FLIGHT BEHAVIOR OF BREEDING PIPING PLOVERS:

IMPLICATIONS FOR RISK OF COLLISION WITH WIND TURBINES

by

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DEDICATION

I would like to dedicate this thesis to the memory of Dr. Scott Melvin. Thank you for devoting your career to the conservation of piping plovers.

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ABSTRACT

Stantial, M.L. Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Wind Turbines. 168 pages, 9 Tables, 43 Figures, 1 Appendix, 2014.

Using flight data, we predicted that the total number of piping plovers killed per breeding season (adjusted for 98 percent avoidance) could range among study sites from 0.01 to 0.29 for a small-scale residential turbine, 0.03 to 0.99 for a medium-sized turbine, and 0.06 to 2.27 with a large, utility-style turbine. Female piping plovers with a nest spent 63.7% ± 4.5% of the time out of detection range at night and 31.5% ± 6.2% of the time out of range during the day (MRBP, Test statistic = -3.261, *P* = 0.011).

Keywords: *Charadrius melodus*, collision risk model, flight frequency, piping plover, nocturnal behavior, wind turbines

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CHAPTER 1. CONSERVATION OF ATLANTIC COAST PIPING PLOVERS AND THE THREAT OF COLLISION WITH WIND TURBINES.

Collision risk with wind turbines

Conservation of migratory birds relies on managing factors that limit survival and reproduction during all phases of the annual cycle (Newton 2013). Wildlife managers are increasingly faced with human-wildlife conflicts. Often they are forced with making decisions that provide benefits to humans and minimize impacts to wildlife. Additionally, anthropogenic activities can favor species that are adapted to human conditions leading to negative impacts on species less suited to living near humans. In human altered landscapes, wildlife may have to contend with novel threats such as anthropogenic structures, human commensal predators and pest outbreaks that degrade habitat (Moore 1967, Cooper and Day 1998, Marzluff and Netherlin 2006, Raffa et al. 2008). New threats introduced by humans to bird populations pose unknown risks and could counteract past successes of protection and recovery. When a potential threat is going to be introduced into the environment deliberately, it is important attempt to characterize the risks prior to construction.

Wind energy is a rapidly growing industry, and in many places turbines have been deployed before risk assessments have taken place. Since the industry is still in its nascent stages, it is not too late to properly evaluate the consequences of wind development to wildlife.

The U.S. Department of Energy has stated that it is possible to achieve 20 percent wind energy in the United States by 2030 (Musial and Ram 2010), yet the total on-shore installed wind power capacity for 2013 was reported at 61,108 MW, which was less than 1.5% of the total production throughout the year (US Department of Energy 2014). However, the National Renewable Energy Laboratory has indicated that the offshore wind power potential for the U.S.

is estimated in excess of 1,071,200 MW in waters less than 30 m deep (Musial and Ram 2010). Wind power offers a promising renewable energy source posing negligible operational costs, requiring a very small physical footprint, and producing no greenhouse gases or water pollution. For this reason, wind energy may become a significant component of the United States energy portfolio and evaluating ways to minimize turbine exposure to wildlife is a key to reducing environmental impacts.

Wind turbines create electricity by harnessing the wind's available kinetic energy. As wind flows across the turbine blades, lift is generated in a similar fashion as the effect of airplane wings which causes the blades to turn. The blades are connected to a drive shaft which is connected to a generator and produces electricity (USEIA 2014). The spinning blades of the turbine pose a potential risk to wildlife, especially birds and bats. Current collision risk models designed specifically for birds have demonstrated that wind power-related collision mortality is affected by factors such as tower height, rotor speed, rotor diameter, bird speed, flight height, and avoidance behavior (Chamberlain et al. 2005, Barclay et al. 2007). Encounter rates of birds with wind turbines might also depend on specifics of habitat arrangement and turbine placement. Wildlife biologists have attempted to assess the impacts of wind turbine development for both on-shore and off-shore wind turbines, for migratory and non-migratory species, and during all three phases of construction (pre-, during, and post-construction).

Mortality events at wind turbines due to collision with turbine blades have been a major focus of impact assessments to wildlife populations. At three wind farms in the Netherlands comprising a total of 25 wind turbines, Krijgsveld et al. (2009) estimated that the collision rate at each turbine was 0.08 birds per day. At the Altamont Pass Wind Resource Area in California, USA, a study area including 4,074 wind turbines, Smallwood and Thelander (2008), estimated a total of 2,710 bird deaths per year (7.42 per day). During a 1995 study at the Buffalo Ridge Wind Resource Area in Minnesota, USA, the estimated number of collision related mortalities was 36 birds at 73 turbines during the entire 12 month period (0.10 per day) (Osborn et al. 2000). Thus, the numbers of estimated collisions with wind turbines can vary greatly between study areas; habitat configuration, numbers and spacing of turbines, and morphological and behavioral characteristics of birds all might contribute to population-level impacts on a particular species. Using a discrete-time, individual-based simulation model, Shaub (2012) demonstrated that local nesting Swiss red kite (*Milvus milvus*) population growth rates decreased as the number of turbines increased and the spacing of the turbines on the landscape increased. In the absence of turbines, the simulated Swiss red kite population increased annually by 5.2 percent (Shaub 2012). These studies indicate that the placement and configuration of wind turbines are a crucial part of the planning process in order to minimize impacts to wildlife.

Although collision mortality is a primary concern for wind turbine impacts on wildlife, avoidance of the footprint and the area surrounding a turbine or wind farm can also directly affect bird populations through habitat loss and the increased energetic cost of dispersal. Leddy et al. (1999) found that at Conservation Reserve Program grasslands within the Buffalo Ridge Wind Resource Area total breeding bird densities were lower in grasslands containing turbines than in grasslands without turbines. Bird densities increased with increased distances from the turbines up to 180 m (Leddy et al. 1999). At 9 wind farms in the United Kingdom (UK), 7 of 12 focal nesting species exhibited significantly lower densities close to turbines, and none of the 12 species were more likely to occur close to the turbines than far from them (Pearce-Higgins et al. 2009). Breeding bird densities within close proximity to the UK wind turbines were predicted to be significantly reduced by 15 percent to 52 percent, depending on the species (Pierce-Higgins et al. 2009). Moreover, common eiders (*Somateria mollissima*) in the Netherlands had a strong flight avoidance response to turbines in the marine environment (Larsen and Guillemette 2007). Flight paths of common eiders were 19 percent less likely to enter into the 200-m corridor surrounding the wind farm and 50 to 53 percent less likely to enter the two corridors within the wind park itself than to fly around the wind farm (Larsen and Guillemette 2007). The avoidance response by birds observed in these studies demonstrates preclusion of habitat use and potentially represents an energetic cost of altering a flight path due to human-related structures.

Special care needs to be taken before adding turbines to already heavily impacted wildlife habitat. Beach nesting shorebirds have experienced extensive habitat loss through coastal development and artificial shoreline stabilization. This habitat loss is expected to increase under varying scenarios of global climate change due to the threat of sea-level rise. Coastal barrier islands are especially vulnerable; because of their low-lying nature, an increase in the rate of sea-level rise beyond a few millimeters per year could result in complete inundation (Zhang et al. 2004). Additionally, coastal barrier islands are attractive for anthropogenic development, yet this human expansion can block and alter the movement of wind, sand, and water preventing the natural migration of these beaches (Zhang et al. 2004). These natural processes lead to the creation of new nesting and foraging habitats for shorebirds; beach nesting shorebirds, including the federally protected piping plover (*Charadrius melodus*), rely heavily on these dynamic processes throughout their annual cycle (Cohen et al. 2009). A careful pre-construction evaluation of any new threat, such as wind turbines added to these already degraded ecosystems, is warranted.

The Atlantic coast population of piping plovers was listed as threatened under the U.S. Endangered Species Act (ESA) in 1986. The primary purpose of the ESA is to provide a framework for recovery by identifying and minimizing threats that are likely to jeopardize recovery and long-term persistence of species at risk. Factors contributing to the species decline include coastal development as well as loss of eggs and young to avian and mammalian predators and anthropogenic disturbance (USFWS 1996). The criteria for the Atlantic coast piping plover population to be considered for removal from ESA regulations include increasing and maintaining a total of 2,000 breeding pairs and achieving a five-year average reproduction rate of 1.5 chicks fledged per pair (USFWS 1996). Since listing, the population has increased from 790 pairs in 1986 to more than 1,898 pairs in 2012 (USFWS 2012). This reflects a 140 percent increase in the total number of pairs from since the time of listing. While conservation of this species has seen great recovery success through protection and management, a population viability analysis that was conducted by Melvin and Gibbs indicated that the Atlantic Coast population is highly sensitive to changes in productivity, adult survival, and hatch year survival (Melvin and Gibbs 1994).

Under the ESA, it is illegal to cause "take" of an endangered species, a term defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect or to attempt to engage in any such actions (16 U.S.C. § 1532). Wind turbines have the potential to cause take and potentially even jeopardize the continued existence of a species if population-level consequences demonstrate an appreciable reduction in the numbers of breeding pairs. There are increasing numbers of proposals to build small wind farms or single turbines in coastal areas that may contain piping plover habitat (USGS 2013). A clearer understanding of the piping plover's spatial patterns, movements, flight characteristics, and behavior under different environmental conditions may allow for the utilization of collision risk models and population viability models which could predict the potential take and the population level consequences. These models could be utilized before structures were permanently placed at or near breeding habitat. The goal of our research is to quantify the flight behavior of breeding piping plovers and to assess site specific risks of collisions with proposed turbine construction using existing collision-risk models (SNH 2000).

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. Piping plovers usually nest above the high tide line on flat, open, low-lying beaches, gently sloping foredunes, or blowout areas behind primary dunes in a sand/cobble/shell substrate and often near sparse vegetation (USFWS 1996). 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). 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). Although a chick may be unable to access this highly desirable foraging habitat, adult piping plovers can fly to these areas throughout the nesting season. Flights to and from foraging habitat through areas of human development can pose a potential risk if turbines are erected in these areas.

Upon arrival at the nesting areas, males begin to establish territories through aerial displays, horizontal threat displays, and parallel run displays which help in the formation of rough territorial boundaries (Cairns 1982). Aerial displays can be performed for long periods of time (up to 30 minutes) and can occur at heights up to 30 m (Cairns 1982). These flights have the potential to cross into areas of human development or sites that are attractive for turbine construction such as dune fields. 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 ranged between 0.00 – 1.05 nesting pairs/ha of potential nesting habitat. The high degree of territoriality during the breeding season may limit the number of individuals using any one flight path through a possible turbine construction site; however, pairs nesting proximal to one another may place more than one pair at risk during a breeding season.

While males continue to establish and maintain territories in early spring, pair-bonds begin to form between males and females. Males perform courtship displays that include nest-cup scraping, tilt displays, and copulation (Cairns 1982). The courtship period can last several weeks prior to a female choosing a nest cup for egg laying (Cairns 1982). Females continue to lay one egg every other day until the clutch is complete (Wilcox 1959, USFWS 1996). In Nova Scotia, the egg-laying period lasts between 5 – 6 days (Cairns 1982) and between 4 – 8 days in Manitoba (Haig 1988). Males and females share incubation responsibilities equally (Wilcox 1959, Cairns 1982). Nests hatched between 27 – 28 days in Nova Scotia (Cairns 1982), 22 – 31 days in Manitoba (Haig 1988), and 27 – 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 meaning that upon hatching, they are covered with down and are able to leave the nest within a few hours to begin foraging under close supervision by their parents (USFWS 1996). This parental care strategy requires eggs that are loaded with high amounts of energy 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 their normal weight by day 12 are less likely to survive than heavier chicks (Cairns 1982). Although piping plover chicks are able to forage without the help of their parents, one or both of the 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).

Causes of Decline of the Piping Plover and Continued Threats

Major causes of decline and continued threats to the recovery of the Atlantic coast piping plover population include degradation of breeding and foraging habitat, anthropogenic disturbances, and increased rates of predation compared to pre-settlement times (Wilcox 1959, Burger 1994, USFWS 1996). Collisions with wind turbines or avoidance of habitat associated with them represent a potential additive stressor to these threats. Piping plovers are highly dependent on dynamic beach habitats for successful breeding; they tend to nest in open, sandy, sparsely vegetated sites, preferring areas which have been recently disturbed by storms. 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). Conversely, beach stabilization processes often lead to increased rates of habitat degradation and increased human development along the coast 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 2009).

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 ever more 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 1990). In 2010, the reported number of piping plovers nesting at Sandy Neck Beach was 38 pairs (Melvin 2010), representing a 660 percent increase in the number of pairs breeding at Sandy Neck Beach, Barnstable, MA. Melvin et al. (1994) also found that despite intensive management efforts to protect piping plovers from vehicles, nine of 18 chicks were killed where vehicle passes were less than 20 passes per day. Off-road vehicles have been shown to cause significant changes in beach-dune morphology (Houser et al. 2013), and 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 lowering wrack abundance and tend to kill other beach dwelling invertebrates (Steinbeck and Ginsberg 2003), 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 habitat 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 mudflat foraging habitat 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. If wind turbines are placed in areas that are adjacent to high quality foraging habitat which is free of human disturbance, further loss of habitat due to anthropogenic activity may occur.

Increased rates of predation have contributed to the decline of the population and continue to threaten recovery efforts. Predators of Atlantic coast piping plover eggs and chicks 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 sp.*), 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). Predator types and abundances tend to vary by location. 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 and predation by red fox (Hoopes 1996a, Hoopes 1996b). 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). Annual survival of crows has been positively associated with human development (Marzluff 2006), demonstrating that predators often respond favorably to human activity whereas piping plovers suffer the consequences of increased predator presence and increased rates of predation.

Management Strategies for Piping Plover Recovery

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 identify limiting factors of 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, predator 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. The effort involved in piping plover recovery has not been trivial: 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). Assessing potential impacts to the species that may hamper recovery is an important tool for sustaining recovery success gained through protection and management. The ESA provides regulatory mechanisms to assess the potential impacts of wind turbines on piping plovers before they are built.

Assessing Risk of Turbine Collision for Piping Plovers

High bird mortality rates have been observed at several wind farms such as the Altamont Pass Wind Resource Area in California, yet other sites have observed little to no bird mortalities. Providing renewable energy is an important and valuable step towards energy sustainability; however, assessing the potential impacts to wildlife such as habitat loss and mortality prior to placement can help in minimizing the overall effects. The Scottish Natural Heritage Program Collision Risk Model (CRM) was developed to help assess the impact of wind turbines on birds by estimating collision risk in the absence of avoidance behavior (SNHP 2000). The model is intended to estimate the number of birds colliding with wind turbines per year by first estimating the total number of birds flying through the rotor-swept zone, calculating the probability of a bird being struck when flying through the rotor-swept zone, and then multiplying the total number at risk by the probability of being struck (SNHP 2000). The number of birds flying through the rotor-swept zone can be calculated assuming two different scenarios: 1) a bird population makes regular flights through the wind farm, possibly in a reasonably defined direction or 2) birds occupy a recognized territory and some understanding of the distribution of flights within their territory is known (SNH 2000). The number of birds flying through the rotor-swept zone and the probability of collision depend on the size of the bird species, the flight behavior, and the specifications of the rotor (SNHP 2000). Due to their highly territorial nature, piping plover flights through a specified area are known for individuals. If a piping plover were to be struck by a wind turbine, it must be assumed that the individual were replaced by a new individual at that nesting site. Additionally, this model assumes no avoidance behavior by individuals, despite some research indicating that a bird will likely alter its flight path to avoid a wind turbine (SNHP 2000). Assessing avoidance behavior is difficult, and data are limited. Even without adjusting for avoidance and the assumption of replacement of individuals, this model provides a valuable baseline assessment to help to identify sites that would be inappropriate for single-turbine projects or wind farm development at or near piping plover breeding areas.

Wind energy development is rapidly increasing and a number of studies have aimed to assess the impacts to wildlife due to wind power development. Estimates of bird mortalities from collisions with wind turbines range between 0 to 40 deaths per turbine per year (Sovacool 2009), and some species are known to be more vulnerable to collision risk than others. Watts (2010) estimated limits for sustainable mortality varied dramatically between species from more than 100,000 individuals per year for Leach’s storm petrel (*Oceanodroma leucorhoa*) to less than 50 individuals per year for marbled godwit (*Limosa fedoa*). This study specifically made note that the Atlantic coast piping plover population was among the least able to sustain mortality due to collisions with wind turbines, estimating a potential biological removal of 61 individuals (Watts 2010).

Flight Behavior Study Objectives

Most collision risk assessments for avian species have focused on migrants (Desholm 2009, Mabee et al. 2006, Watts 2010). Because it is assumed that new birds are using the space throughout the course of a migration period, quantifying the numbers of birds using a designated area is a sufficient and accurate way of calculating the numbers of birds that may be struck by wind turbines annually. However, due to their territorial nature, it is important to understand how piping plover flight behavior is defined within an area and how frequently inter-territorial movements occur. This allows us to quantify the number of birds that may be at risk, given that a turbine is erected within a designated area of a breeding site. Our study has aimed to examine flight paths and flight frequency of breeding piping plovers within their nesting and foraging territories, focusing on how each individual uses the space within their territory and within a site.

Assessing collision risk also requires knowledge of species flight speed and flight height. Many studies examining these two flight characteristics use methods such as radar and thermal imaging to determine height and speed of passing migrants (Gauthreaux and Livingston 2006, Mabee et al. 2006, Larkin and Thompson 1980). These studies do not tend to focus on a single species of interest and often categorize birds into passerines and non-passerines, and radar beams are typically fixed to a given area where flights are known to occur on a regular basis. Additionally, flight altitude of migrants is known to be much higher than for resident species, making radar an ideal method for this type of assessment. However, because our study focuses solely on piping plovers and flights are thought to be unpredictable and occur at much lower altitudes these methods are not ideal. Our study has aimed at developing new methodologies to collect accurate information on flight speed and flight height which can be used in the CRM for estimating the potential number of birds killed at piping plover breeding beaches if wind turbines were to be installed.

Estimation of population parameters such as reproductive success and survival are not always addressed prior to construction of wind farms. Assessing collision risk allows quantification of population-level effects of building new turbines, but this assessment is only meaningful when population parameters are known prior to construction. Our study has aimed at examining weekly survival rates of breeding piping plovers during different phases of the breeding cycle. Furthermore, we have examined the amount of time piping plover spend at their nest during both day and night, to help determine activity patterns that might lead to increased collision risk.

Unfortunately, construction of even a single turbine on any landscape will likely result in collision-related bird mortalities; however, evaluating ways to minimize exposure is a key to reducing impacts of bird collisions. Our goal is to quantify the flight behaviors of nesting piping plovers in order to provide a better understanding of how wind power development may impact the species' continued recovery, prior to turbine construction.

CHAPTER 2. USING A COLLISION RISK MODEL TO ASSESS POTENTIAL IMPACTS TO PIPING PLOVERS ALONG THE ATLANTIC COAST

Abstract

Collision with wind turbines is an increasing conservation concern for migratory birds that are already facing many threats. Existing collision risk models take into account parameters of the wind turbines and bird flight behavior in order to estimate collision probability and mortality rate. We studied flight characteristics and flight behavior of a threatened shorebird, the piping plover (*Charadrius melodus*), at six study sites along the Atlantic coast of the United States. We used an existing collision risk model to predict the number of piping plovers potentially killed per year at each site given flight parameters and varying wind turbine specifications. Average measured flight height with an optical range finder was 2.62 m ± 0.60 SE. Average visually estimated flight height for breeding piping plovers was 2.59 m ± 0.08. Average calculated flight speed was 9.30 m/s ± 0.53 (n = 17). The center points of flight paths were clustered by breeding pair (MRPP, $P < 0.05$ all years and all sites). The best-fitting model for diurnal flight frequency contained an interaction between breeding status and tidal stage and an interaction between site and temperature (Negative Binomial Regression, AIC_c weight = 0.821). We inferred several flights at night using radio-telemetry but were unable to precisely quantify flight frequencies at night, so we corrected our flight frequency to include night flights using existing literature from the Great Plains. Using these flight data, we predicted that the total number of piping plovers killed per breeding season (adjusted for 98 percent avoidance) could range among sites from 0.01 to 0.29 for a small-scale residential turbine, 0.03 to 0.99 for a medium-sized turbine, and 0.06 to 2.27 with a large, utility-style turbine. A proliferation of proposals for single-turbine wind projects on U.S. Atlantic beaches where piping plovers nest poses a potential threat to this species. Our techniques provide inexpensive, replicable procedures for estimating collision risk parameters where the focus is discrete nesting areas with predictable flight paths.

Key words: *Charadrius melodus*, collision risk, flight behavior, Massachusetts, New Jersey, piping plover, wind power, wind turbine

Conservation of migratory birds relies on managing factors that limit survival and reproduction during all phases of the annual cycle (Newton 2013). Wildlife managers are increasingly faced with human-wildlife conflicts and are forced with making decisions that provide benefits to humans and minimize impacts to wildlife. Additionally, anthropogenic activities often favor species that are adapted to human conditions leading to negative impacts on species less suited to human activities. In human altered landscapes, wildlife may have to contend with novel threats such as anthropogenic structures, human commensal predators and pest outbreaks that degrade habitat (Cooper and Day 1998, Marzluff and Netherlin 2006, Raffa et al. 2008). New threats introduced by humans to bird populations pose unknown risks and could counteract past successes of protection and recovery. Evaluating the effect of a treatment, such as the building of new roads or the application of pesticides, is a necessary step in the decision-making process for whether or not these actions are worth the potential risks posed to wildlife.

Wind energy is a rapidly growing industry and in many places turbines have been deployed before risk assessments have taken place. However, since the industry is still in its nascent stages it is not too late to properly evaluate the consequences of wind development to wildlife. The U.S. Department of Energy has stated that it is possible to achieve 20 percent wind energy in the United States by 2030 (Musial and Ram 2010), yet the total on-shore installed wind power capacity for 2013 was reported at 61,108 MW, which was less than 1.5% of the total production throughout the year (US Department of Energy 2014). However, the National Renewable Energy Laboratory has indicated that the offshore wind power potential for the U.S. is estimated in excess of 1,071,200 MW in waters less than 30 m deep (Musial and Ram 2010). Wind power offers a promising renewable energy source posing negligible operational costs, requiring a very small physical footprint, and producing no greenhouse gases or water pollution. For this reason, wind energy may become a significant component of the United States energy portfolio and evaluating ways to minimize turbine exposure to wildlife is a key to reducing environmental impacts.

Avian mortality events at wind turbines due to collision with turbine blades have been a major focus of impact assessments to wildlife populations. At three wind farms in the Netherlands comprising a total of 25 wind turbines, Krijgsveld et al. (2009) estimated that the collision rate at each turbine was 0.08 birds per day. At the Altamont Pass Wind Resource Area in California, USA, a study area including 4,074 wind turbines, Smallwood and Thelander (2008), estimated a total of 2,710 bird deaths per year (7.42 per day). During a 1995 study at the Buffalo Ridge Wind Resource Area in Minnesota, USA, the estimated number of collision related mortalities was 36 birds at 73 turbines during the entire 12 month period (0.10 per day) (Osborn et al. 2000). Thus, the numbers of estimated collisions with wind turbines can vary greatly between study areas; habitat configuration, numbers and spacing of turbines, and morphological and behavioral characteristics of birds all might contribute to population-level impacts on a particular species. Shaub (2012) demonstrated using a discrete-time, individual-based simulation model that local nesting Swiss red kite (*Milvus milvus*) population growth rates decreased as the number of turbines increased and the spacing of the turbines on the landscape increased. In the absence of turbines, the simulated Swiss red kite population increased annually by 5.2 percent (Shaub 2012). These studies indicate that the placement and configuration of wind turbines are a crucial part of the planning process in order to minimize impacts to wildlife.

