cohen, K. Amaral, J. Denoncour, A. Hecht, P. Loring, K. O'Brien, K. Parsons, C. Spiegel, and A. Wilke. "Addressing Scientific Uncertainty in Management Actions for a Data-Rich Species." 8th Western Hemisphere Shorebird Working Group Meeting, Panama City, Panama. October 24-28, 2019.

Stantial, M.L., J.B. Cohen. 2018. "Using Manual and Automated Telemetry for Monitoring Breeding Piping Plovers." Eastern Bird Banding Association Annual Meeting, Rochester, NY, April 12-13.

Stantial, M.L., J.B. Cohen. 2017. "Using miniaturized GPS tags to study breeding season habitat use and migration in threatened Piping Plovers." 27th International Ornithological Congress, Vancouver, Canada, August 19-26, 2018. 3-minute Speed Talk.

Stantial, M.L., J.B. Cohen. 2017. "Using miniaturized GPS tags to study breeding season habitat use and migration in threatened Piping Plovers." Waterbird Society, 42nd Annual Meeting, Vancouver, Canada, August 18-20, 2018.

Stantial, M.L., J.B. Cohen. 2017. "Understanding Spatial and Temporal Distribution of Red Foxes (*Vulpes vulpes*) in Piping Plover Nesting Habitat in Southern New Jersey." The Wildlife Society, 24th Annual Meeting, Albuquerque, NM, September 23-27.

Stantial, M.L., J.B. Cohen. 2016. "Understanding Spatial and Temporal Distribution of Red Foxes (*Vulpes vulpes*) in Piping Plover Nesting Habitat in Southern New Jersey." 6th North American Ornithological Congress, Washington, DC, August 16–20.

Stantial, M.L., J.B. Cohen. 2015. "Using Manual and Automated Telemetry for Monitoring Breeding Piping Plovers." Western Hemisphere Shorebird Group, 6th Bi-Annual Meeting, Wallops Island, VA, September 12-16.

Stantial, M.L., J.B. Cohen. 2014. "Using a Collision Risk Model to Assess Potential Impacts to Breeding Piping Plovers along the Atlantic Coast." Waterbird Society, 38th Annual Meeting, La Paz, Mexico, November 4-7.

Stantial, M.L.., J.B. Cohen. 2014. "Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures." 26th International Ornithological Congress, Tokyo, Japan, August 18-24.

Stantial, M.L.., J.B. Cohen. 2013. "Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures." Waterbird Society, 37th Annual Meeting, Wilhelmshaven, Germany, September 24-29.

Stantial, M.L.., J.B. Cohen. 2013. "Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures." Northeast Association of Fish & Wildlife Agencies, 69th Annual Meeting, Saratoga Springs, NY, April 7-9.

Stantial, M.L., J.B. Cohen. 2012. "Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures." Bridging the Implementation Gap: Bird Conservation Conference in the Northeast, Plymouth, MA, October 16-19.

Ellis, J.C., S.J. Courchesne, V.I. Shearn-Boschler, and **M.L. Stantial**. 2010. "Cyclic mass mortality of common eiders at Cape Cod, MA: an ongoing puzzle." Pacific Seabird Group, 37th Annual Meeting, Long Beach, CA. February 17-21.

OTHER PROFESSIONAL PRESENTATIONS

NJ State Cooperator's Meeting   Cape May, New Jersey
20 Minute Oral Presentation   December 2019
"Effects of Mesopredator Release on an Endangered Shorebird in New Jersey"

MA State Cooperator's Meeting   Barnstable, Massachusetts
20 Minute Oral Presentation   August 2018
"Evaluating the Efficacy of Predator Removal on Nest and Chick Survival in Massachusetts"

20 Minute Oral Presentation
"Using miniaturized GPS tags to study breeding season habitat use and migration in threatened Piping Plovers"

NJ State Cooperator's Meeting   Cape May, New Jersey
20 Minute Oral Presentation   December 2017
"Nest Initiation Dates, Daily Survival Rates and Preliminary Results of GPS Tags for Banded Piping Plovers In NJ"

"Science Saturdays" LBI Foundation   Loveladies, New Jersey
1 ½ Hour Guest Lecture   January 2017
"Piping Plovers of LBI: How Our Plovers Fit into the Big Picture of Conservation"

NJ ENSAC Meeting   Cape May, New Jersey
Webinar   December 2016
"Factors Limiting Abundance and Productivity of Piping Plovers in Southern New Jersey"