Wind turbines have the potential to cause both individual mortalities and potentially inflict population-level consequences, depending on placement. Wildlife management agencies need to understand potential population-level consequences of turbine collisions to evaluate the effects of proposed turbines on endangered species. A population viability analysis that was conducted by Melvin and Gibbs indicated that the federally-threatened Atlantic Coast population of piping plovers is highly sensitive to changes in productivity, hatch year survival, and adult survival (Melvin and Gibbs 1994). The Atlantic coast population was listed as threatened under the U.S. Endangered Species Act (ESA) in 1986. Factors contributing to the species decline include coastal development as well as loss of eggs and young by avian and mammalian predators and anthropogenic disturbance (USFWS 1996). Since listing, the population has recovered from 790 pairs to an estimated 1898 pairs in 2012 (USFWS 2012). The primary purpose of the ESA is to provide a framework for planning species recovery by identifying and minimizing threats that are likely to jeopardize recovery and long-term persistence of species at risk. Wind power development in breeding areas represents a novel threat to piping plovers and should be evaluated.

There are increasing numbers of proposals to build small wind farms or single turbines in coastal areas that may contain piping plover habitat (Diffendorfer 2014). A clear understanding of natural patterns of space use, movements, flight characteristics, and behavior under different environmental conditions may allow for the use of existing collision risk models and construction of population viability models before structures are permanently placed at or near breeding habitat. The goal of our research was to determine flight characteristics of breeding piping plovers that are required by existing collision risk models (SNH 2000) and to use those models to assess the collision risk for piping plovers under different hypothetical turbine scenarios on the Atlantic Coast (SNH 2000). We hypothesized that: 1) flight frequency would be affected by habitat configuration causing a higher number of collisions/yr at study sites where bayside foraging and oceanside nesting habitats were separate, yet accessible through flight, 2) flight paths would be clustered by territory and that pairs whose territories contained a wind turbine would be at risk of collision, 3) flight frequency is affected by weather variables such as wind speed and temperature, 4) flight frequency is affected by breeding status, and 5) flight frequency differs among tidal stages. Our objectives were to: 1) estimate diurnal and nocturnal flight frequencies at sites with different configurations of nesting and foraging habitat, 2) estimate flight heights and speeds, 3) determine probabilities of object avoidance during flight, and 4) predict the number of piping plovers killed per year using the Scottish Natural Heritage Collision Risk Model (SNH 2000) based on various turbine configurations.

Studies that have examined avian flight height and flight speed use methods such as radar and thermal imaging to determine height and speed of passing migrants (Gauthreaux and Livingston 2006, Mabee et al. 2006, Larkin and Thompson 1980). These methods cannot identify a single species of interest and often categorize birds into passerines and non-passerines, and radar beams are typically fixed to a given area where flights are known to occur on a regular basis. Additionally, flight altitude of migrants is known to be much higher than for resident species, making a radar feasible method of determining flight altitude for migration studies; however, because our study focuses solely on piping plovers and flights are thought to be unpredictable and occur at very low altitudes, radar and thermal imaging would not allow us to meet our objectives. We tested novel methodologies in order to collect accurate information on flight speed and flight height which can be used in the collision risk model (CRM) for predicting the potential number of birds killed at piping plover breeding beaches if wind turbines were to be installed. Our results will provide new information on ecological correlates that affect movement and space use by nesting shorebirds during the breeding season and will inform permitting decisions for turbines in piping plover habitat.

METHODS

Study Areas

Five study sites were selected for the 2012 field season, and a sixth study site was added in 2013. Three study sites were located in southern New Jersey: Avalon-Dunes, Avalon, Stone Harbor Point, Stone Harbor and in 2013, Strathmere Natural Area, Strathmere; three study sites were located on Cape Cod, Massachusetts: Spring Hill Beach, Sandwich; Chapin Beach, Dennis; and Dead Neck/Sampson's Island, Barnstable (Fig. 2.1). Chamberlain et al. (2006) suggested that data for the collision risk model should be derived from localities as similar as possible to the locations under consideration, and bird collision probabilities have been shown to depend on topographic features (de Lucas et al. 2008). Therefore, study sites were chosen to represent a variety of habitat configurations that consisted of differing arrangements of nesting habitat that may or may not be contiguous with desirable foraging habitat. We also gave consideration to sites that have historically supported samples sizes of at least 5 breeding pairs of piping plovers to obtain a sample size big enough for statistical inferences.

Avalon-Dunes, Avalon, New Jersey (N 39.079176, W -74.732010) was located in the southern part of the state on the northern portion of a barrier island along the Atlantic Ocean called Seven Mile Island. The site consisted of sparsely vegetated areas and open, sandy areas on the berm of the beach below the well-developed dune system, which provided suitable nesting habitat for piping plovers. Foraging areas contiguous with nesting habitat for both adults and chicks were limited to the ocean side intertidal zone and wrack line given that access to bayside foraging was obstructed by coastal development. The site experienced relatively moderate levels of anthropogenic disturbance from beach visitors; however, off-road vehicle use and dogs were not permitted.

Stone Harbor Point, Stone Harbor, New Jersey (N 39.028307, W -74.777536) was located at the southern-most end of Seven Mile Island at the Hereford Inlet. The site consisted of low-lying, open sand and cobble areas and sparsely vegetated dunes, which provided suitable nesting habitat for piping plovers. Ample bayside and oceanside foraging existed and corridors between bayside and oceanside have been maintained by frequent washover events that occur during strong storms and monthly high tides allowing for nesting and foraging habitat to remain contiguous. An additional foraging area for piping plovers had been created on the northern end of the site and included an artificial pond (former contained dredge facility) that was tidally influenced. The site experienced relatively low levels of anthropogenic disturbance from beach visitors (pedestrians and boat traffic), and off-road vehicles and dogs were not permitted.

Strathmere Natural Area, Strathmere, New Jersey (N 39.202334, W -74.651514) was located on the northern portion a barrier island known as Ludlam Island at Corson's Inlet. The site consisted of sparsely vegetated areas and open, sandy areas on the berm of the beach below the dune, which provided 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 experienced high levels of anthropogenic disturbances from beach visitors; however, off-road vehicle use and dogs were not permitted.

Spring Hill Beach (N 41.762756, W -70.477318) was located on Cape Cod Bay, on the north side of Cape Cod in Sandwich, MA. The site contained a barrier spit with a rocky/cobble/sand-mixed beach on the north side and an extensive marsh system on the south side. The areas of the study site extending 0.88 km east of the tip of the barrier spit were free of coastal development, and private homes were distributed within the dune system for the remaining 1.2 km. The nesting habitat was varied, including sparsely vegetated, sandy areas below the toe of the dune, open cobble areas on the berm of the beach, and sparsely-vegetated and open washover areas to the west. Bayside foraging access for chicks was obstructed by coastal development to the east; however, adults could easily access this foraging habitat through flight. The bay side was easily accessible to the west through washover corridors by both adults and chicks. Human access to the site was restricted to private property owners and their renters; therefore, the site experienced relatively low levels of anthropogenic disturbance.

Chapin Beach (N 41.72780, W -70.23870) was located on Cape Cod Bay on Cape Cod in Dennis, MA. The site contained a barrier spit free of coastal development that extended southwest toward Barnstable Harbor. Open sandy areas and sparsely vegetated dunes provided nesting habitat for piping plovers. Ample bayside and oceanside foraging areas existed, and corridors between the bayside and oceanside were maintained by frequent washover events that occurred during strong storms and monthly high tides. Due to extreme tidal fluctuations, additional foraging areas for piping plovers included the extensive sand flats exposed at low tide both on the ocean side and bay side, where flight was required for accessibility. The site experienced high levels of anthropogenic disturbance prior to nest hatching, primarily due to off-road vehicle traffic. A single wind turbine was proposed at this site for the Aquacultural Resource Center which was located on the bay side, behind the dune system.

Dead Neck/Sampson’s Island (N 41.60627, W -70.42130) is located on Nantucket Sound, on the south side of Cape Cod in Barnstable, MA. This site was constructed primarily of dredge materials, which had been deposited at both the east and west ends of the island. Our study occurred on the east end (Dead Neck) due to ease of access and concentrations of nesting birds in 2012; however, the banding and research efforts were extended in the 2013 field season to include the west end (Sampson's Island). A variety of nesting habitats existed on the island: sparsely vegetated, sandy areas below the toe of the dune occurred towards the center of the island and open cobble areas and sparsely-vegetated areas became more frequent to the east where the dredge materials had been deposited. Foraging habitats included the intertidal zone on the bayside and large accumulations of wrack that occurred on the oceanside. Additionally, a tidally fed pond served as foraging habitat for piping plovers nesting towards the center of the island. Flight was required over the dredge materials for access to either side of the island. This site experienced high levels of anthropogenic disturbance, entirely due to recreational boating.

Field and Analytical Methods

We uniquely marked piping plovers with leg bands and attached radio transmitters to a subsample in order to obtain individual-specific data on flight paths and flight characteristics. We captured adult plovers on their nests using walk-in funnel traps (Cairns 1977), and chicks were captured by hand near fledging (>20 days old). We marked adults and chicks individually using colored Darvic bands (yellow, dark green, dark blue, light blue, black, gray, red, or orange). At study sites in Massachusetts, each marked individual received a single color-band on each upper leg. At study sites in New Jersey, each individual was marked with two color-bands on each upper leg. In addition to color-banding, we fitted a subset of females and fledglings with radio transmitters prior to release. Furthermore, we weighed each bird and measured the culmen, tarsus, and wing chord.

We fixed radio transmitters to the intrascapular region of both adult females and fledglings. Methods of tag application to adult females evolved throughout the course of the 2012 field season as we attempted to improve retention time of radio transmitters. From 11 May 2012 to 15 May 2012, we plucked a small patch of feathers in the intrascapular region to expose the skin of the bird, applied cyanoacrylate superglue to the transmitter, glued the transmitter directly to the skin of the bird, and then held the transmitter in place for 1 min to 2 min prior to release of the bird. Between 23 May 2012 and 28 May 2012, we used two different methods for applying radio transmitters. The first method employed Osto-bond (Montreal Ostomy, Quebec, Canada) medical glue, which has been formulated for the attachment of medical devices to human skin. The Osto-bond glue was applied in the same manner as previously stated; however, this glue required a longer drying time, and we placed the birds in a soft-shelled holding cage for 5 min prior to release. For the second method, we clipped feathers down to 1 mm to 2 mm of stubble in the intrascapular region using fingernail scissors (no feathers were plucked), and applied the transmitter to the stubble using cyanoacrylate superglue (Gorilla Glue Super Glue, Cincinnati, OH). We held the transmitter in place for 60 s to 90 s until the glue was firm, and then the adult was placed into a soft-shelled holding cage to allow the glue to dry further. Radio transmitters were applied to all fledglings by spreading the feathers to reveal a patch of skin and attempting to glue directly to the skin and feather bases. Only cyanoacrylate superglue was used to affix radio transmitters to fledglings, and no feathers were clipped or plucked from fledgling piping plovers. For transmitter attachment during the 2013 field season, we employed the "clipping" method which proved to be the method with the longest retention times for 2012.

To determine diurnal flight frequency, we conducted two-hour behavioral observations (2012) and one-hour behavioral observations (2013) of color-banded and radio-tagged piping plovers. Behavioral observation periods were reduced in 2013 to allow more time for other research objectives. Prior to each field day, we randomly selected the individual to be observed, without replacement. Once all individuals had been observed, we replaced them into the sampling pool and started over. We located and identified color-banded birds at each site using a

60x spotting scope and radio telemetry equipment, if applicable. Behavioral observations were conducted between the hours of 06:00 and 20:00 from 15 March to 15 August. During each observation, we recorded the start and end time and identified each flight that we observed by an individual during that period. If a bird flew or walked out of view during an observation period, we used a stopwatch to record the amount of time that the bird was not visible to the observer. This time out of view was subtracted from the total time of the observation period to determine the observation duration, allowing us to compute the number of flights per hour. If a bird flew or walked out of view during an observation period, we attempted to find the bird using radio-telemetry or by following the visual path of the flight. We divided all observations into low-falling, mid-falling, high-falling, low-rising, mid-rising, and high-rising tidal stages, each 2.2 h in length. Prior to beginning each observation, we recorded weather variables such as wind speed and temperature with wind chill using a Kestrel 2000 Pocket Wind and Temperature Meter (Kestrel, Downingtown, PA) in addition to the wind direction, percent cloud cover, visibility, and tidal stage.

Once flight paths had been verified during telemetry follows, we attempted to determine flight behavior during periods of poor weather (i.e. dense fog) and at night. We used radio telemetry to determine movements by recording the observer location using a GPS unit, start time of the movement, bearing to the start point of the movement, and bearing to the end point of the movement. We categorized movements into unknown or confirmed flights by the strength of the signal and length/speed of the movement (Sitters et al. 2001). If the signal strength and the directionality of the signal changed quickly, we considered the movement to be a confirmed flight; however, if only the strength of the signal changed and the directionality of the signal remained the same, this could indicate that the bird flew away from us or that the bird simply changed its orientation relative to the receiving antenna. These movements were classified as unknown movements. If a bird flew or walked out of range during an observation period, we used a stop watch to record the amount of time that the signal was not present. This time out of range was subtracted from the total time of the observation period to determine the duration of the observation period, allowing us to compute the number of flights per hour.

We modeled the number of diurnal, non-courtship flights per hour (hereafter flights/h) using negative binomial mixed regression (Hilbe 2011) with bird as a random effect using SAS statistical software (SAS Institute, Cary, NC) and the log of the total observation time as an offset (Kéry 2010). Negative binomial regression is an extension to Poisson regression. The mean and variance of the Poisson probability density function are equal (Hilbe 2011); however, the negative binomial model is used in a situation where counts exhibit over-dispersion relative to the Poisson model, with a variance that is much larger than the mean (Rodriguez 2013). We chose negative binomial regression to accommodate the excess variation in the counts of the number of flights per hour. We chose to place emphasis on non-courtship flights because although courtship flights may reach heights of ≥ 10 m, these flights also tend to last several seconds to several minutes flying over many different habitats types, and the start and end point do not allow for an accurate flight path to be drawn; therefore, we used non-courtships in our all of our analyses.

In addition to estimating the total number of non-courtship flights per hour, we also estimated the number of diurnal, non-courtship flights through the ‘risk window’ at each study site for use in the collision risk model. We modeled the number of flights ≥ 10 m altitude through the interior of each study site per hour (hereafter flights/h through the risk window) using negative binomial regression with site as a fixed effect. From field observations and flight path maps, we found that most flights < 10 m likely did not traverse the interior of the study site; however, flights ≥10 m high likely completed a crossing from the ocean side to the bay side over the interior. Emphasis was placed on only flights that occurred through the risk window for each study site, as required by the collision risk model. We defined the interior of each study site by established dune systems and human development and assumed these were the most likely areas where turbines would be placed.

We tested models of flight frequency that included combinations of breeding status, year, tidal stage, wind speed, wind direction, air temperature, cloud over, and interactions among them. We ranked the models based on Akaike's Information Criterion adjusted for small sample size (AIC_c) and selected the best model based on the lowest AIC_c value (Burnham and Anderson 2002). AIC_c is a measure used to aid in the selection of the best fitting model that uses the fewest possible parameters to fit the data (Burnham and Anderson 2002). We considered all models with a likelihood of <0.125 to have some support, and if there were several, we calculated model-averaged predicted values for the whole model set (Burnham and Anderson 2002).

During a behavioral observation we estimated the start and end point of each flight path if possible. To calculate start and end points, we recorded the latitude and longitude of the observer using a GPS unit, we estimated the distance from the observer to the bird at the start point of the flight, recorded the bearing to the bird at the start point of the flight (using a compass), estimated the distance from the observer to the bird at the end point of the flight, and recorded the bearing to the bird at the end point of the flight. If we were unable to ascertain the point where the bird landed or the flight began, the distance and bearing to the vanishing point were recorded. Piping plover flight paths were uploaded into ArcGIS ArcMap 10.1 (ESRI, Redlands, CA) to create maps for each study area displaying the flight paths for each individual during the breeding season. Additionally, the center points for each flight path were calculated using the Feature Vertices to Points tool. We used Multi-Response Permutation Procedure (MRPP) in Blossom Statistical Software (Cade and Richards 2005) to determine whether center points of flight paths were random with respect to individual bird. 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 and Grace 2002). In contrast to MANOVA, MRPP does not require distributional assumptions such as normality or homogeneity of variances (McCune and Grace 2002). MRPP calculates the mean distance within each group and generates a weighted mean of the distances (McCune and Grace 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 and Grace 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 and Grace 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 and Grace 2002).

Observer bias can affect visually-estimated flight heights of birds. Laser-based rangefinders are not useful for acquiring data from fast-moving targets going short distances, such as piping plovers commuting from nesting to foraging sites. We therefore developed a new method to more accurately determine flight altitude than traditional methods (Furness et al. 2013, Garthe and Hüppop 2004, Garthe et al. 2014), using an optical range-finding reticle. We mounted a rifle scope with an optical range-finding reticle to a gun stock and attached a point-and-shoot camera with video capabilities (Canon Power Shot SX230HS, Melville, New York) to the viewing end of the rifle scope. We also mounted a digital inclinometer to the left side of the gun stock with screws. To determine flight height, the rifle scope was pointed at flying piping plovers, and when a bird crossed through the reticle, the angle (θ) to the flying bird from the observer was recorded using the "hold" button on the inclinometer. Using a still image of the bird flying through the reticle captured from the video, the wingspan or head-to-tail length of the bird (l), and the known calibration of the reticle bars at 10x magnification (one minute of angle [MOA] = 0.0254 m at 34.38 m), the distance (r) from the observer to the bird was calculated (Equation 1).

$$r = \left(\frac{l}{MOAs}\right) * 34.38 \qquad [1]$$

We were then able to calculate flight height using the distance of the bird (r) from the observer, the angle of the bird from the observer (θ), and the observer's eye height (h) (Equation 2).

$$bird\ height = \mathrm{r} * \sin(\theta) - h \qquad [2]$$

If the land surface elevation differed between the bird's flight path and the observer's location, we used the inclinometer and stakes to measure and correct for the elevation difference. In addition to calculating flight height with the rifle scope, the observer visually estimated the flight height of the bird as it was passing through the reticle (Fig. 2.2). We made several measurements prior to the field season of known objects and calculated their heights during 2012 to test the accuracy of the rifle scope calculations and found this method to be accurate to within one meter.

Flight height also was visually estimated during diurnal behavioral observations. After we determined that the rifle scope was an accurate way of estimating heights of stationary objects, we continued to use this method to calibrate observer estimates in the field. We first visually estimated the heights and distances of objects such as small buildings, trees, outdoor staircases, and road signs. We then measured the distances and heights small objects using a tape measure to determine the precise height of the object. For heights of taller objects, we aimed the rifle scope at the top of the object and recorded the angle to the top using the attached tilt-meter, then we aimed the rifle scope at the bottom of the object and recorded the angle to the base, and we measured the distance from the observer to the object. The height of the object was calculated by adding the tangent of the angle to the top (θ_1) and base (θ_2) then multiplying by the distance (r) from the observer (Equation 3):

$$object\ height\ =\ r * (tan(\theta_1) + tan(\theta_2)) \qquad [3]$$

We compared our visually estimated heights to the actual heights to determine the accuracy of each of the observers. This proved to be a valuable way of allowing us to practice estimating distances and heights of objects in order to provide more accurate visual estimates during behavioral observations of piping plovers, which were easier to collect than range-finder estimates.

We estimated the average flight speed of piping plovers commuting to and from foraging areas. Flight speed trials were conducted at sites where flight paths had been observed during behavioral observations. Two metal posts were placed 8 m to10 m apart (d = interpost distance) along the length of a commonly-used flight path. A video camera set at 24 frames per second was used to record the flight between the two metal posts. The camera was placed at a 90-degree angle to the left post. The angle from the video camera to the right hand post was measured using a protractor (θ_1). When a piping plover flew past the two posts, a human recorder at the camera recorded the side of the filming zone that the bird entered from (right or left). A second human referee, sitting in line with the two posts on the right side of the setup, recorded where the bird entered the filming zone in relation to the posts (right, left, or centered directly over the posts), where the bird exited the filming zone (left, right, or center), the angle of the flight in relation to the posts using a protractor (θ_2), and the distance (a) from the right post where the bird passed the filming zone. We used trigonometry to calculate the distance traversed by the bird as perceived by the camera (Fig. 2.3, Appendix A). For example, if a bird were to enter the filming zone on the right side, fly parallel to the post line, and to the left of the referee, we could calculate the camera's perceived distance as:

$$r = d - (a * \tan\theta_2 * \sin(90 + \theta_2)) \,/\, \sin(90 - \theta_2) \qquad [4]$$

We analyzed videos of flights frame by frame to determine the passage of time between the stakes. We calculated flight speed (S) as:

$$S = (r * f)/F \quad \text{, where} \qquad [5]$$

r = the distance traveled,

f = frames per second,

F = number of frames.

During 2012 behavioral observations, we identified typical flight paths and crossing areas of piping plovers, and we targeted these areas for object avoidance experiments. Experiments were conducted at each site, in areas where crossings seemed to occur most frequently. Two crossing sites (30-m plots) were identified at a site, separated by at least 100 m, and one observer was stationed at each plot. We recorded all flights or walk-through activity by piping plovers within the 30-m plot for a 2-h period. At the end of the observation, one plot received a treatment of a 1.8-m diameter helium balloon attached to a 40-m flagged tether, which was anchored so that the balloon stood in the center of the experimental plot. The second plot received no treatment. We recorded the flight and walk-through activity at each plot, as well as behavioral modifications observed within the balloon plot (list of choices), for a second 2-h observation period. At the end of the observation period, the balloon experiment was repeated in the second plot, while the first plot went untreated. Again, we recorded the flight and walk-through activity at each plot, as well as behavioral modifications made within the balloon plot, for a second 2-h observation period. We determined the identity of individual birds where possible.

Due to unexpected logistical difficulties and negative reactions of some birds to the balloon's presence in their territory, this protocol did not yield data suitable for analysis. We found that deployment of the balloon required maximum wind speeds to be ≤ 8.04 km/h for the balloon to remain relatively upright. Wind speeds ≥ 8.04 km/h led to instability of the balloon, which caused unnecessary disturbances to both piping plovers and other beach nesting birds within the area around the base of the balloon. Wind speed ≥ 16.09 km/h were impossible to keep the balloon stable, and we immediately discontinued the experiment if conditions became unfavorable. These circumstances resulted in planning difficulties and few opportunities for deployment due to the variable nature of weather in coastal environments.

In addition to object avoidance experiments, avoidance behavior was monitored during diurnal behavioral observations. For each flight, we identified whether or not an existing structure (human or natural) fell within the flight path and recorded any changes in the flight behavior of the bird in response to the structure. These structures were stationary objects such as houses, trees, overhead power lines, or symbolic fencing that were within the line of sight of the bird and directly in line with the direction of travel.

In order to calculate the potential bird mortality caused by a wind turbine at or near a piping plover breeding area, we used the Scottish Natural Heritage Program Collision Risk

Model (CRM) (SNH 2000). This methodology assumes a 2-stage process for assessing collision risk. Stage 1 is used to determine the number of birds flying through the rotor swept zone per year and stage 2 is used to calculate the probability that a bird flying through the rotor swept zone will be struck (SNH 2000). By multiplying the calculation results from these two stages together, it is possible to estimate the potential number of birds colliding per year with wind turbines (SNH 2000). This phase of the model assumes no avoiding action by the bird as it approaches a wind turbine and is used prior to construction of the wind farm. Estimates of collisions, therefore, tend to be overestimates because it is likely that birds can avoid collisions under many circumstances. These behavioral changes may be species specific or dependent upon factors such as topography or weather conditions (SNH 2010). An extension of the CRM which incorporates avoidance rates should be used in conjunction with this model post-construction of the wind farm for a more accurate prediction of the number of birds killed per year (SNH 2010).

We identified the interior of a study site, including established dune fields and areas of human development, to be the most probable location for a turbine to be constructed. We calculated the number of transits each pair made through the risk window per breeding season (15 Mar to 15 Aug) during the daytime-only at each site, or bird occupancy, as:

$$n = (f * 12\ hours * 154\ days) * site\ width/t, \text{ where} \qquad [6]$$

n = bird occupancy,

f = flights/h through risk window,

t = transit time (s) of a bird through the rotor = (d + l)/v,

d = depth of the rotors,

l = length of the bird = 0.17 m for piping plovers,

v = flight speed (m/s).

We then calculated the volume swept out by the wind farm rotors as:

$$V_r = N * \pi R^2 * (d + l), \text{ where} \qquad [7]$$

V_r = volume of the rotor-swept zone,

N = number of turbines,

R = radius of the turbines (m).

We calculated the "risk volume window" (V_w) for each study site, which is the potential area of the wind farm multiplied by the height of the potential wind turbines (SNH 2000). Because piping plovers are highly territorial, we identified the areas of the interior of each study site which corresponded to the territory of each pair and defined these areas as the risk window for each pair. We averaged the risk windows for each study site to obtain the average risk window per pair per study site. We estimated these potential risk areas by drawing polygons around each pair's flight paths in ArcGIS using a 30-cm resolution true color digital orthophotos (NJ: scale = 1:2400; MA: scale = 1:5000).

We made simplifying assumptions that any plovers killed within a risk window would be replaced immediately by a new territory holder and the rotors were spinning constantly. We used specifications for the E-3120 (50kW) residential scale turbine made by Endurance Wind Power (Surrey, British Colombia) (30.5 m hub height, 9.6 m rotor radius), the V82 1.65 MW commercial scale wind turbine (Vestas, Denmark) (70 m hub height, 41 m rotor radius), and a hypothetical turbine with a 35 m hub height and 22.5 m rotor radius when calculating V_w and V_r (Table 2.1). We calculated n_r, the number of transits through the rotors during daytime in the breeding season and therefore at risk of collision, as:

$$n_r = n * (\frac{V_r}{V_w})/t \qquad [8]$$

Stage 2 of the CRM calculates the probability of a bird being struck when making a transit through the rotor swept zone (SNH 2000). This calculation depends on the size of the bird (head-to-tail length and wingspan), the flight speed of the bird, and the characteristics of the turbine blades (length, pitch, and rotation speed) (SNH 2000). We calculated the probability of collision for a piping plover given a range of different turbine specifications in order to determine what factors were most important for minimizing collision risk. We varied turbine parameters such as diameter, chord width, rotation period, and pitch angle in the CRM to obtain values for the probability of collision given different turbine specifications (Table 2.2). We then interpolated the probability of collision for turbine dimensions that were not directly tested using the R package ‘akima’ (Akima et al. 2013), and plotted these values to help visualize what turbine parameters may be most important in determining probability of collision.

Due to the complications of modeling a collision event, Stage 2 of the CRM makes several simplifications. The model assumes that 1) a bird is simple, cross-shaped object with the wings at the halfway point between the nose and the tail, 2) the rotor blades have a width and a pitch angle but have no thickness or depth, 3) a bird's flight will be unaffected by a near miss, and 4) bird flight velocity is likely to be the same relative to the ground both upwind and downwind (SNH 2000). Stage 2 of the model derives the probability of collision if a bird is located at a radius (r) from the center of the turbine and at a position along a radial line which is an angle (φ) from the vertical (SNH 2000). Because a bird could enter at any angle and at any radius, it is then necessary to integrate p(r, φ) over all possible entry points of the rotor (SNH 2000). Therefore, the probability of collision for a bird at radius r is defined as:

$$p(r) = (b\Omega/2\pi v)[K|\pm c\sin(\gamma) + \alpha\, c\cos(\gamma)| + \begin{matrix} l\ for\ \alpha < \beta \\ w\alpha F\ for\ \alpha > \beta \end{matrix} \qquad [9]$$

where,

b = number of blades in rotor,

Ω = angular velocity of rotor (radians/sec),

c = chord width of blade,

γ = pitch angle of blade,

l = length of bird = 0.17 m for piping plover

w = wingspan of bird = 0.375 m for piping plover

β = aspect ratio of bird

v = velocity of bird through rotor

r = radius of point of passage of bird

α = v/rΩ

F = 1 for a bird with flapping wings (no dependence on φ)

= (2/π) for a gliding bird

K = 0 for one-dimensional model (rotor with no zero chord width)

= 1 for three-dimensional model (rotor with real chord width)

The sign of the c sin(γ) term depends on whether the flight is upwind (+) or downwind (-).

The SNHP has developed a spreadsheet that calculates p(r) at intervals of 0.05 m from the rotor center, and then undertakes a numerical integration from 0 to the radius of the outer tip of the rotor blades for both a bird flying downwind and upwind (Band 2014). The total risk is then the summation of these contributions for each case (SNH 2000). The result is an average probability of a bird being struck as it passes through a rotor (SNH 2000).

To determine the number of birds killed per year, the two parts of the model are then multiplied together (SNH 2000) (Equation 10).

$$Number\ of\ birds\ killed\ per\ year = n * p(r) \qquad [10]$$

We multiplied our results from Stage 1 using the dimensions for the two actual wind turbines and one hypothetical turbine by our results from Stage 2, given the specifications for the same turbines. We estimated the variance of the number of collisions/yr using the delta method (Larkin 2007). The delta method is a useful technique for estimating variance when it is necessary to combine parameter estimates to indirectly calculate another parameter (Larkin 2007). In this case, we needed to estimate the number of collisions/yr using our estimate for the number of diurnal flights/h through the risk window and also our estimate of flight speed both of which were random variables estimated with error, and we used the delta method to calculate the confidence intervals for the transformed variable.

Sherfy et al. (2012) found that piping plover movements occurred almost exclusively between the hours of 20:00 and 05:00 (n = 113; 86 percent). Their data demonstrated that piping plover nocturnal movement frequency (as determined by detections away from the study site) was at least 2.45 times higher than diurnal movement frequency (See Figure 2, Sherfy et al. 2012). Because our own results for night time flight frequency stemmed from low sample sizes, and we could not assess directionality or height, we modeled total daily flights under the assumption that the number of night time flights relative to number of daytime flights would be the same the number of movements as in Sherfy et al. (2012) and the proportion of those flights through the rotor-swept zone would be the same as by day. To determine daily flight frequency, we therefore multiplied the number of diurnal flights/h through the risk window by 2.45 to estimate flight frequency across a 24-hr period. We used the delta method to calculate the confidence intervals for each site estimate. We then calculated the number of bird transits per breeding season through the rotor swept zone and multiplied that by p(r) for the two actual wind turbines and one hypothetical turbine. We used the delta method to calculate the confidence intervals for the transformed variable.

Although we do not have specific information regarding post-construction turbine collisions, the CRM proposes the use of a default value of 98 percent for bird species with no reported avoidance data (SNH 2010). Additionally, plovers are known to possess excellent visual acuity with the ability to routinely forage during poor light conditions (del Hoyo et al. 2011). We therefore applied the default avoidance rate to the predicted number of collisions per year in order to calculate an adjusted number of collisions per year using the CRM extension.

Based on data for Spring Hill Beach, MA, we predicted the number of collisions/yr given varying heights of wind turbines with a 9.6m radius to demonstrate the effect of raising the wind turbines on the number of collisions/yr. Additionally, we used data from Spring Hill Beach, MA, and interpolated the number of collisions per breeding season for turbine dimensions that were not directly modeled in order to determine the sensitivity of collision risk to particular combinations of turbine specifications.

RESULTS

We trapped and banded 61 piping plovers in the 2012 nesting season at study sites in Massachusetts and New Jersey out of 77 piping plovers estimated to be present, and a total of 30 piping plovers were equipped with radio transmitters. We trapped and banded 37 piping plovers during the 2013 nesting season at study sites in Massachusetts and New Jersey, and a total of 19 piping plovers were equipped with radio transmitters (Table 2.3). Including marked birds that returned from 2012, there were 56 banded plovers in our study areas in 2013 out of 82 piping plovers estimated to be present.

Flight Behavior

We spent 1017 hours conducting diurnal behavioral observation, and 1689 diurnal, non-courtship flights were observed. Of 61 candidate models of diurnal flight frequency, the best-fitting model contained an interaction between breeding status and tidal stage, and an interaction between site and temperature (Negative Binomial Regression, Model likelihood = 1.000, AIC_c weight = 0.821). The second best model, and the only other model to have some support based on our criteria, contained an interaction between breeding status and tidal stage, site and temperature, and tidal stage and wind speed (Negative Binomial Regression, Model likelihood = 0.218, AIC_c weight = 0.179). We used the first model for further analyses.

Flight frequency was greater at Dead Neck/Sampson's Island, MA than at Spring Hill, MA, Stone Harbor, NJ, and Avalon, NJ but not different than Chapin, MA or Strathmere, NJ (Fig. 2.4). The number of flights/hr that occurred during a low-falling tidal stage was greater than the number of flights/hr during high-falling and high-rising tidal stages (Fig. 2.5). Additionally, flight frequency during high-rising tides was lower than during any other tide cycle. Diurnal flight frequency differed among breeding strata (Fig. 2.6). Piping plover adults tending a brood made more than twice as many daytime flights as nesting adults and those without a nest. Flight frequency was highest among adults tending a brood across all tidal stages (Fig 2.7). Flight frequency increased with temperature (Fig. 2.8); however, the magnitude of this increase varied among study sites and no correlation was apparent at Stone Harbor, NJ. Due to low reproductive success in the study region, we were only able to radio-tag 2 chicks in Massachusetts, 2 chicks in New Jersey, and band 9 chicks in Massachusetts and 8 chicks in New Jersey. We conducted 12 behavioral observations of radio-tagged or banded fledglings. We observed 7 flights in total, and all flights were ≤ 5 m on the open beach (none crossing water or through the interior). During the only nocturnal observation of a fledgling, we documented relatively frequent flights but the bird was highly disturbed by a nearby fireworks display so this may not represent typical behavior.

The number of diurnal flights piping plovers made through the risk window varied by study site (Fig. 2.9). Flight frequency through the risk window was highest at Spring Hill Beach, MA and lowest at Strathmere, NJ, although these differences were not significant. There were no flights through the risk window at Strathmere, NJ. All flights at Stone Harbor, NJ were considered to be "through the interior" since the study site comprised a barrier spit and piping plovers used the entire area for nesting and foraging.

Nocturnal flight frequency did not differ among sites when unknown flights were considered and were not considered; however, sample size was very small (Fig 2.10). The number of flights we predicted would be made through the risk window during a 24-hr period, based on the results of Sherfy et al. (2012), also varied by study site and was highest at Spring Hill Beach, MA and lowest at Strathmere, NJ (Fig. 2.11).

We mapped 189 non-courtship flights in 2012 at New Jersey study sites, and 516 non-courtship flights at Massachusetts study sites (Fig. 2.12 – Fig. 2.16). We mapped 392 non-courtship flights in 2013 at New Jersey study sites, and 182 non-courtship flights at Massachusetts study sites (Fig. 2.17 – Fig. 2.22). The center points of flight paths were clustered by territory, indicating that birds tended to commute to foraging areas using pair-specific routes.

Nineteen flights were captured using the rifle scope videography, and flight heights ranged from 0.65 m to 10.49 m (Table 2.4). Visual estimates for piping plovers passing through the reticle ranged from 0.25 m to 10.0 m. Average visually-estimated flight height of piping plovers from 1,066 observed flights during 2012 behavioral observations was 2.63 m, and average visually-estimated flight height of piping plovers from 608 observed flights during 2013 was 2.51 m (Table 2.5). Of the 1,066 flights in 2012, 49.9 percent were less than 1.5 m high (Fig. 2.23), and of the 608 flights observed in 2013, 52.6 percent were less than 1.5 m high (Fig. 2.24).

During the 2012 early season practice sessions (23 April – 10 May), the average error of visual estimation compared to measured heights for Massachusetts observers was 2.6 m and 3.1 m, with ranges for the two observers from -2.8 m to 11.7 m (SE ± 1.68, Interquartile range (IQR): -0.54, 3.65) and 0.2 m to 11.7 m (SE ± 1.39, IQR: 1.24, 3.33), respectively (*n* = 8 trials). Observers tended to overestimate during this period. During the mid- to late season practice sessions (9 June – 23 July), the average error for Massachusetts observers was 0.7 m and 0.2 m with ranges for each observer from -1.7 m to 4.8 m (SE ± 0.38, IQR: -0.14, 1.21) and -2.4 m to 3.0 m (SE ± 0.30, IQR: -0.57, 0.85) (n = 21). Observers also tended to overestimate during this time period. The 2012 average error of visual estimation compared to measured heights for New Jersey observers was 1.47 m and 3.42 m with ranges for each observer from -6.32 m to 10.2 m (SE ± 1.42, IQR: -0.75, 3.50) and -5.32 m to 15.2 m (SE ± 1.89, IQR: 0.12, 4.21). The 2013 average error of visual estimation compared to measured heights for Massachusetts observers was -0.25 m and 0.17 m with ranges for each observer from -4.8 m to 2.3 m (SE ± 0.26, IQR: -0.75, 0.44) and -2 m to 2.77 m (SE ± 0.16, IQR: -0.15, 0.47). The average visual estimation compared to measured heights for New Jersey observers was 0.26 m and 0.24 m with ranges for each observer from -2.1 m to 3.1 m (SE ± 0.12, IQR: -0.1, 0.56) and -2.1 m to 10 m (SE ± 0.21, IQR: -0.2, 0.36).

We video-recorded and analyzed 17 flight paths to determine flight speed. The average flight speed was 9.30 m/s ±1.02 SE (Table 2.6). All flight speed observations were conducted parallel to the waterline, because pathways through the interior of the study sites were difficult to predict.

The results of the object avoidance experiments were inconclusive. The logistical difficulties encountered when planning the execution of this experiment made for few trials. During behavioral observations, we observed piping plovers to occasionally alter their flight path by veering left or right in response to a pre-existing structure (Table 2.7). No collisions of piping plovers with existing structures within their habitat were observed.

Collision Risk

No flights through the risk window were observed at Strathmere, thus, we did not include Strathmere in our estimates for the probability of collision because the estimates would be zero. Using the flight parameters determined in our study and assuming 2.45 times as many night flights as day flights, the Scottish Natural Heritage model predicted that when a single, large turbine (41 m radius) was positioned within a pair's territory, the number of collisions per year ranged from 2.996 to 113.31, with the greatest number of collisions/yr occurring at Spring Hill Beach, MA. This was greater than for a single, medium turbine (22.5 m radius) where the collisions/yr ranged from 1.31 to 49.41, and for a single, small turbine (9.6 m radius) where collisions/yr ranged from 0.39 to 14.63 (Fig. 2.25).

Using the predicted number of collisions per year in a pair's territory from the baseline assessment, we applied a 98 percent avoidance rate. The adjusted predicted number of collisions per year ranged from 0.06 to 2.27 for a single large turbine (41 m radius), 0.03 to 0.99 for a turbine with a 22.5 m radius, and 0.01 to 0.29 for a single, small turbine (9.6 m radius) (Fig. 2.26).

Turbines with a smaller diameter, smaller percent chord width, and slower rotation period yielded a lower probability of collision for a piping plover passing through the rotor swept zone than turbines with a larger diameter, larger percent chord width, and faster rotation period. Diameter and chord width appeared to be the most important specifications for determining the probability of collision (Fig. 2.27a). In general, as diameter and chord width increased, the probability of collision also increased. Rotation periods ≥ 1 s led to a higher probability of collision for a piping plover entering the rotor swept zone than for rotation periods < 1 s (Fig. 2.27b). Wider diameter turbines with a slower rotation period led to a lower probability of collision. Pitch angle of the blades did not serve as an important factor in predicting the probability of collision. With the highest angle of pitch and the largest diameter of turbine, the probability of collision was 0.09; however, a small diameter turbine at any pitch angle had a probability of collision of 0.08 (Fig. 2.27c). The probability of collision appeared to be lowest for a turbine with a 20 m diameter, a 2 s to 4 s rotation period, and a pitch angle between 15 degrees and 20 degrees. The number of collisions/yr adjusted for avoidance at Spring Hill Beach, MA given a wind turbine with a 9.6 m radius and rotor height of 39.5 m was 0.29, and as the height of the wind turbines increased, the number of collisions/yr decreased (Table 2.8).

For a single turbine placed at Spring Hill Beach, MA the number of collisions/yr increased with turbines of a wider diameter and chord width, wider diameter and faster rotation speed, and wider diameter and higher pitch angle. A turbine with a 45 m diameter led to the highest number of collisions per year: 0.21 to 1.46 assuming 98% avoidance depending on the percent chord width (Fig. 2.28a). For large diameter turbines with a rotation period of < 1 s, the number of collisions per year was 1.38; however, the slower the rotation period for any turbine diameter, the fewer the predicted collisions (Fig. 2.28b). For turbines with a large diameter and any pitch angle, the number of collisions per year increased, further suggesting that pitch angle is not an important factor in predicting the number of collisions per year (Fig. 2.28c).

DISCUSSION

Our predictions indicated that large, fast-spinning turbines on a narrow beach where plovers tend make frequent flights between oceanside nesting and bayside foraging habitats could lead to a high number of collisions relative to the size of many local breeding populations. However, our risk assessment is likely a “worst-case” analysis of number of mortalities, in that we assumed the default avoidance value of 98 percent, full replacement of killed individuals by new territory holders, and constantly spinning rotor blades. Percival (2007) suggested that the ideal way to estimate avoidance rate of wind turbines for a particular species would require bird flight rate through the wind farm to be measured before and after construction. The SNH strongly suggests the use of the CRM to predict the number of collisions without avoidance prior to construction, measuring the actual number of collisions post-construction, and calculating the avoidance rate using an extension of the CRM as (Equation 11) (Percival 2007, SNH 2010):

$$Avoidance\ rate = 1 - \frac{Observed\ collisions}{Predicted\ collisions} \qquad [11]$$

We have, therefore, provided a thorough baseline risk assessment for piping plovers prior to the construction of a wind turbine at or near piping plover breeding areas, unadjusted for avoidance. The SNH extension of the CRM takes into account both behavioral avoidance (emergency maneuvers or high/low flights to avoid collision) and behavioral displacement (avoiding the wind farm entirely) and can be used post-construction in conjunction with the pre-construction predictions (SNH 2010). Wildlife managers can apply an anticipated avoidance rate to the predicted number of collisions per year for each of our study sites based on the habitat characteristics of a site with a proposed wind turbine. In the event that collision risk is anticipated to be low and turbines were to be built, the avoidance rate could be adjusted post-construction based on the actual number of collisions observed.

The CRM was developed as a transparent and objective model to be used by any interested party during the wind farm planning and development stage (Percival 2007). The majority of stakeholders in the United Kingdom, including the British Trust for Ornithology (BTO) and the Royal Society for the Protection of Birds, use the Scottish Natural Heritage's Collision Risk Model when evaluating the impacts of individual projects on birds (Masden 2014). Our intent was to use the CRM in a replicable manner for estimating collision risk at or near piping plover breeding areas during the pre-construction phase.

We have additionally provided information on the turbine specifications that may be most important to consider when evaluating permit requests at or near piping plover breeding areas. Turbines with a large rotor diameter and wide, fast-moving blades lead to the highest number of collisions per year. Furthermore, because collision risk is a function of the area of the risk window, increasing the height of the turbines at a site where piping plovers are nesting would lead to a decrease in the predicted number of collisions per year; however, raising the height of the turbines may lead to unexpected impacts to other species, and this should be considered prior to construction.

We confirmed that Atlantic coast piping plovers make nocturnal flights within the study areas; however, due to small sample size and the difficulties involved in confirming night time flights, we felt that the number of nocturnal flights confirmed may have been lower than the actual number of nocturnal flights completed. If our assumption that the Sherfy et al. (2012) findings of at least 2.45 times more night flights than day flights applied to our study sites is true, then including night flights greatly increased annual collision mortality. It is possible that the number of nocturnal flights is greater than 2.45 times more than diurnal flights, as the Great Plains study examined movements away from study areas, not flights. However, the movements observed by Sherfy et al. (2012) were marked detections away from their study sites; therefore, the number of nocturnal flights/h within the study area could also be interpreted as less than 2.45, yet those flights away from the study areas at night could also increase collision risk to piping plovers departing study areas at night. Dirksen et al. (2000) found that local flights of wading birds and diving ducks during both day and night were all less than 100 m, placing both day and night flights within the typical height of the rotor swept zone. Ronconi et al. (2015) found that the most frequently observed effects at off-shore oil and gas platforms were attractions and collisions associated with lights and flares which often resulted in death, which can be exacerbated during times of poor visibility. Hüpop et al. (2006) observed 50% of all bird strikes at an off-shore platform to occur on only two nights of the study period which were characterized by periods of very poor visibility due to mist and drizzle. On the second of these two nights, a thermal imaging camera indicated that many birds flew in an obviously disoriented manner (Hüpop et al. 2006). Further study would be needed to validate night time flight frequency and flight heights on Atlantic Coast piping plovers, especially in light of the fact that collision risk increases during times of poor visibility (i.e. night-time, fog, and precipitation).

Our study attempted to examine avoidance rates of piping plovers with novel structures placed within their nesting territories; however, we were unable to assess avoidance behavior due to logistical difficulties. While we documented avoidance of piping plovers to existing human structures and no collisions were observed, it has been established that birds are at risk of collision with stationary objects such as buildings and power lines within their environment. Data collected by Project Safe Flight from 1997 to 2008 recorded over 5400 bird collisions with buildings in Manhattan, mostly occurring during the day and at the lower levels of buildings (Gelb and Delacretaz 2009). Another study found that deer fencing was a frequent cause of mortality in capercaillie, a species of high conservation concern in the UK (Baines and Summers 1997). Bird collisions and mortality due to overhead power lines have been well-documented (Anderson 1978, Cooper and Day 1998, Silva 2014); furthermore, Savereno et al. (1996) found that avoidance behavior to overhead power lines was related to taxonomic group and that shorebirds changed behavior more than expected. The power line study demonstrates that avoidance behavior by piping plovers to wind turbines may be higher than other taxonomic groups, yet the avoidance of non-stationary objects such as wind turbines has yet to be examined.

Although avoidance rates are meant be incorporated post-construction, we applied an avoidance rate to the predicted number of collisions per year to provide a more reasonable estimate for the number of mortalities that may occur at sites given the construction of a wind turbine. Given our behavioral observations where birds were not observed colliding with anthropogenic structures, piping plovers are likely capable of avoiding wind turbines to some degree, if they are placed within their nesting areas. Additionally, piping plovers are known to be nocturnally active and birds are more at risk of collision during times of low visibility, yet piping plovers possess high visual acuity (del Hoyo et al. 2011) and may also be able to avoid structures at night. Our applied avoidance rate is likely an underestimate yet provides some information about how the application of an avoidance rate using the CRM extension would modify and reduce the predicted number of collisions per year.