NJ State Cooperator's Meeting   Cape May, New Jersey
20 Minute Oral Presentation   December 2016
"Factors Limiting Abundance and Productivity of Piping Plovers in Southern New Jersey"

2016 Atlantic Coast Piping Plover and Least Tern Workshop   Shepherdstown, West Virginia
20 Minute Oral Presentation   January 2016
"Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures"

Poster Presentation
"Using Manual and Automated Telemetry for Monitoring Breeding Piping Plovers"

Poster Presentation
"Radio Telemetry for Plover Chicks"

Round-Table Discussion Leader
"Using Technology to Aid in Coast-wide Data Collection and Coordination"

NJ State Cooperator's Meeting   Cape May, New Jersey
20 Minute Oral Presentation   December 2015
"Factors Limiting Abundance and Productivity in Southern New Jersey"

Annual Atlantic Coast Flyway Meeting   Albany, New York
20 Minute Oral Presentation   July 2015
"Using Automated Telemetry for Monitoring Breeding Piping Plovers"

USFWS Webinar Meeting   Webinar
30 Minute Oral Presentation   February 2015
"Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures"

Onondaga Audubon Society Meeting   Baldwinsville, New York
45 Minute Oral Presentation   February 2015
"The Active Night Life of Birds"

NJ State Cooperator's Meeting   Cape May, New Jersey
20 Minute Oral Presentation   December 2014
"Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures"

Goldenrod Foundation   Plymouth, Massachusetts
45 Minute Oral Presentation   June 2014
"Something to Crow About: How Researchers are Tracking Bird Movements on Cape Cod and Beyond"

2014 Atlantic Coast Piping Plover and Least Tern Workshop   Shepherdstown, West Virginia
25 Minute Oral Presentation   February 2014
"Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures"

Massachusetts's Coastal Bird Cooperator's Meeting   Hyannis, Massachusetts
20 Minute Oral Presentation   August 2013
"Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures"

Mass Audubon Staff Meeting   Barnstable, Massachusetts
15 Minute Oral Presentation   June 2013
"Automated Telemetry for Tracking Piping Plover Movements: A Novel Approach for Evaluating Risks of Wind Turbine Collision on the Breeding Grounds"

Goldenrod Foundation Board of Trustee's Meeting   Plymouth, Massachusetts
20 Minute Oral Presentation   May 2013
"Automated Telemetry for Tracking Piping Plover Movements: A Novel Approach for Evaluating Risks of Wind Turbine Collision on the Breeding Grounds"

Massachusetts's Coastal Bird Cooperator's Meeting   Hyannis, Massachusetts
20 Minute Oral Presentation   August 2012
"Piping Plover Movements, Flight Heights, and Avoidance of Obstructions During the Breeding Season: Implications for Risk of Collision with Turbines and Other Human Structures"

OTHER EXPERIENCE

Other Skills
R, JAGS, NIMBLE, ArcGIS, SAS, SPSS, Microsoft Excel, Access, Word, PowerPoint, and Publisher, eBird, Bandit, FileMakerPro, Outboard Motor Operator (13ft – 23ft power boats)

Professional Memberships
Onondaga Audubon Society, Board Member; The Waterbird Society, Student Member; American Ornithological Union, Student Member; Massachusetts Audubon Society, Member; Association for Women in Science, National and Local Chapter, Student Member; The Wildlife Society, Student Member

Certifications
200-hr Yoga Teacher Training, MOCC (Motorboat Operators Certification Course), USPS Boater Safety Certification, Hunter Safety Certification, National Wildfire Wilderness Fire Certification (S-130, L-180 and S-190), FEMA IS-700, FEMA IS-100, National Safety Council Defensive Driving, Red Cross CPR for the Professional Rescuer, Red Cross First-Aid, Red Cross Small Craft Safety and Rescue

Languages
English (primary), French (intermediate), Spanish (beginner), German (beginner)

Travel Destinations
International: Panama, Austria, Morocco, Bahamas, Costa Rica, India, England, France, Germany, Netherlands, Iceland, Japan, Mexico, Canada
Domestic: Ohio, Michigan, Pennsylvania, West Virginia, Virginia, Kentucky, Tennessee, South Carolina, Mississippi, Alabama, Georgia, Florida, Maryland, New Jersey, New York, Connecticut, Massachusetts, New Hampshire, Vermont, Maine, Rhode Island, Louisiana, Wyoming, Montana, Idaho, Arizona, Nevada, California, and Oregon