Although collision mortality is a primary concern for wind turbine impacts on wildlife, avoidance of the footprint and the area surrounding a turbine or wind farm can also directly affect bird populations through habitat loss and the increased energy cost of dispersal. Leddy et al. (1999) found that at Conservation Reserve Program grasslands within the Buffalo Ridge Wind Resource Area total breeding bird densities were lower in grasslands containing turbines than in grasslands without turbines. At 9 wind farms in the United Kingdom (UK), 7 of 12 focal nesting species exhibited significantly lower densities close to turbines, and none of the 12 species were more likely to occur close to the turbines than far from them (Pearce-Higgins et al. 2009). Dirksen et al. (2000) concluded that turbines can act as a flight path barrier when they stand between feeding and roosting sites for diving duck species. Piping plovers are known to select sites that contain fewer people and the time piping plovers spent actively foraging was negatively associated with human presence (Burger 1994). Habitat loss and degradation continue to be a threat to recovery, and if turbines are placed near important piping plover breeding or foraging areas, avoidance of these areas could result in a functional loss of habitat.

Given the highly territorial nature of piping plovers, it was not surprising that that flight paths remained within boundaries most likely corresponding to nesting and feeding territories. Nonrandom use of flight habitat could have implications for wind turbine development: pairs that occupy and utilize a territory in proximal to a wind turbine may be at higher risk of collision than pairs that are distal to the placement of the turbine; hence, our risk assessment considers only the risk window for a single pair occupying a territory containing a single wind turbine. If birds are not replaced by a new territory holder once killed by a collision, the number of collisions per year at a site would be less than our modeling predicts (i.e. collision/yr ≤ 2).

The optical range finder method of calculating flight height proved to be an accurate, yet difficult method to implement in the field. We found it to be most useful as a way to repeatedly calibrate our visual estimates and to make them more accurate than they would have been otherwise. The rifle scope method requires the observer to be a very skilled marksman with the ability to predict when a piping plover will fly in addition to keeping the bird centered in the view finder. A total of 53.35 hours were spent in the field attempting to measure flight heights using this method, and only 19 flights were captured. The use of the optical range finder for predicting heights may be useful if the placement of a wind turbine is known. Positioning the range finder apparatus in a fixed position pointing towards the portion of the sky for which the rotor would be located, it may be possible to measure flight heights of birds passing through the area of concern, given that the individuals can be identified to species.

While the use of the optical range finder proved to be difficult, we are confident that observers made high-quality estimates of flight heights as a result of repeated practice in estimating and measuring heights of inanimate objects. Observers were able to improve height estimates over time through multiple practice sessions over the course of the field season.

Our methods for evaluating flight speed of piping plovers commuting to and from foraging areas were relatively easy to execute and provided accurate estimates for flight speed. This method, however, requires a specific knowledge of flight paths in order to be useful. If a species of interest does not utilize specified paths to and from foraging areas, this method may not be suitable in determining flight speed.

We found that flight frequency differed with respect to breeding status, tidal stage, study site, and changes in temperature. Adult piping plovers tending a brood of chicks made twice as many flights per hour as adults without chicks. It is possible that foraging flights are the primary reason for flying during the incubation stage or when birds do not have a nest; however, protecting chicks from human disturbance and predators in addition to regular foraging flights may be the cause of increased flight frequency for adults tending a brood. Although piping plover chicks are precocial, it is common for flight activity in birds to increase during the chick rearing phase. For example, Furness et al. (2013) noted that flight activity for seabirds tends to increase during the chick rearing season because adults are making frequent departures from the nesting sites in search of food for chicks.

Piping plovers made the fewest flights during high tidal stages, and flight frequency differed among study sites. Ideal piping plover foraging occurs in tidally dependent areas containing moist substrate and an abundance of invertebrates, such as ephemeral pools, mudflats, and sandflats (Elias et al. 2000, Cohen and Fraser 2010), which tend to only be exposed between mid-falling to mid-rising tides. MacCarone and Parsons (1988) observed differences in flight frequency between species in relation to tide level. Their study suggested that flight patterns of wading birds likely reflect differences in location and temporal availability of food resources (MacCarone and Parsons 1988). Farmer and Parent (1997) found at three migration stopovers in the Great Plains that as the distance between wetlands decreased and the proportion of the landscape composed of wetlands increased, movement frequency of pectoral sandpipers (*Calidris melanotos*) increased, demonstrating an effect of habitat configuration on movement frequency of shorebirds. Fleisher et al. (1983) found that ruddy turnstones (*Arenaria interpres*) in Costa Rica foraged exclusively at high tide and rested during high tide. Finally, a study conducted on wintering sanderlings at Bodega Bay, California (Connors et al. 1981) found that during high tidal stages, sanderlings (*Calidris alba*) could be found foraging on the outer (oceanside) beaches and preferred foraging on bayside tidal flats during low tide. These two foraging habitats were separated by approximately 1.5 km, demonstrating the need for birds to fly from preferred habitats during tidal fluctuations. Many nesting sites are limited to nesting and foraging habitat located exclusively on the oceanside beach similar to that of Avalon, NJ, where foraging habitat is restricted to wrack at high tide and the intertidal zone of the oceanside beach during mid- to low-tidal stages. The differences that we found in flight frequency among tidal stage and study site demonstrate that flight frequency is highly dependent upon habitat configuration, which includes both the proximity and availability of tidally dependent, high quality foraging.

Our findings that temperature may have affected flight behavior are in accord with some studies on the relationship between weather and movements. Sergio (2003) found that black kites (*Milvus migrans*) hunted more during periods of favorable weather, and that nestling provisioning rates declined during periods of rain. Furthermore, Grubb (1978) found that with increases in wind speed and decreases in temperature, wintering birds in Ohio spent more time stationary (less time foraging) and decreased their travel distances. However, Ricklefs and Hainsworth (1968) found that as temperature increased, cactus wrens (*Campylorhynchus brunneicapillus*) foraged in microhabitats with cooler temperatures, and on days when absorbing temperatures exceeded 35^{o}C, cactus wrens were most active during sunrise and sunset and least active in the afternoon during the hottest part of the day. Additionally, Murphy (1987) found that total foraging rate of Eastern kingbirds (*Tyrannus tyrannus*) was independent of air temperature, demonstrating that bird behavior is not necessarily dependent upon changes in temperature. The observed increase in flight frequency in response to increased temperature may not be a temperature driven response, as temperature was seasonally confounded with breeding status. As birds arrive on the breeding grounds in early March, temperatures are often cold and birds are without a nest brood. As temperatures increase throughout the breeding season, chicks begin to hatch resulting in an increase in flight frequency. However, because changes in temperature are not likely to cause an increased or decreased risk of collision with wind turbines, and wind speed was not in our top model, we do not feel that the relationships between weather variables and flight frequency require further exploration.

Our study focused on the flight characteristics and collision risk for piping plovers within the breeding season; however, emphasis should be placed on studies that continue to examine the impacts of wind power development on migrating and wintering piping plovers. For example, Burger et al. (2011) determined that piping plovers may be at risk of encountering off-shore wind turbines during spring or fall migration but assumed that migration routes were near-shore; however, little is known about the migratory pathways and stopover sites of this species and this information would be crucial to providing an accurate assessment of whether or not piping plovers would be at risk during the migratory and wintering portions of their annual cycle.

We found that habitat configuration should be the most important consideration when conducting assessments of wind turbine proposals at or near piping plover breeding areas, and a thorough evaluation of the flight frequency among various habitat types within a site as well as detailed surveys of preferred nesting and foraging locations by piping plovers should be systematically conducted over the course of an entire breeding season. For example, Spring Hill Beach, Sandwich, MA had been monitored for nesting piping plovers since the species was listed in 1986. Prior to our study, beach managers felt confident that nesting and foraging habitats were contiguous and restricted to the oceanside wrack line and intertidal zone; however, our study documented that piping plovers make regular flights from oceanside nesting habitats to bayside foraging habitats located within the extensive marsh system. These regular movements place piping plovers at higher risk of collision than sites where piping plovers are not inclined to make regular flights to access ideal foraging habitats; therefore, a thorough evaluation of preferred habitat-types is highly recommended prior to construction.

Conclusions

We used an existing collision risk model (SNH 2000) to predict the number of piping plovers potentially killed per year at each site given flight parameters, varying wind turbine specifications, and numbers of wind turbines on the landscape. We found habitat configuration and size of the wind turbine to be the most important elements when assessing collision risk for a given site. Study sites where nesting and foraging habitats are separate, yet accessible by flight, that contain large wind turbines lead to the highest number of collisions per year. In contrast, sites where nesting and foraging habitat are contiguous and restricted to the oceanside intertidal zone and wrack line, have the fewest number of collisions per year.

Our results demonstrate that while the majority of piping plover flights occur below the rotor swept zone, depending on the site configuration, the proportion of flights that occur through the rotor swept zone can lead to a high number of collisions per breeding season relative to the local population. Our predictions can be used to guide decision makers regarding placement of wind turbines at or near breeding areas.

Future Recommendations

We make specific recommendations for further research and management considerations regarding piping plovers and wind power development:

1. Avoidance rates of piping plovers with non-stationary objects have not been well-studied. Chamberlain et al. (2005) caution that small variations in avoidance rates can lead to relatively large changes in the predicted number of collisions/yr. Prior to construction of wind turbines at or near piping plover breeding areas, avoidance rates should be more closely examined.

2. Piping plover avoidance of the footprint and the area surrounding a turbine could contribute to habitat loss. Habitat loss has been a contributing factor to the decline of the Atlantic coast piping plover (USFWS 1996), and habitat loss due to avoidance of constructed wind turbines demonstrates a continued threat to the recovery of the species. The response of piping plovers to wind turbines constructed within their habitat should be closely evaluated post-construction.
3. Avoidance by piping plovers of various age classes (i.e. fledglings, 1st breeders, and adults) are unknown. Piping plovers show high site fidelity (Cohen et al. 2006) and adults nesting at sites where wind turbines are placed may learn to avoid the turbine through experience. However, first year breeding birds that have not yet encountered such an obstacle may have a higher collision risk. Additionally, newly fledged birds may not be able to complete last-minute maneuvers as readily as adults, demonstrating a higher collision risk.
4. Nocturnal behavior and extra-territorial flights are difficult to study but should be addressed. Birds are more at risk of collision during periods of poor visibility (Avery et al. 1976, Hüppop et al. 2006), and a better understanding of habitat use and flight paths during these periods would allow for a better overall understanding of collision risk.
5. Impacts of wind power development on post-breeding, migrating, and wintering piping plovers have not been well-studied. Piping plovers may encounter off-shore wind farms during migration (Burger et al. 2011); however, their migratory pathways are largely unknown. Confirming whether piping plovers remain near-shore during migration or make long- distance, off-shore movements would allow for a better understanding of how wind power development might affect piping plovers during migration. Additionally,

habitat use and territory size of wintering piping plovers differs from breeding piping plovers, and those differences should be taken into consideration.

6. Habitat configuration should be the most important consideration when conducting assessments of wind turbine proposals at or near piping plover breeding areas. Pre-siting surveys for wind turbine proposals should involve a thorough evaluation of the flight behavior among various habitat types within a site as well as detailed surveys of preferred nesting and foraging locations by piping plovers.

Table 2.1. Turbine specifications used in Stage 1 and Stage 2 of the risk assessment to calculate the number of collisions per year of piping plovers at study sites in MA and NJ.

Turbine	Output	Radius (m)	Rotation Period (s)	Chord Width (m)	Total Height (m)	p(collision)
E-3120	50kW	9.6	1.429	0.27	39.5	0.057
V-82	1.65MW	41	4.168	3.08	111	0.068
Hypothetical	Unknown	22.5	2.0	0.67	57.5	0.51

Table 2.2. Turbine parameter values used to calculate probability of collision in the Scottish Natural Heritage collision risk model, if a piping plover were to enter within the rotor swept zone.

	Diameter (m)	Chord Width	Rotation Period (s)	Pitch Angle (°)
Varied Diameter	1 - 45	1%	2.0	20
Varied Diameter	1 - 45	3%	2.0	20
Varied Diameter	1 - 45	6%	2.0	20
Varied Pitch	10	3%	2.0	15 - 31
Varied Pitch	20	3%	2.0	15 - 31
Varied Pitch	45	3%	2.0	15 - 31
Varied Rotation Period	10	3%	0.5 - 4.5	20
Varied Rotation Period	20	3%	0.5 - 4.5	20
Varied Rotation Period	45	3%	0.5 - 4.5	20

Table 2.3. Sample sizes of banded and radio-tagged piping plovers in MA and NJ, 2012 - 2013. All radio-tagged birds were also banded, and are therefore included in both categories.

		2012				2013				
Method	Site	Male	Female	Fledgling	Total	Male	Female	Fledgling	Total	Grand Total
MA Banding	Spring Hill	7	8	1	16	3	4	6	13	29
	Chapin	2	2	0	4	2	2	0	4	8
	Dead Neck/Sampson's Island	6	6	2	14	2	3	0	5	19
	All	15	16	3	34	7	9	6	22	56
MA Radio Tagging	Spring Hill	0	6	1	7	0	4	0	4	11
	Chapin	0	2	0	2	0	3	0	3	5
	Dead Neck/Sampson's Island	0	5	1	6	0	3	0	3	9
	All	0	13	2	15	0	10	0	10	25
NJ Banding	Avalon	5	4	3	12	0	0	2	2	14
	Stone Harbor Point	5	9	1	15	2	3	0	5	20

	Strathmere	N/A[a]	N/A	N/A	N/A	4	2	2	8	8
	All	10	13	4	27	6	5	4	15	42
NJ Radio Tagging	Avalon	0	4	0	4	0	2	0	2	6
	Stone Harbor Point	0	9	1	10	0	4	0	4	14
	Strathmere	N/A	N/A	N/A	N/A	0	3	0	3	3
	All	0	13	2	15	0	9	0	9	24

[a] N/A, not applicable. Strathmere was not a study site in 2012.

Table 2.4.Flight heights (m) of piping plovers in NJ and MA, 2012-2013, estimated using a rifle scope with an optical range finding reticle and a tilt meter, and by visual estimation. Each measurement is for a single flight by an individual.

Site	Year	Calculated Flight Height (m)	Visually Estimated Flight Height (m)
Chapin	2012	10.49	10.0
Spring Hill	2012	0.65	0.25
Spring Hill	2012	1.05	1.0
Spring Hill	2013	1.309	2.0
Chapin	2013	2.067	2.7
Chapin	2013	1.265	1.6
Chapin	2013	4.901	4.5
Chapin	2013	8.135	7.0
Strathmere	2013	2.034	0.25
Strathmere	2013	0.895	0.25
Strathmere	2013	1.614	2.0
Strathmere	2013	1.729	0.25
Strathmere	2013	1.967	0.5
Strathmere	2013	2.432	1.5
Strathmere	2013	2.91	3.0
Strathmere	2013	0.886	1.0
Strathmere	2013	1.605	1.0
Stone Harbor	2013	1.836	1.15
Stone Harbor	2013	2.064	1.15

Table 2.5. Flight heights (m) of non-courtship flights by piping plovers estimated visually during diurnal behavioral observations at Spring Hill, Dead Neck, and Chapin, MA and Stone Harbor, Avalon and Strathmere, NJ.

	2012				2013			
Site	Number of Flights	Average flight heights (m)	Range (m)	Median (m)	Number of Flights	Average Flight Heights (m)	Range (m)	Median (m)
Spring Hill	209	2.57	0.25-40	1	77	3.27	0.20-25	1.5
Dead Neck	279	2.66	0.25-30	2	80	3.47	0.20-20	2.6
Chapin	196	3.05	0.25-25	2	39	2.57	0.25-7	2
Stone Harbor	164	2.5	0.50-30	1.5	122	2.48	0.25-15	1.25
Avalon	218	2.39	0.50-20	1	153	2.38	0.20-40	1
Strathmere	N/A[a]	N/A	N/A	N/A	137	1.67	0.25-11	1
All	1066	2.634	0.25-40	1.5	608	2.51	0.20-40	1.5

[a] N/A, not applicable. Strathmere was not a study site in 2012.

Table 2.6. Flight speeds (m/s) of piping plovers at Spring Hill and Dead Neck, MA and Avalon, NJ, 2012 and 2013.

Site	Year	Speed
Spring Hill	2012	11.8
Spring Hill	2012	9.07
Spring Hill	2012	8.06
Spring Hill	2012	10.7
Spring Hill	2012	7.9
Dead Neck	2012	8.61
Avalon	2012	7.03
Dead Neck	2013	8.39
Dead Neck	2013	10.7
Dead Neck	2013	7.6
Dead Neck	2013	8.55
Spring Hill	2013	8.87
Spring Hill	2013	5.1
Spring Hill	2013	11.9
Spring Hill	2013	12.7
Spring Hill	2013	12.9
Spring Hill	2013	8.17
All (mean)		9.30

Table 2.7. Summary of encounter behaviors of breeding piping plovers recorded during behavioral observations, Massachusetts and New Jersey, 2012-2013.

Obstacle	Flew Above	Flew Under	Flew Left or Right	Flew Toward and Hesitated	Collision
Symbolic Fencing[a]	159	20	0	1	0
Electric Fencing[b]	9	0	0	0	0
House	7	0	5	0	0
Utility Pole	1	0	0	0	0
Utility Wires	11	0	0	0	0
Dune	87	0	0	0	0
Tree	1	0	1	0	0
Other	4	0	1	0	0
Total	279	20	7	1	0

[a] Fence posts connected with a single strand of twine, to protect nesting areas.

[b] Mesh fencing around nesting areas, to deter predators.

Table 2.8. Number of predicted collisions/yr at Spring Hill Beach, MA adjusted for 98 percent avoidance with incremental increases in the total height of the turbine by 20 m.

Rotor Radius	Total Turbine Height	Collisions/Yr
9.6	39.5	0.2927
9.6	59.5	0.1943
9.6	79.5	0.1454

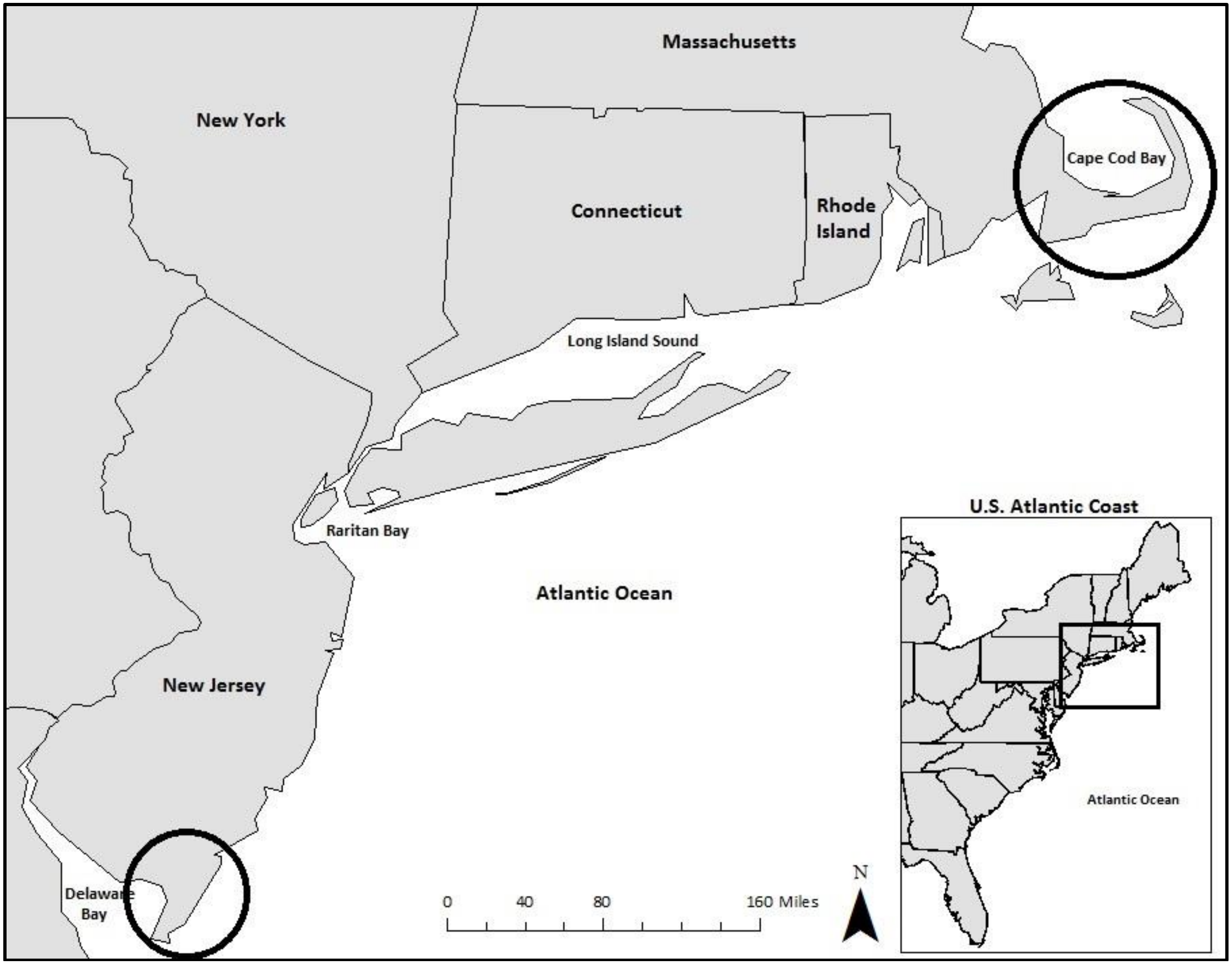


Figure 2.1. Location of study sites for piping plover flight characteristic study in southern New Jersey and Cape Cod, Massachusetts, 2012-2013.

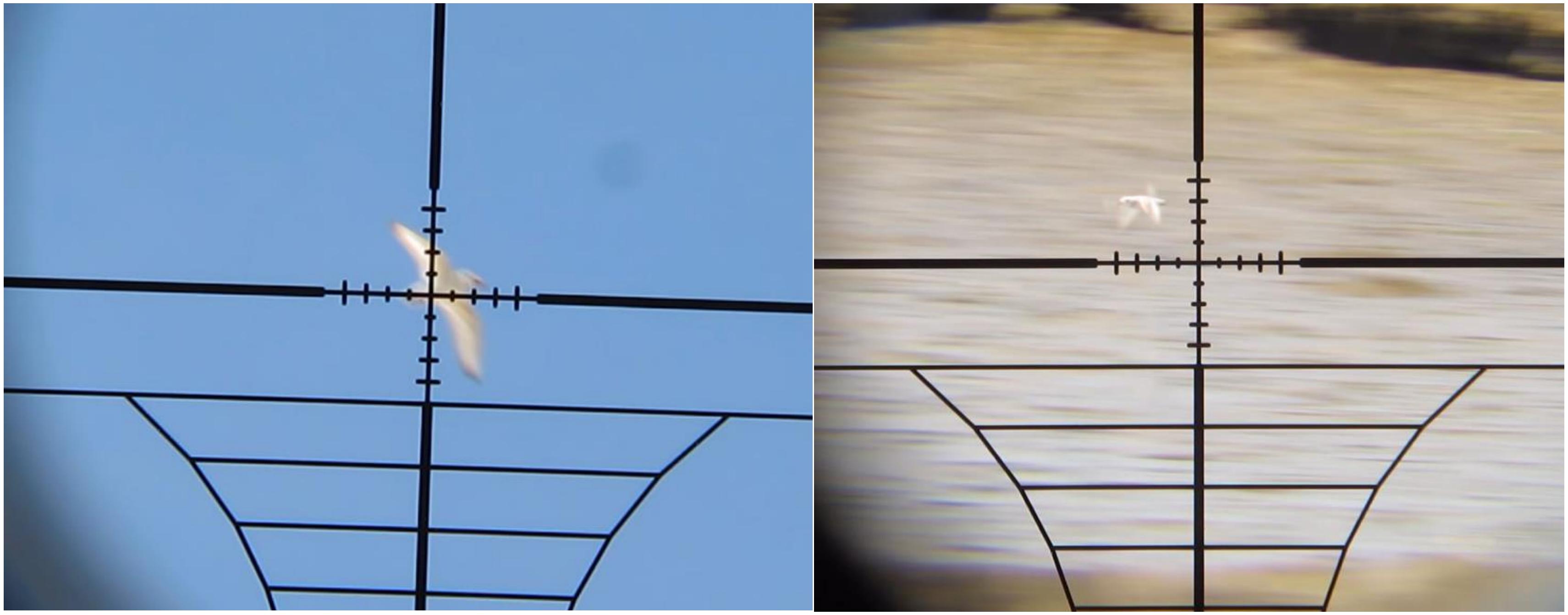


Figure 2.2. Examples of flights of piping plovers captured during flight height estimation using the rifle scope. The flight height in the photo on the left was calculated to be 10.49 m, and the flight height in the photo on the right was calculated to be 1.30 m.

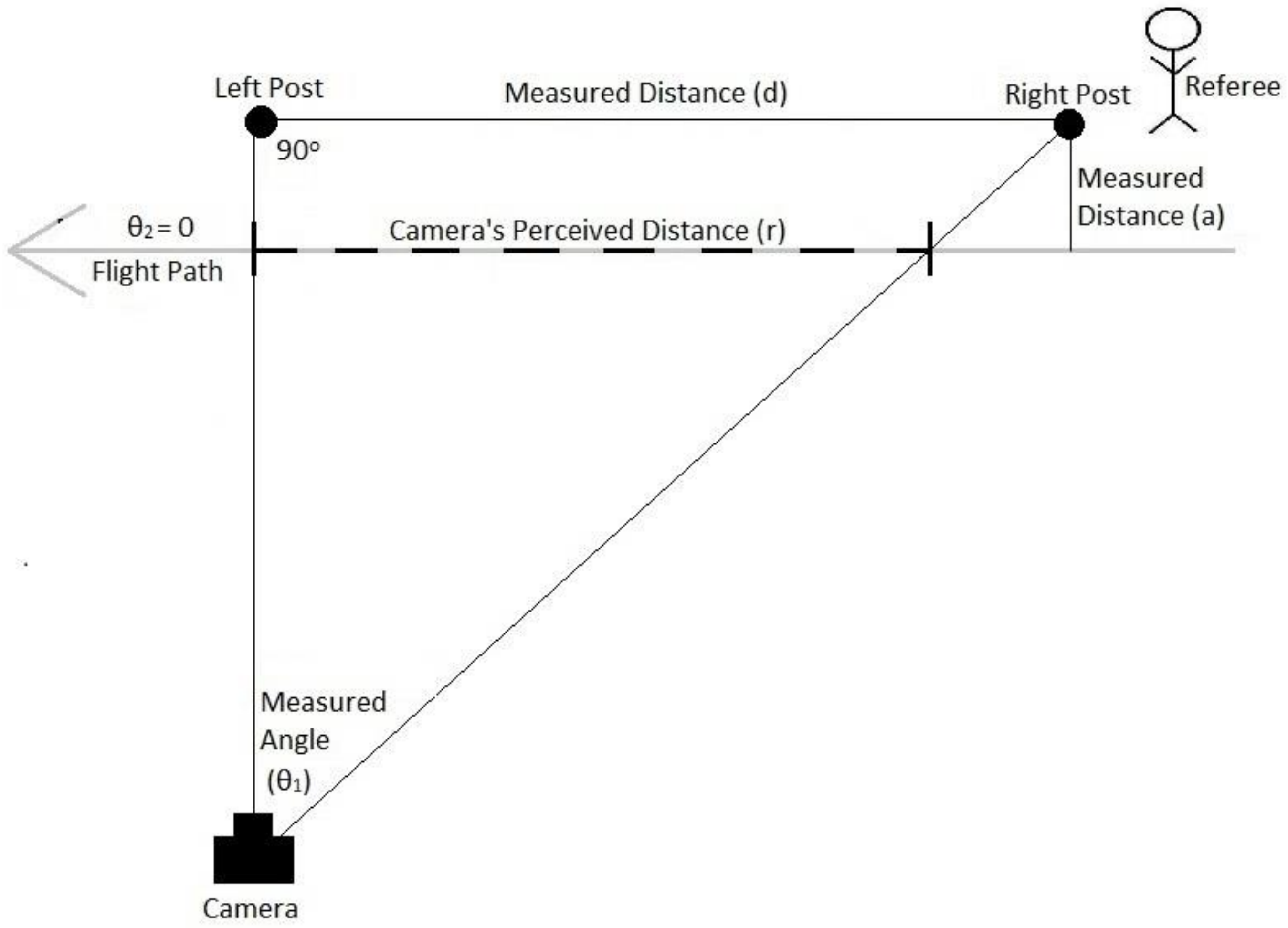


Figure 2.3. Example flight speed trial setup for piping plovers in MA and NJ, 2012 and 2013. In this example, the bird enters the filming zone from the right, flying parallel to the post line, and to the left of the referee. The measured distance from the right post to the flight path (a), the perceived distance (r) from the camera's viewpoint, and the measured angle from the camera to the right post (θ) were used in calculating flight speed. Note the perceived distance (r) is smaller than the measured distance (d) between the two posts.

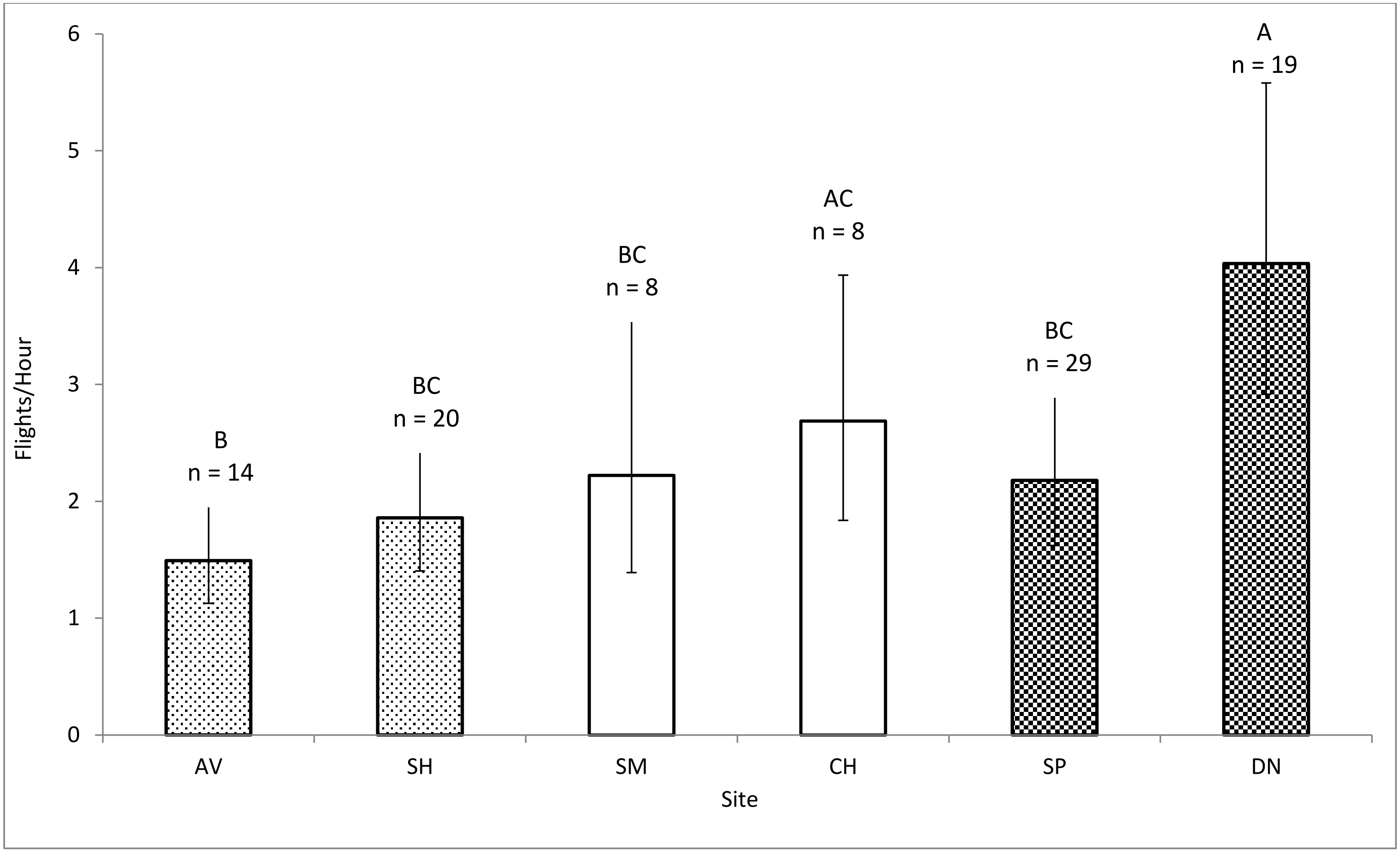


Figure 2.4. Mean number of diurnal non-courtship flights/h by piping plovers for six study sites. Sites include Avalon (AV), Stone Harbor (SH), and Strathmere (SM), NJ, Chapin Beach (CH), Spring Hill Beach (SP), and Dead Neck (DN), MA. Sample size (birds) is shown over the 95% confidence intervals. Sites are listed with contiguous nesting and foraging habitat (left) to separate nesting and foraging habitat (right). Means with the same capital letter are not significantly different (negative binomial regression, site, $F_{5, 408}$= 3.66, P = 0.003).

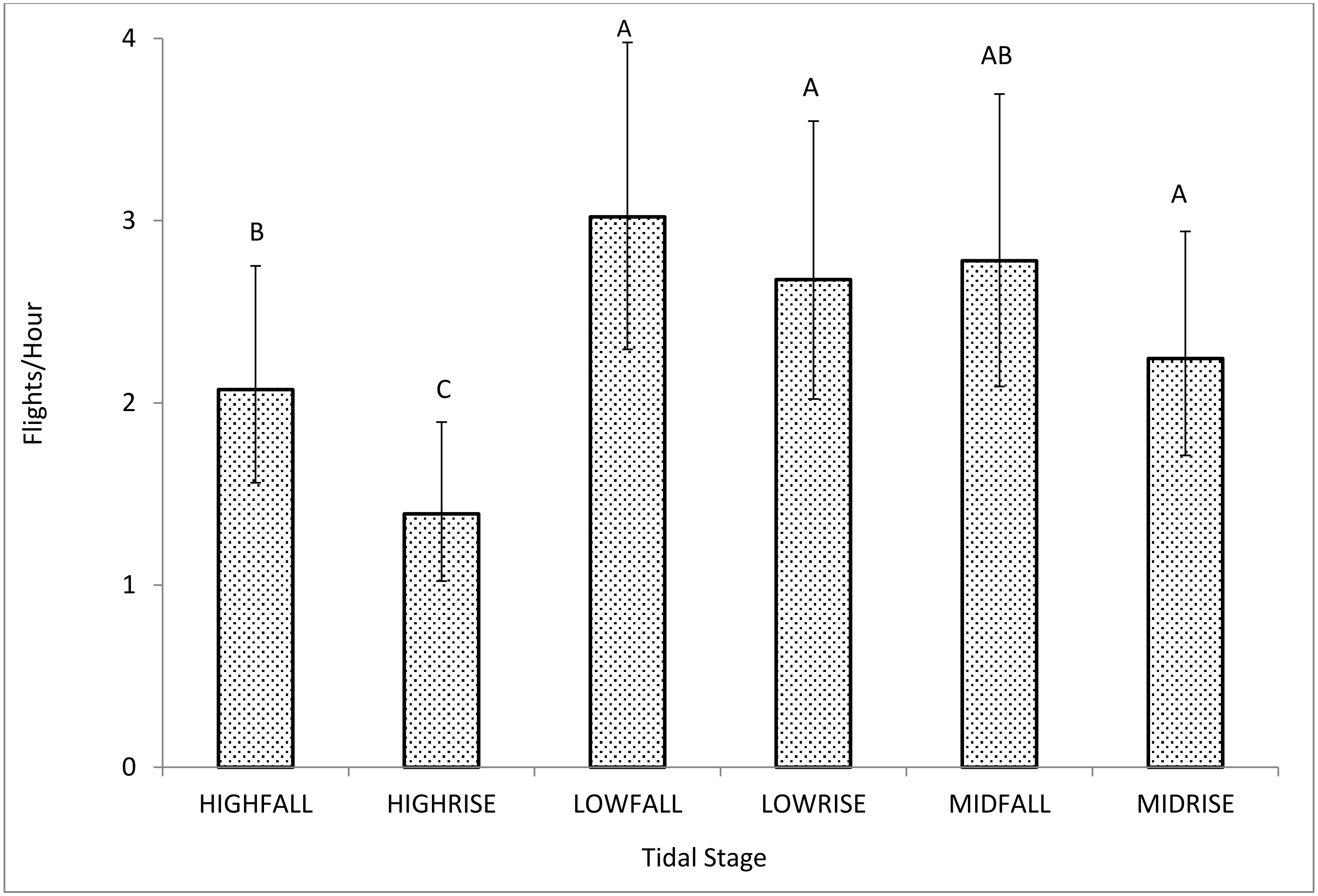


Figure 2.5. Mean number of diurnal non-courtship flights/h by piping plovers for six tidal stages with 95% confidence intervals. Means with the same capital letter are not significantly different (negative binomial regression, stage, $F_{5,\,408}$= 3.88, P = 0.002).

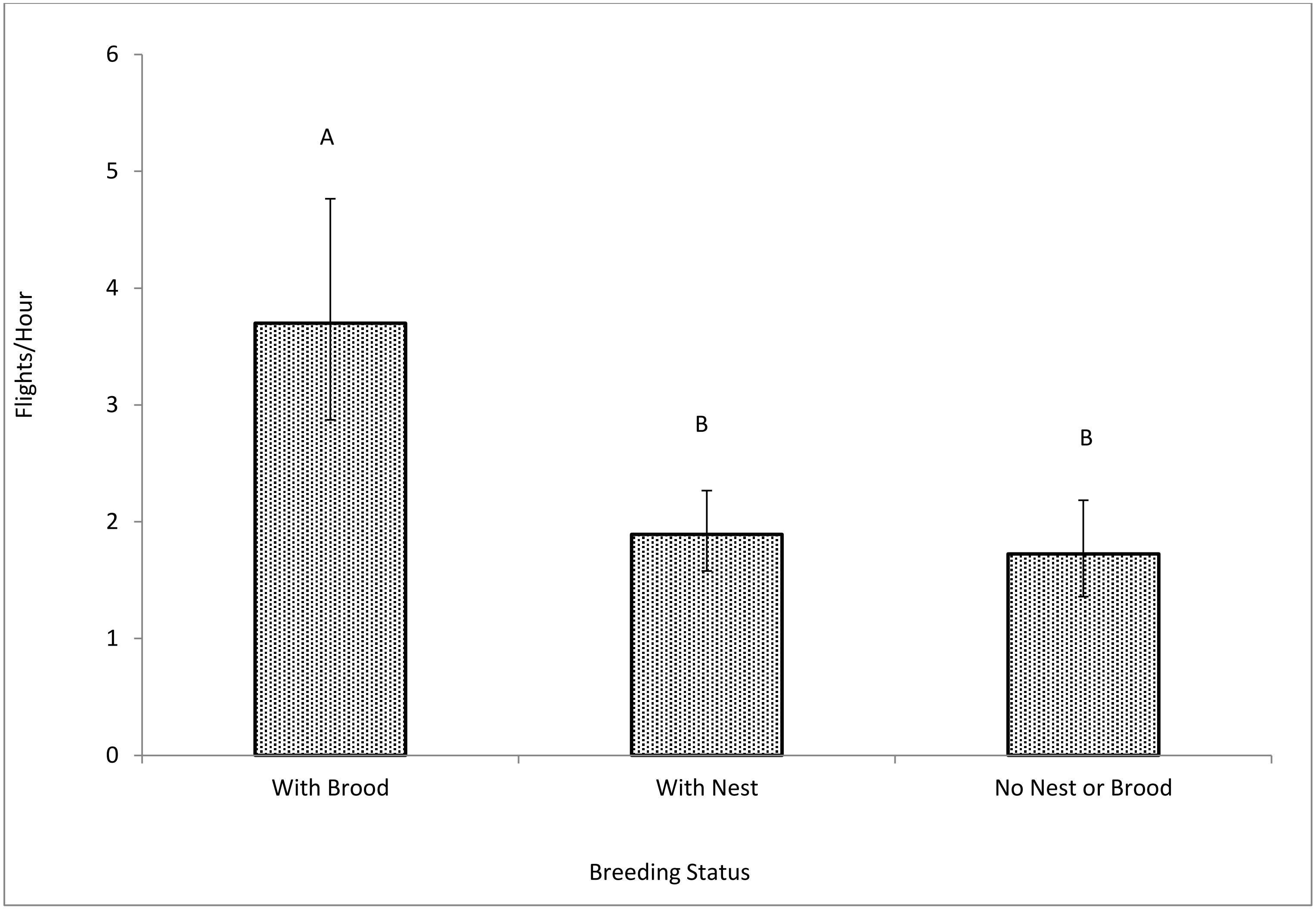


Figure 2.6. Mean number of diurnal non-courtship flights/h by piping plovers for three different breeding strata with 95% confidence intervals. Breeding strata included adults tending a brood (1), adults with a nest (2), and adults without a nest or brood (3). Means with the same capital letter are not significantly different (negative binomial regression, stratum, $F_{2, 408} = 12.78$, $P < 0.0001$).

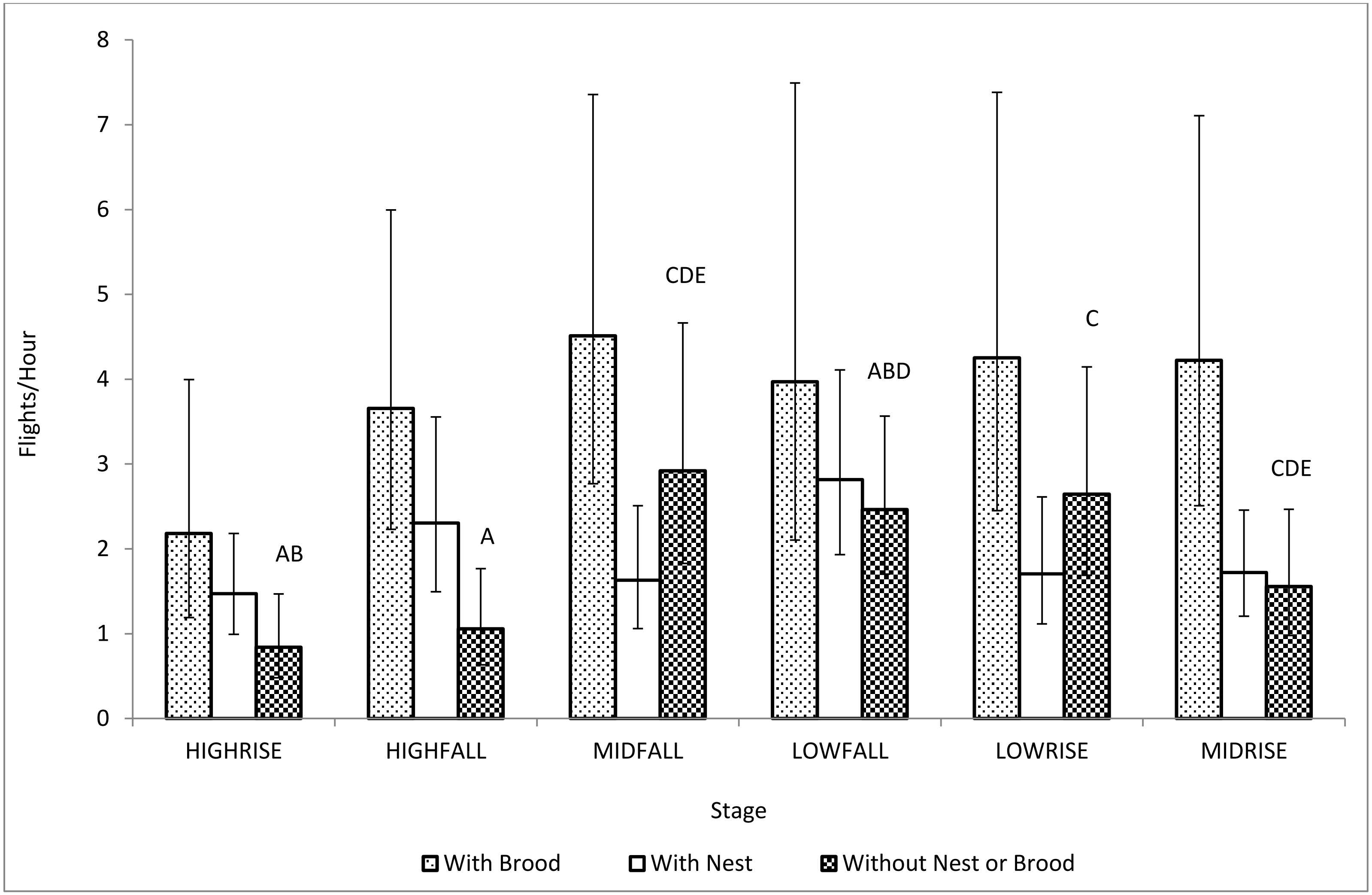


Figure 2.7. Mean number of diurnal, non-courtship flights/h by piping plovers given six different tidal stages and three different strata with 95% confidence intervals. Breeding strata included adults tending a brood (1), adults with a nest (2), and adults without a nest or brood (3). Among strata means with the same capital letter or symbol are not significantly different (negative binomial regression, stage*stratum interaction, $F_{10, 408}$= 1.63, P = 0.097), and 95% confidence intervals are shown.

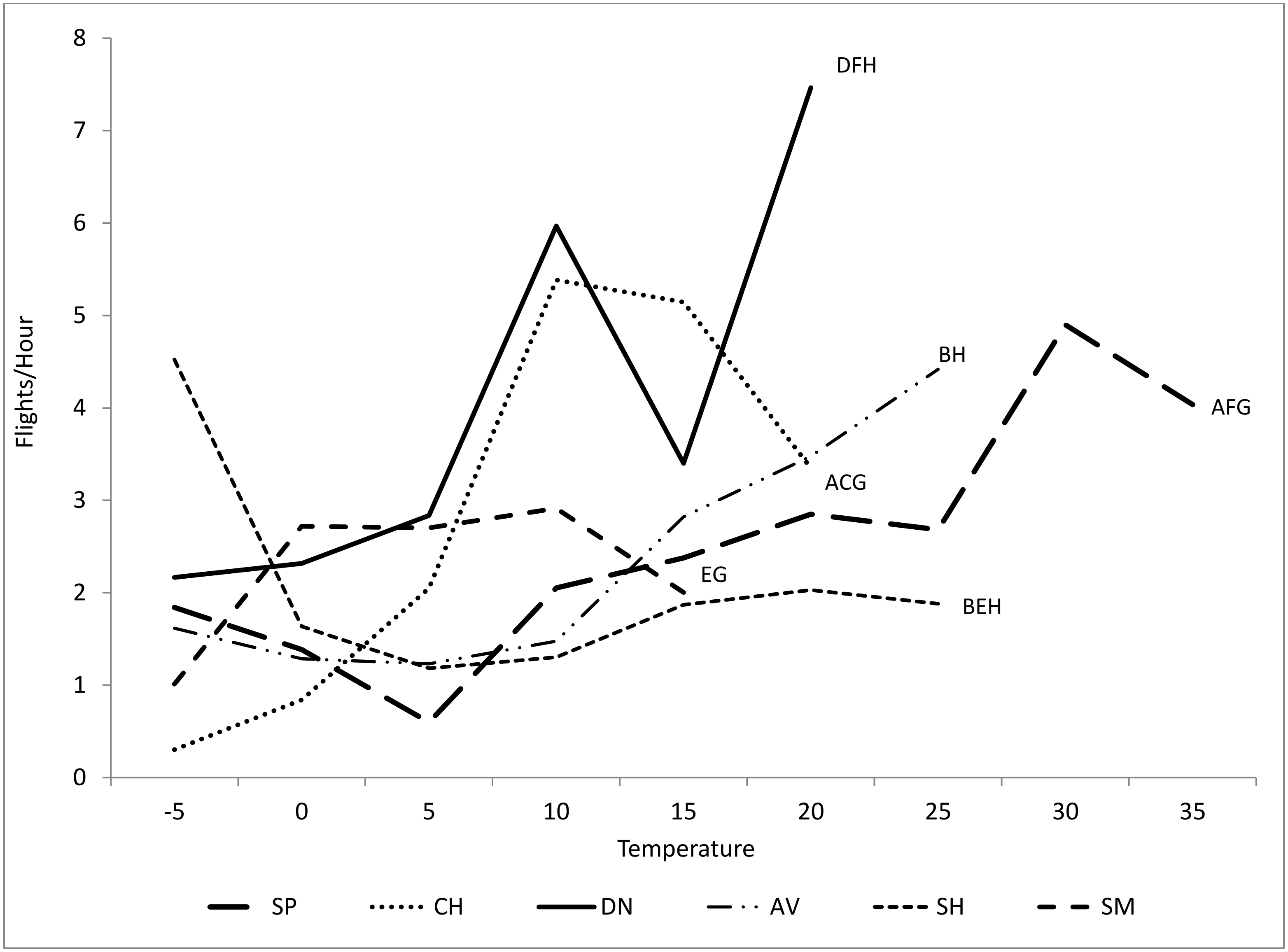


Figure 2.8. Predicted number of diurnal, non-courtship flights/h vs. temperature (C^o) by study site (negative binomial regression, site*temperature, $F_{5, 408}$= 6.65, P < 0.0001). Slopes with the same capital letter are not significantly different. Sites include Spring Hill Beach (SP), Chapin Beach (CH), and Dead Neck (DN), MA, Stone Harbor (SH), Avalon (AV), and Strathmere (SM), NJ. The prediction lines are not smooth because we averaged predictions within temperature bins, and the averages were affected by tidal stage and plover breeding status within bins.

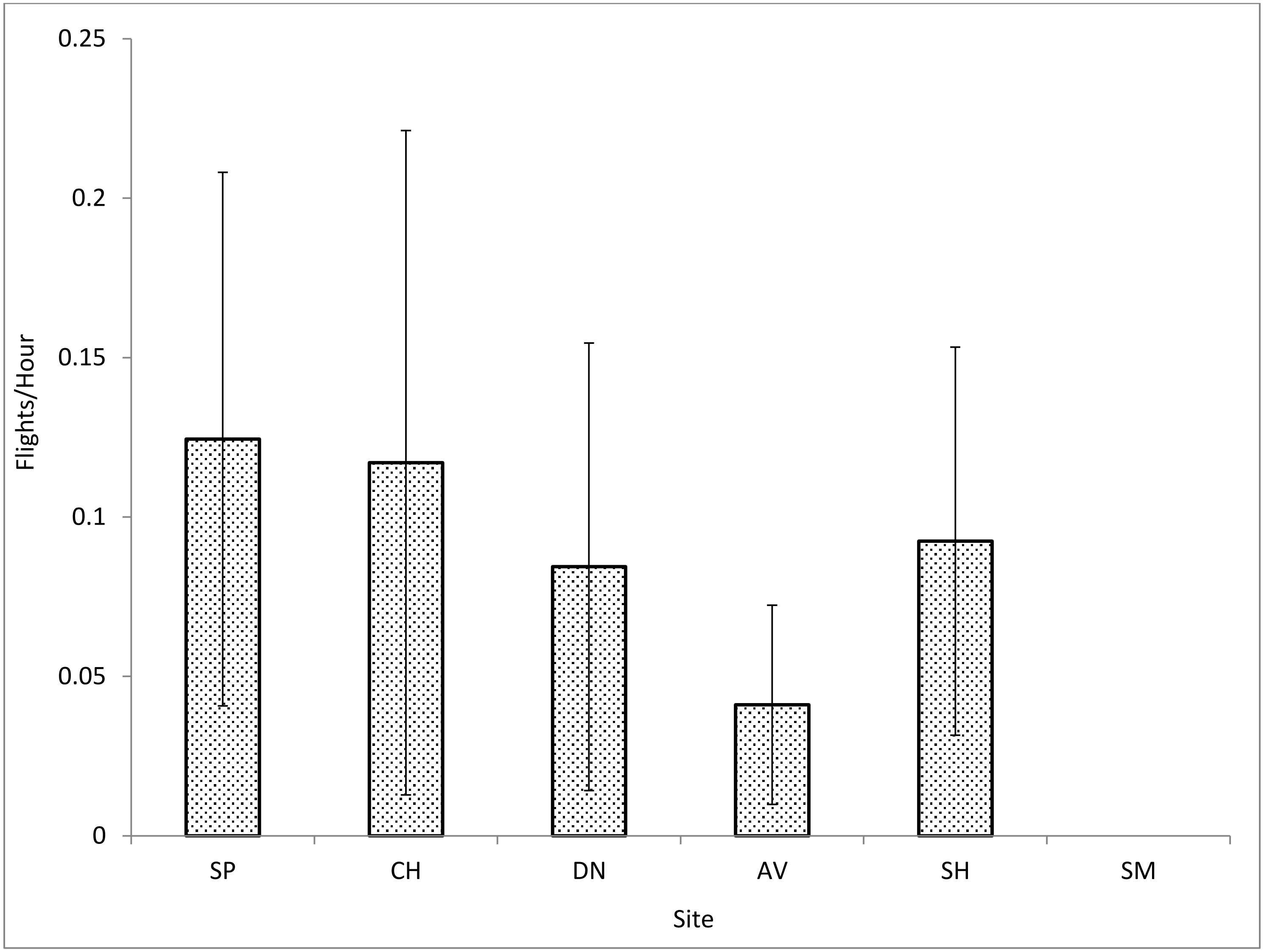


Figure 2.9. Mean number of diurnal non-courtship flights/hour by piping plovers through the risk window of each study site, 2012-2013. Sites include Spring Hill Beach (SP), Chapin Beach (CH), and Dead Neck (DN), MA and Avalon (AV), Stone Harbor (SH), and Strathmere (SM), NJ (negative binomial regression, $F_{5,728} = 1.11$, $P = 0.354$), 95% confidence interval bars are shown.

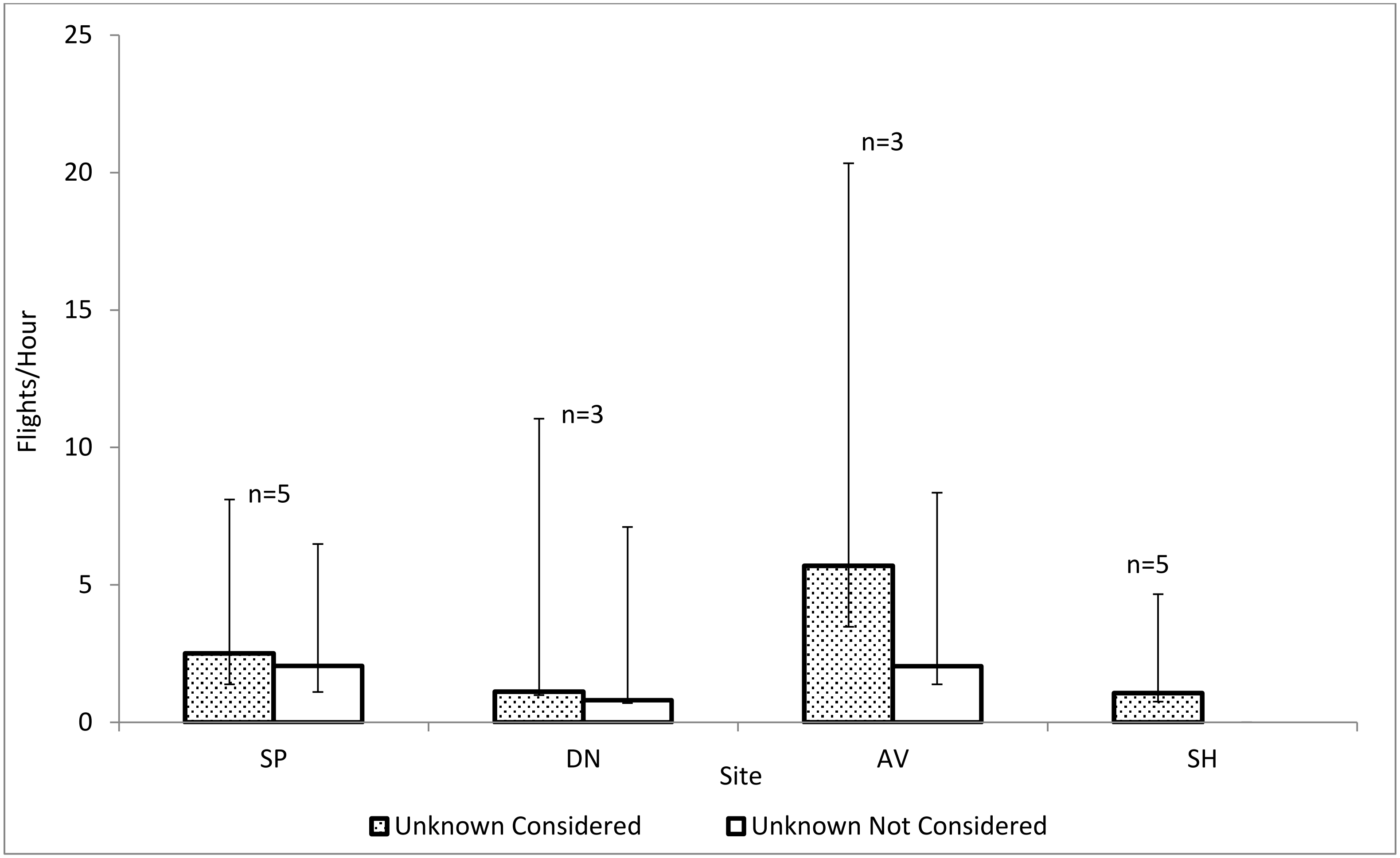


Figure 2.10. Mean number of night-time flights/hour by piping plovers, 2012. Unknown movements considered (movements where we could not determine whether a bird was flying or walking) represents the upper bound of flight frequency at night. Unknown movements not considered (movements where we could not determine whether a bird was flying or walking) represents the lower bound of flight frequency at night. Sites include Spring Hill Beach (SH), Chapin Beach (CH), and Dead Neck (DN), MA and Avalon (AV) and Stone Harbor (ST), NJ. Sample size (birds) is shown over the standard error bars. Means with the same capital letter are not significantly different (negative binomial regression, $F_{3, 13} = 3.58$, p = 0.044).

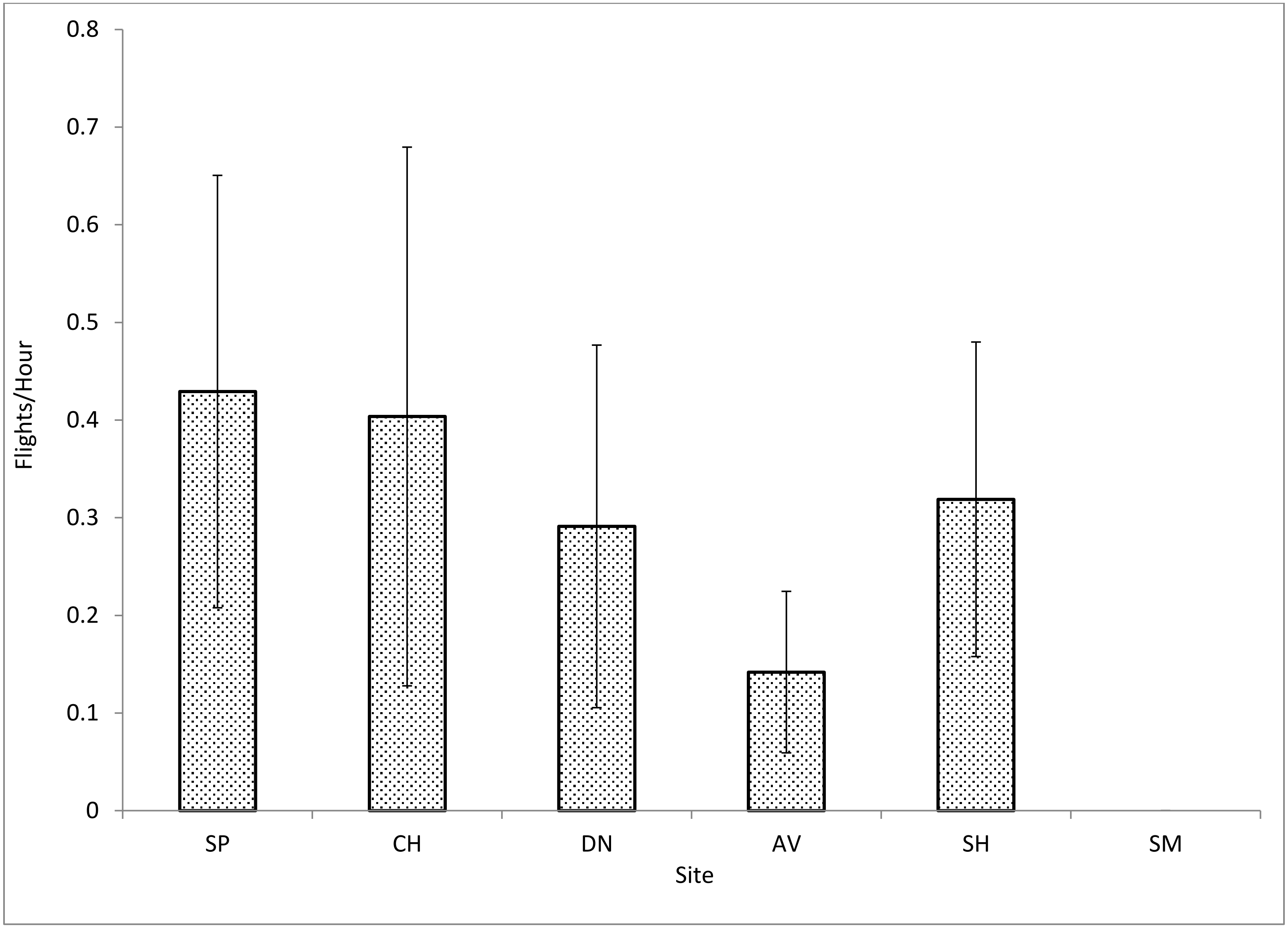


Figure 2.11. Mean number of diurnal non-courtship flights/hour through the risk window of each study multiplied by 2.45 to correct for increased flights at night (Sherfy et al. 2012). Sites include Spring Hill Beach (SP), Chapin Beach (CH), and Dead Neck (DN), MA and Avalon (AV), Stone Harbor (SH), and Strathmere (SM), NJ (negative binomial regression, $F_{5,728} = 1.11$, $P = 0.3535$), and 95% confidence interval bars are shown.

Figure 2.12. Flight paths of 15 piping plovers at Spring Hill, MA, 2012. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -35.87, *P*<0.001).

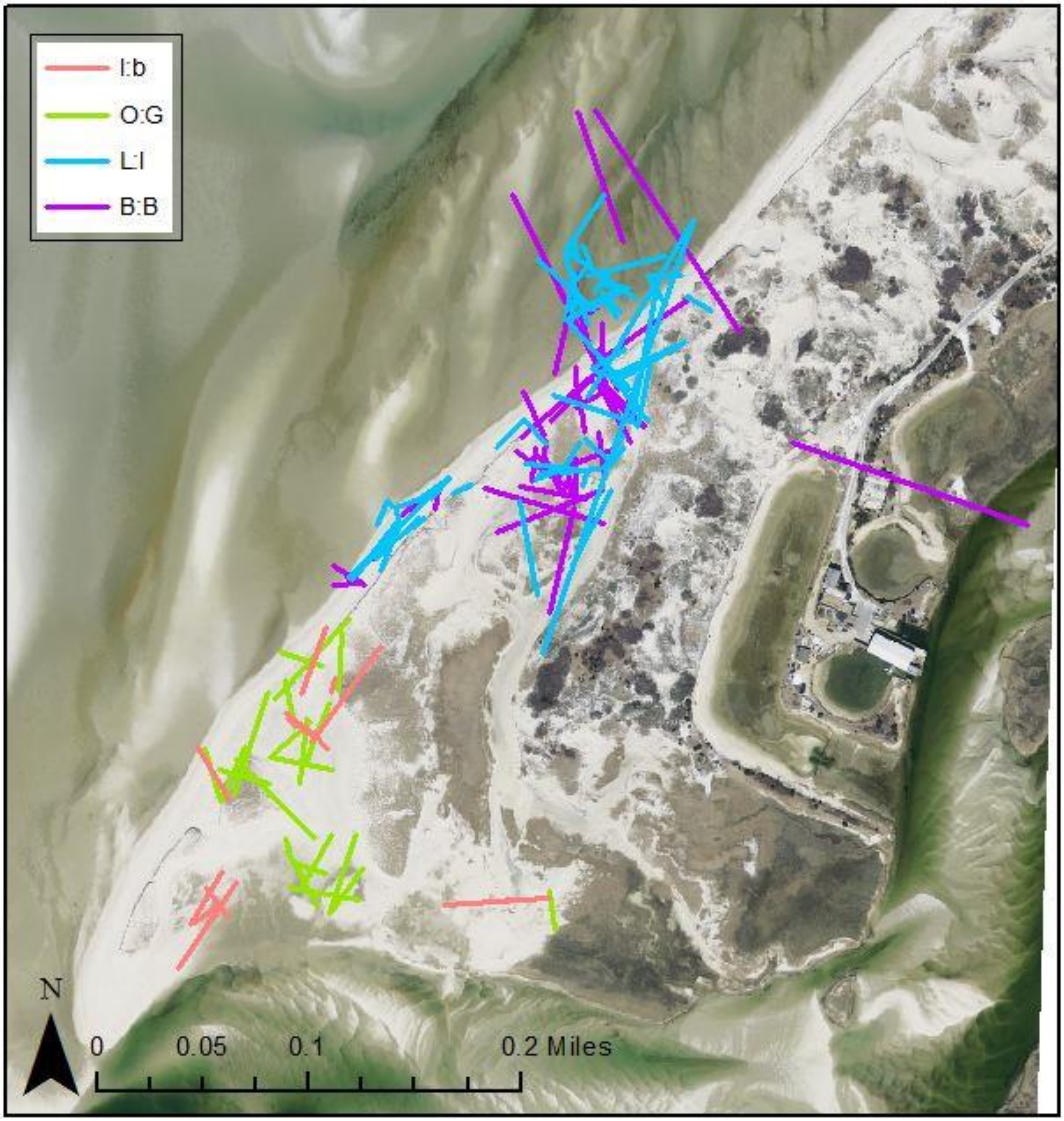


Figure 2.13. Flight paths of 4 piping plovers at Chapin Beach, MA, 2012. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -43.78, *P*<0.001).

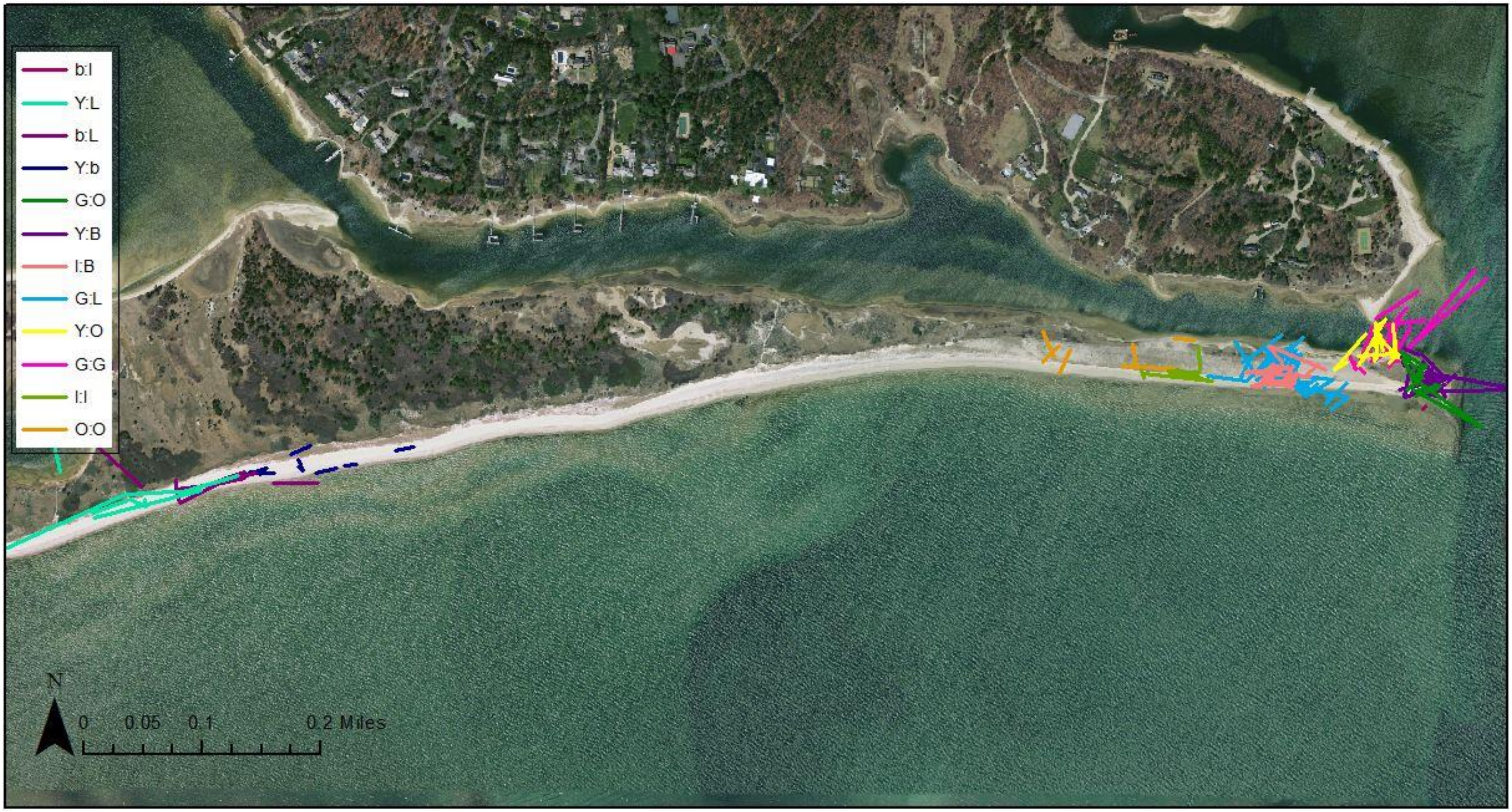


Figure 2.14. Flight paths of 12 piping plovers at Dead Neck, MA, 2012. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -50.20, *P*<0.001).

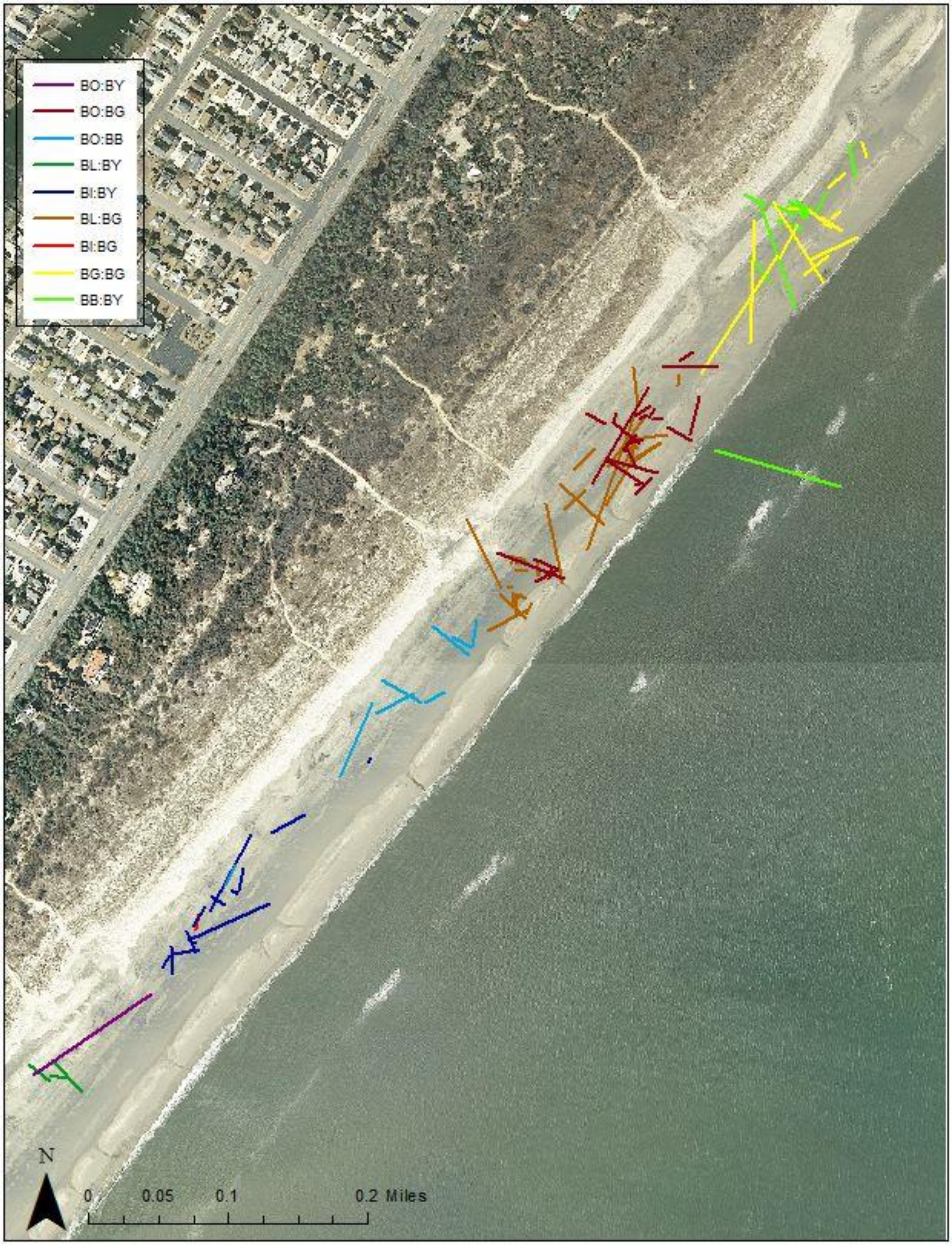


Figure 2.15. Flight paths of 9 piping plovers at Avalon, NJ, 2012. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -39.59, *P*<0.001).

Figure 2.16.Flight paths of 16 piping plovers at Stone Harbor, NJ, 2012. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -13.60, *P*<0.001).

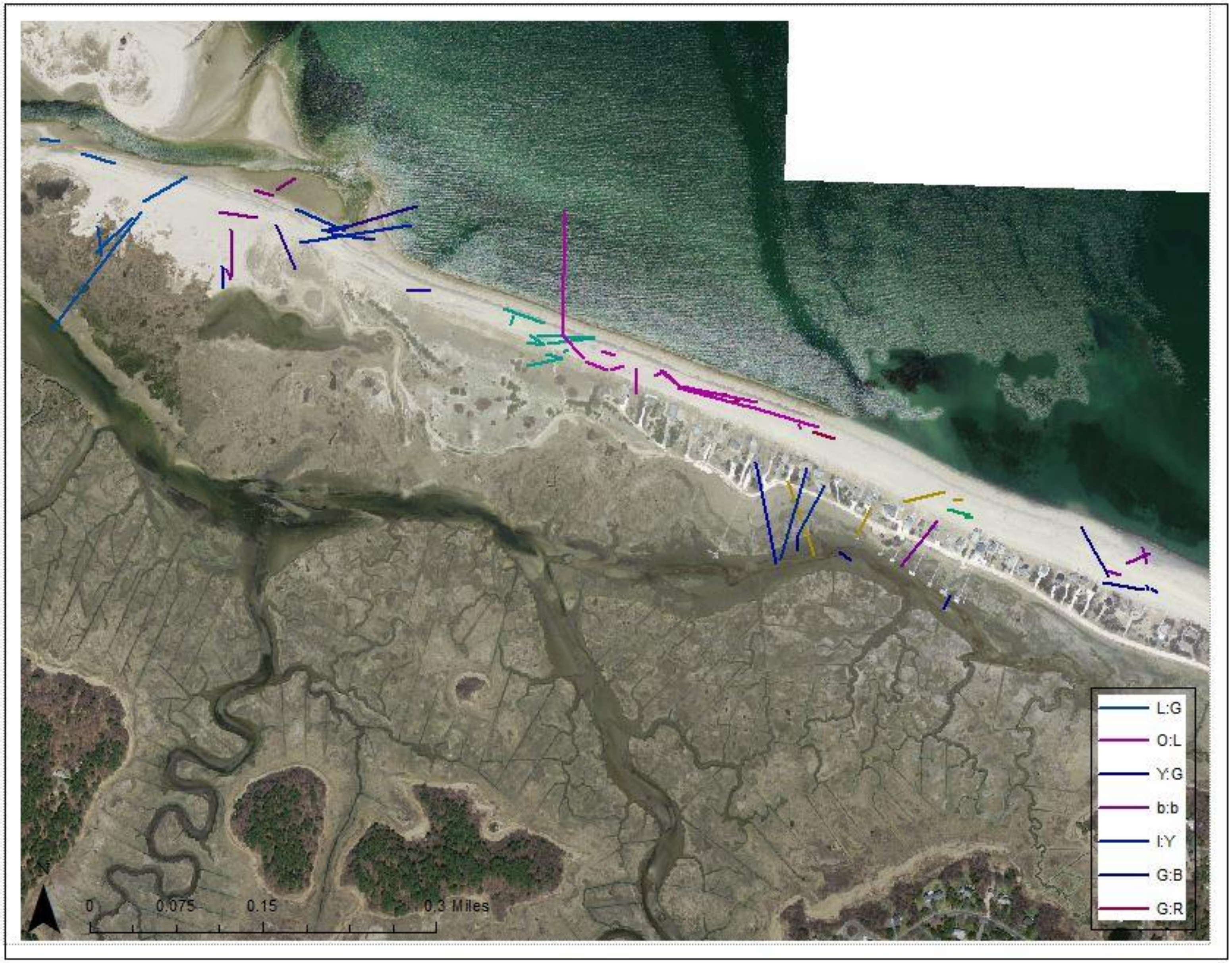


Figure 2.17. Flight paths of 7 piping plovers at Spring Hill, MA, 2013. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -13.97, *P*<0.001).

Figure 2.18. Flight paths of 5 piping plovers at Chapin Beach, MA, 2013. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -11.97, *P*<0.001).

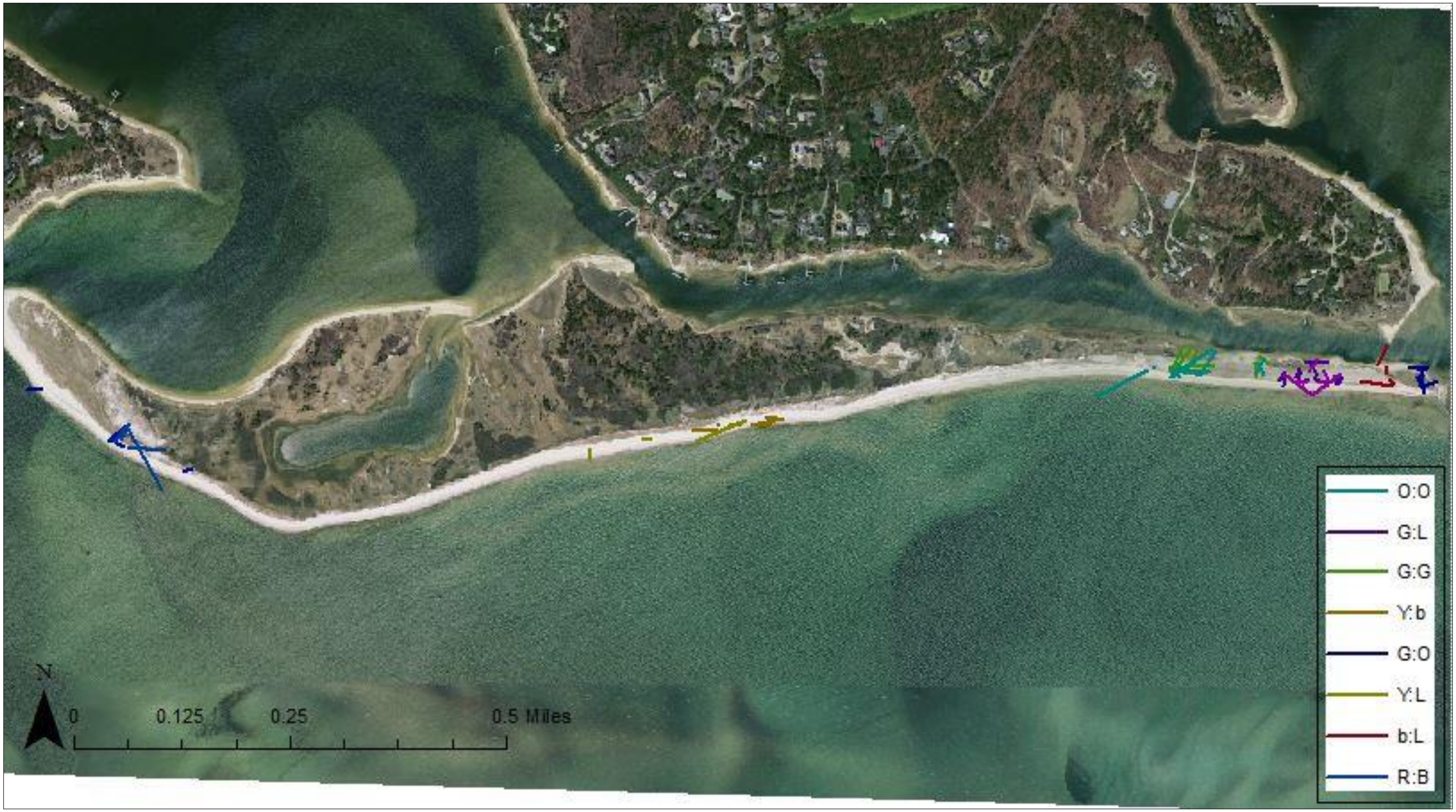


Figure 2.19. Flight paths of 12 piping plovers at Dead Neck, MA, 2013. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -19.04, *P*<0.001).

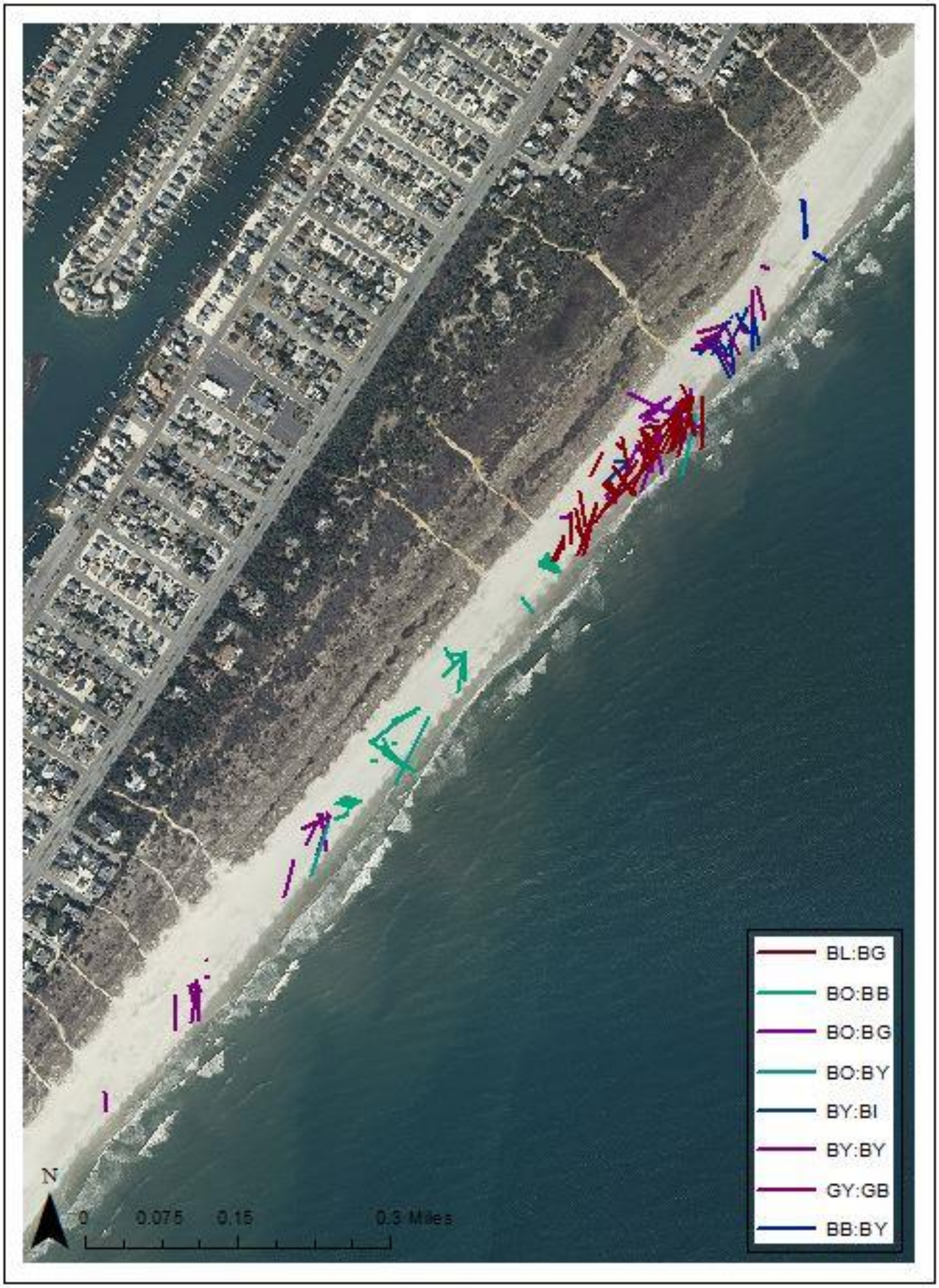


Figure 2.20. Flight paths of 8 piping plovers at Avalon, NJ, 2013. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -38.35, *P*<0.001).

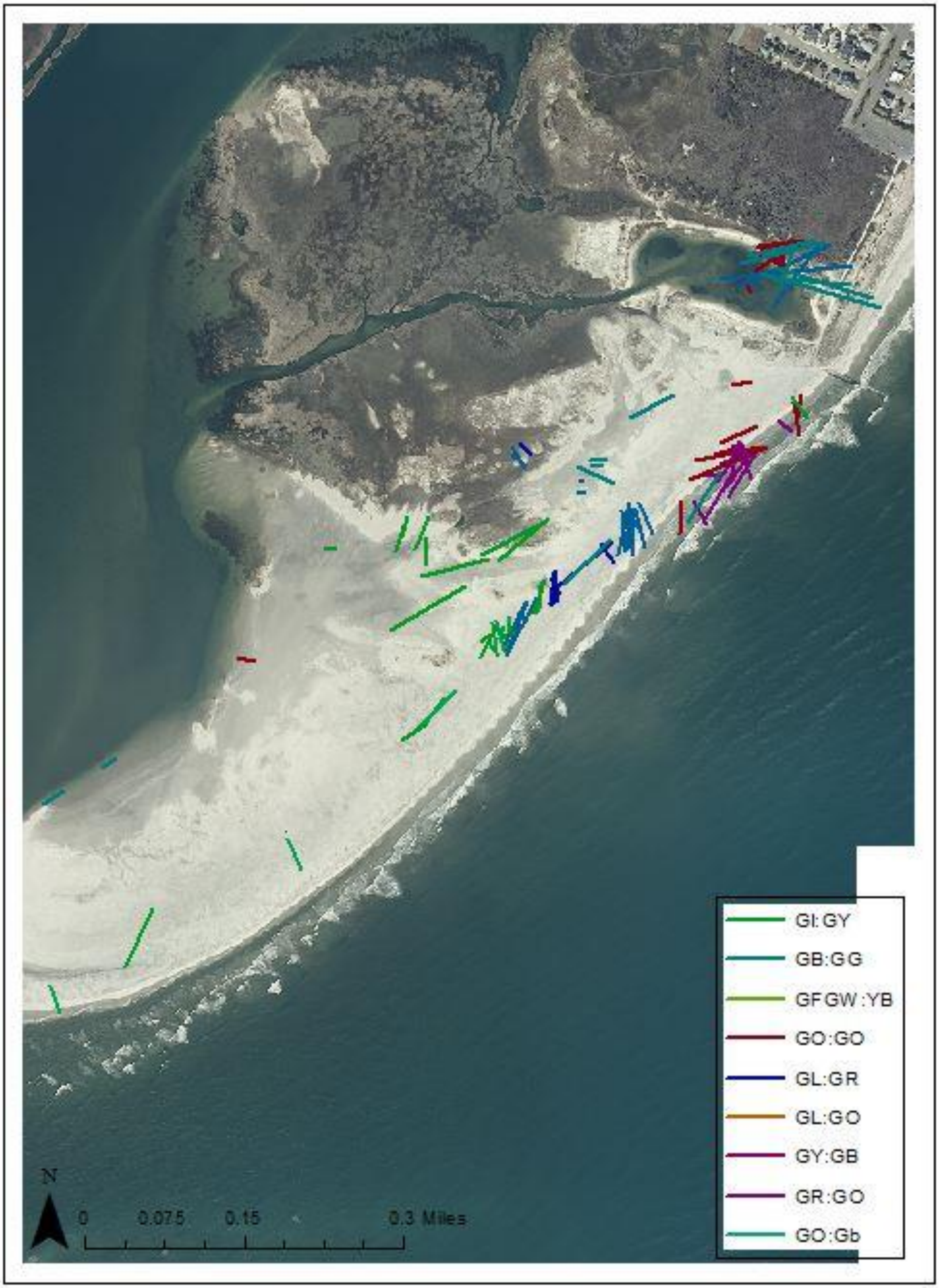


Figure 2.21. Flight paths of 9 piping plovers at Stone Harbor, NJ, 2013. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -17.36, *P*<0.001).

Figure 2.22. Flight paths of 9 piping plovers at Strathmere, NJ, 2013. The distribution of the center points of flight paths are clustered by territory (MRPP, Test Statistic = -31.33, *P*<0.001).

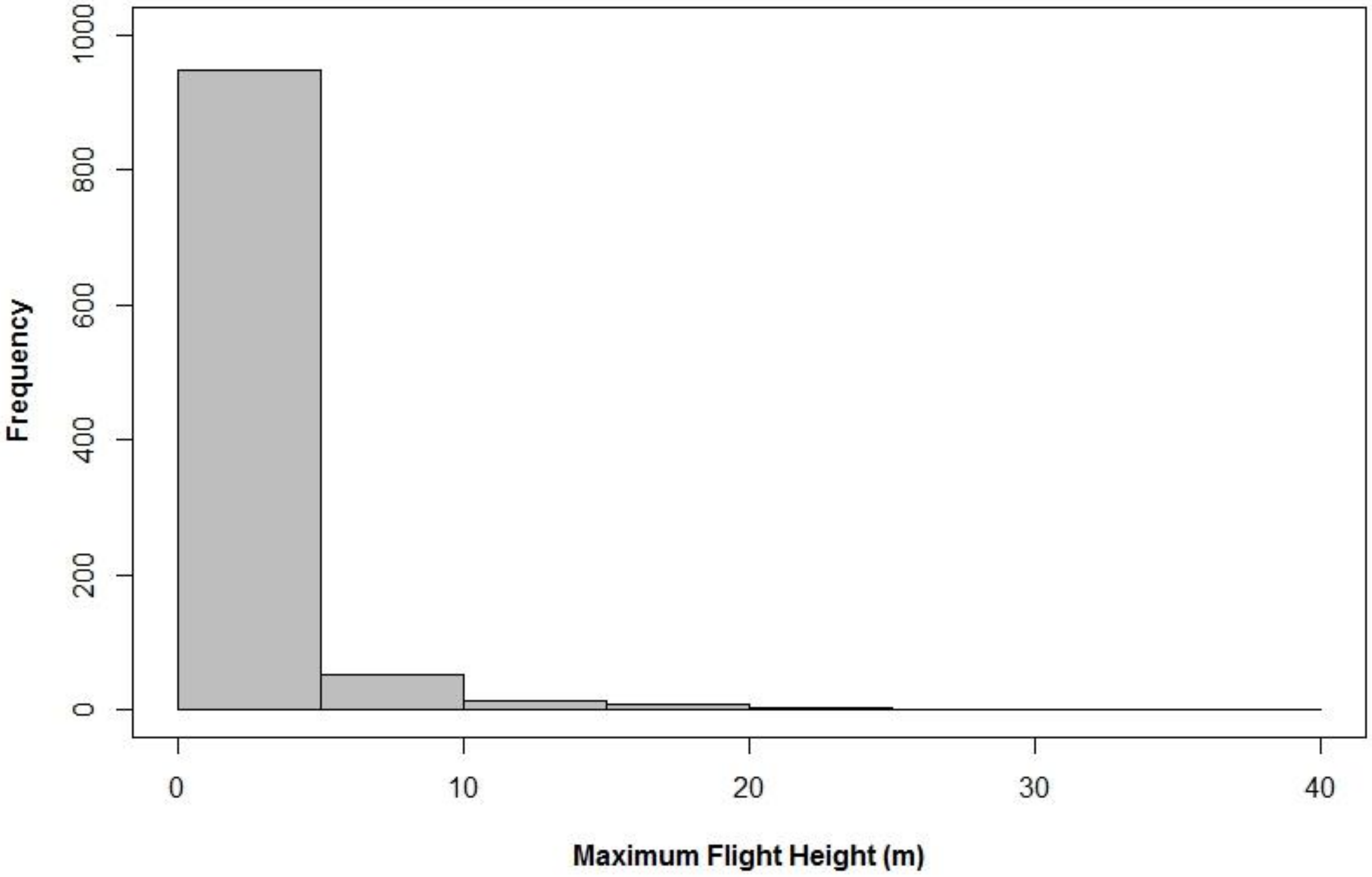


Figure 2.23. Histogram of visually-estimated maximum flight height (m) of 1,066 non-courtship flights made by piping plovers, MA and NJ, 2012.

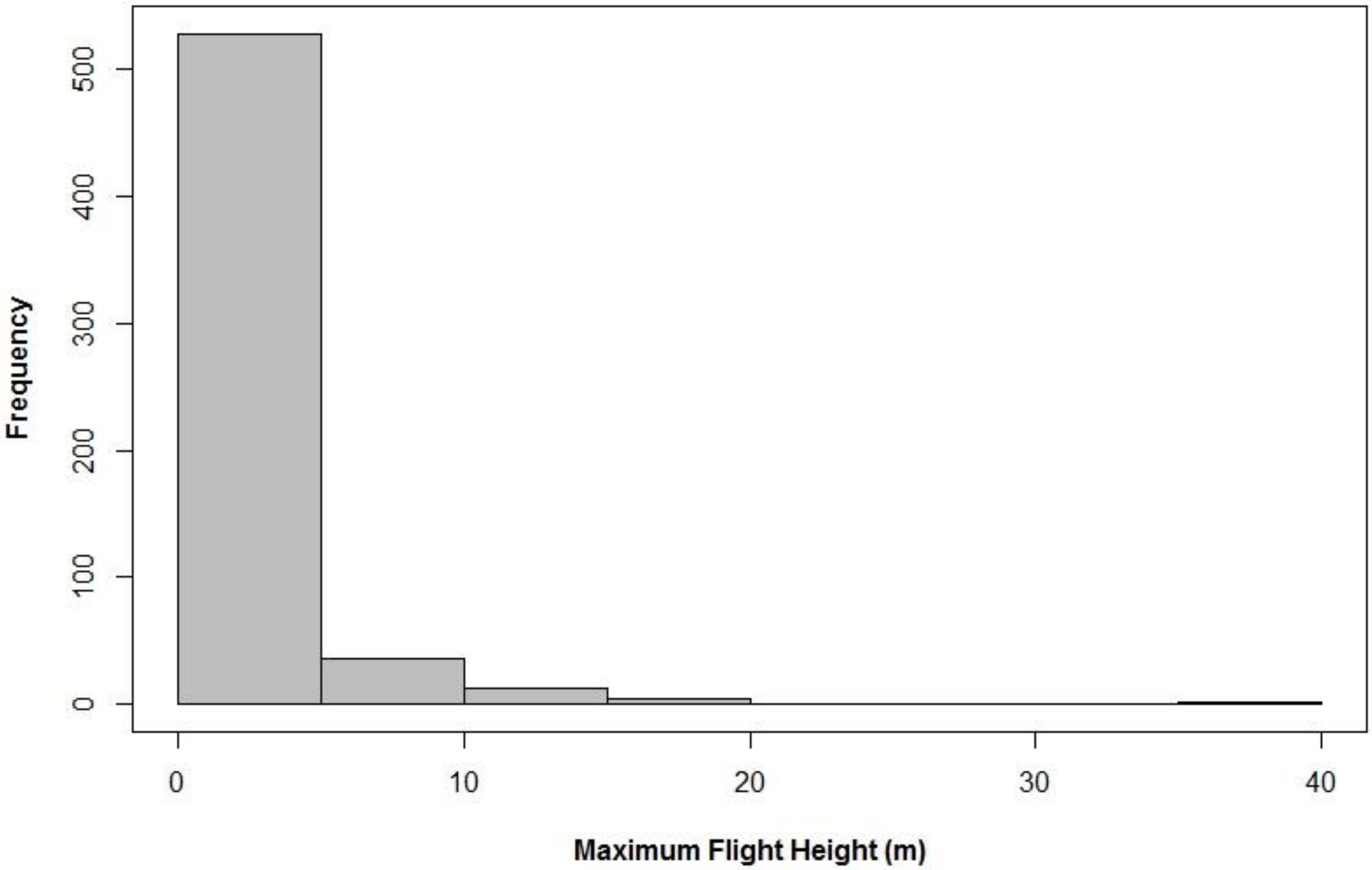


Figure 2.24. Histogram of visually-estimated maximum flight height (m) of 608 non-courtship flights made by piping plovers, MA and NJ, 2013.

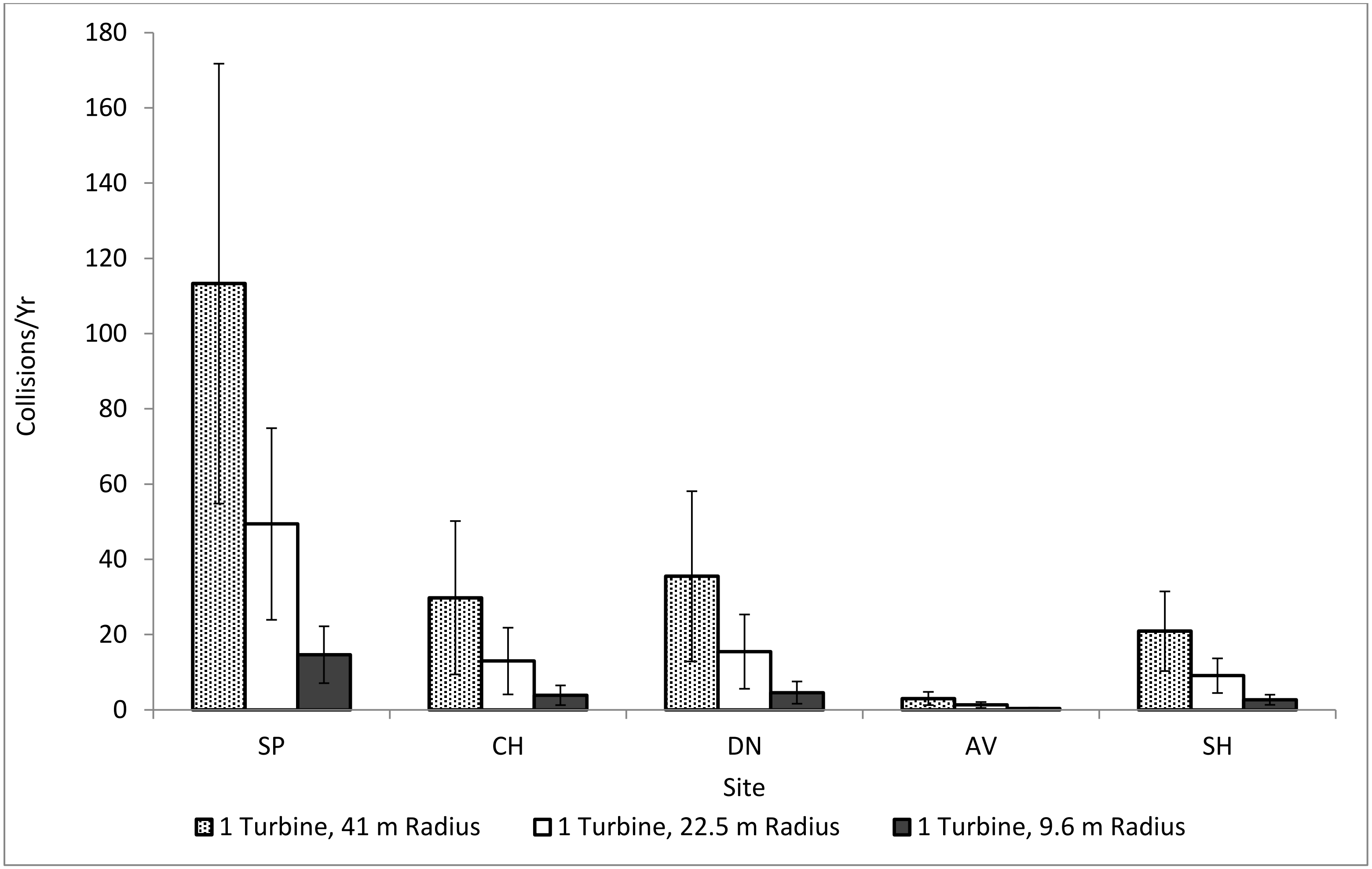


Figure 2.25. Estimated number of piping plover collisions unadjusted for avoidance at a hypothetical wind farm within a piping plover territory on an annual basis for flights/hr across a 24-hr period. Estimates are calculated using diurnal flight frequency through the risk window of a study site multiplied by 2.45 to account for increased numbers of flights at night, flight speed (m/s), site width (m), volume of the potential wind farm (m^3), and volume of the rotor swept zone (m^3). Sites include Spring Hill Beach (SP), Chapin Beach (CH), and Dead Neck (DN), MA and Avalon (AV) and Stone Harbor (SH), NJ, and 95% confidence interval bars are shown.

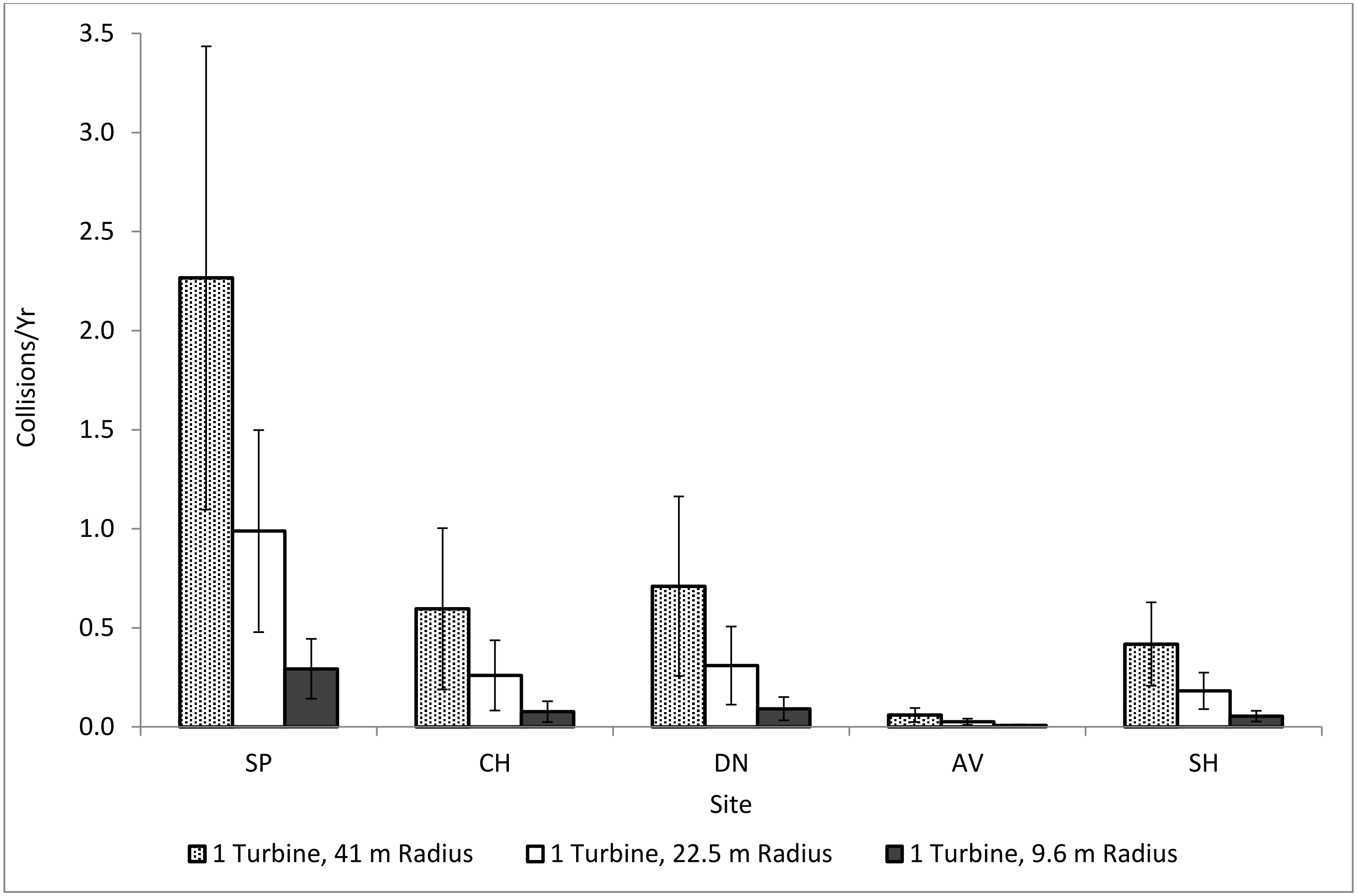
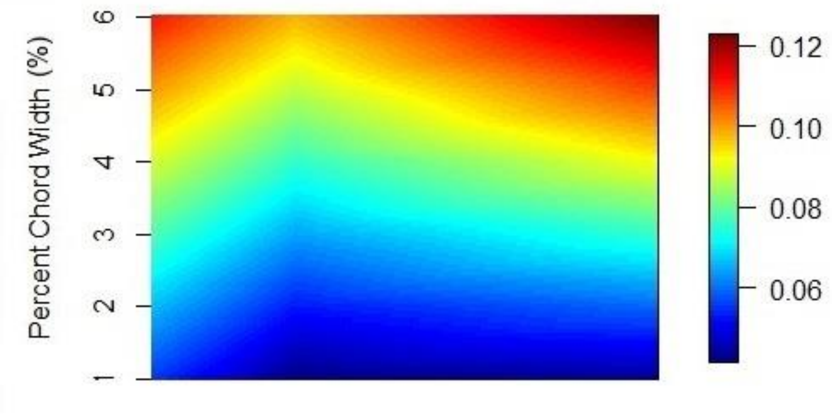
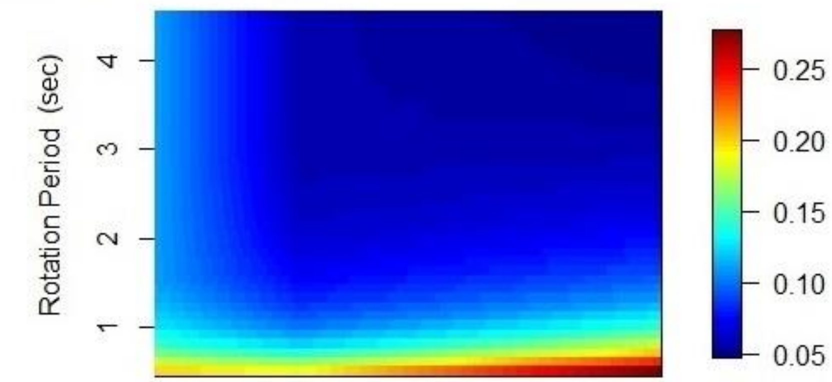


Figure 2.26. Estimated number of piping plover collisions adjusted for 98 percent avoidance at a hypothetical wind farm within a piping plover territory on an annual basis for flights/hr across a 24-hr period. Estimates are calculated using diurnal flight frequency through the risk window of a study site multiplied by 2.45 to account for increased numbers of flights at night, flight speed (m/s), site width (m), volume of the potential wind farm (m^3), and volume of the rotor swept zone (m^3). Sites include Spring Hill Beach (SP), Chapin Beach (CH), and Dead Neck (DN), MA and Avalon (AV) and Stone Harbor (SH), NJ, and 95% confidence interval bars are shown.

a) Varied Chord Width



b) Varied Rotation Period



c) Varied Pitch

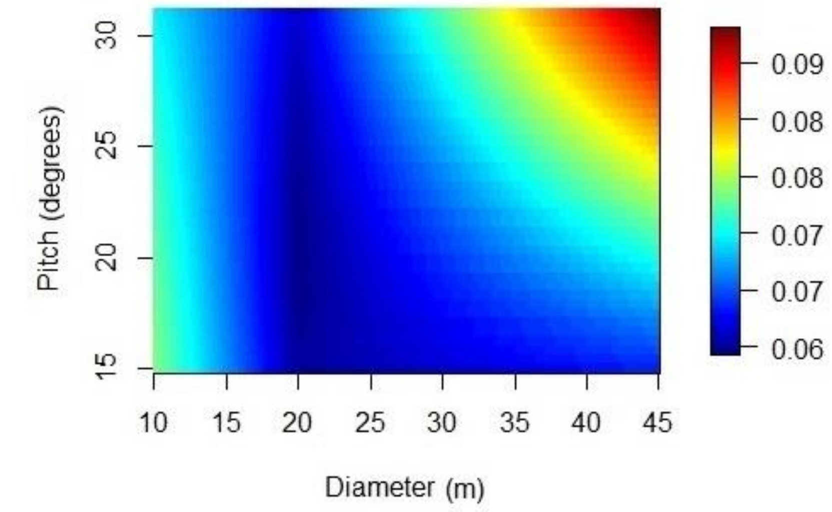
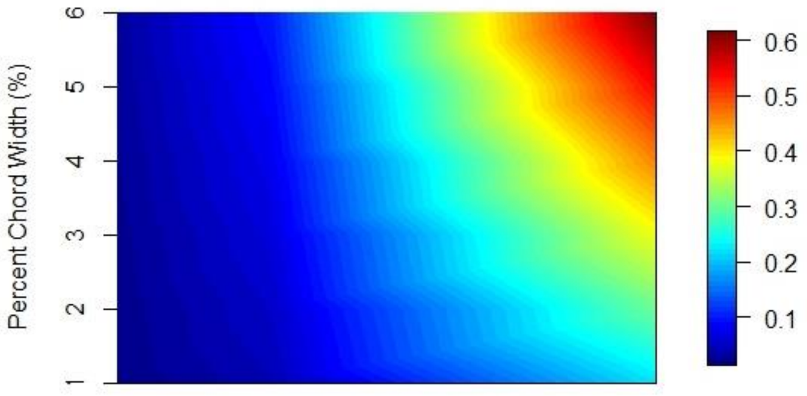
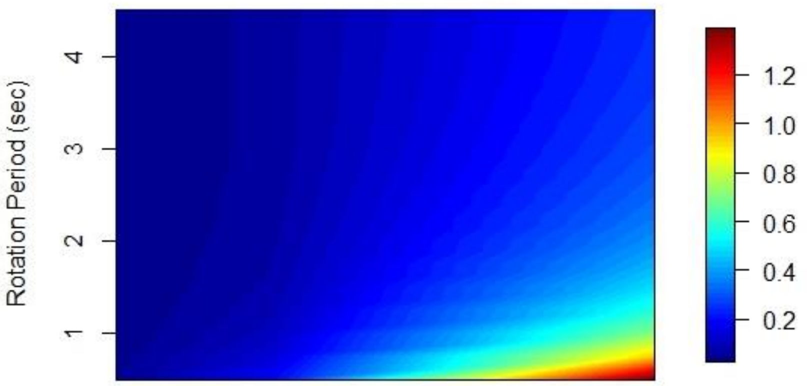


Figure 2.27. Probability of collision for a piping plover passing through the rotor swept zone of a wind turbine given diameter and a) chord width (% of the diameter), b) rotation period, and c) blade pitch.

a) Varied Chord Width



b) Varied Rotation Period



c) Varied Pitch

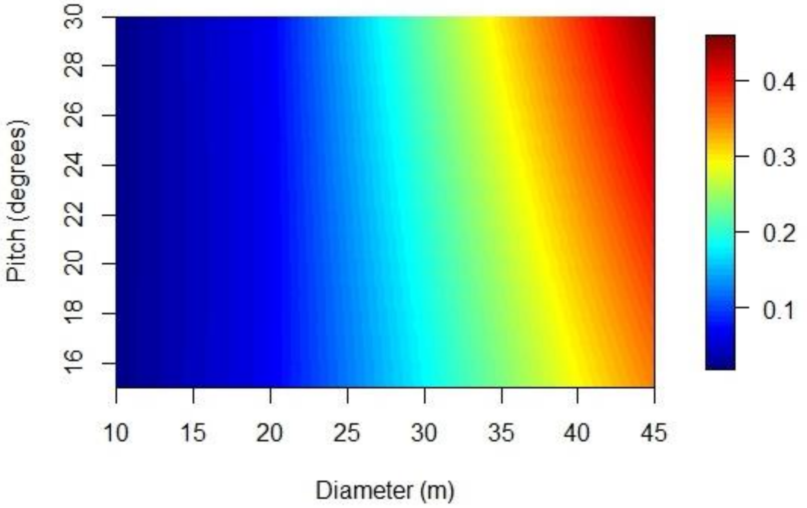


Figure 2.28. Estimate number of collisions with wind turbines per year given 98% avoidance for piping plovers given diameter and a) chord width (% of the diameter), b) rotation period, and c) blade pitch.

Appendix 2.A. Equations used to calculate the distance traversed by the bird as perceived by the camera during flight speed trials, 2012 – 2013.

	E	S_1	S_2	O	Equation for r	Notes
1	L	C	C	C	d	bird flies over post line
2	R	C	C	C	d	bird flies over post line
3	R	C	R	R	$d/\cos(\theta_2)$	one end of the flight path is at a post
4	R	C	L	L	$d/\cos(\theta_2)$	one end of the flight path is at a post
5	L	R	C	R	$d/\cos(\theta_2)$	one end of the flight path is at a post
6	L	L	C	L	$d/\cos(\theta_2)$	one end of the flight path is at a post
7	R	R	C	L	$d/\sin(\theta_2)$	one end of the flight path is at a post
8	R	L	C	R	$d/\sin(\theta_2)$	one end of the flight path is at a post
9	L	C	R	L	$d/\sin(\theta_2)$	one end of the flight path is at a post
10	L	C	L	R	$d/\sin(\theta_2)$	one end of the flight path is at a post
11	R	R	R	C	$(a*\sin(\theta_1))/(\sin(90- \theta_1)) + d$	bird flies parallel to post line, to the right of referee
12	L	R	R	C	$(a*\sin(\theta_1))/(\sin(90-A)) + d$	bird flies parallel to post line, to the right of referee
13	R	L	L	C	$d - (a*\tan(\theta_1)*\sin(90+ \theta_1))/\sin(90- \theta_1)$	bird flies parallel to post line, to the left of referee

14	L	L	L	C	$d - (a*\tan(\theta_1)*\sin(90+ \theta_1))/\sin(90- \theta_1)$	bird flies parallel to post line, to the left of referee
15	R	R	R	R	$(a*\sin(\theta_1))/(\sin(90- \theta_1+ \theta_2)) + d/\cos(\theta_2)$	neither end of the birds' flight path is at the post line, bird does not cross post line during flight
16	L	R	R	R	$(a*\sin(\theta_1))/(\sin(90- \theta_1+ \theta_2)) + d/\cos(\theta_2)$	neither end of the birds' flight path is at the post line, bird does not cross post line during flight
17	R	R	R	L	$(a*\tan(\theta_1)*\sin(90+ \theta_1))/\sin(90- \theta_1- \theta_2) + d/\cos(\theta_2)$	neither end of the birds' flight path is at the post line, bird does not cross post line during flight
18	L	R	R	L	$(a*\tan(\theta_1)*\sin(90+ \theta_1))/\sin(90- \theta_1- \theta_2) + d/\cos(\theta_2)$	neither end of the birds' flight path is at the post line, bird does not cross post line during flight
19	R	L	L	L	$d/\cos(\theta_2) - (a*\tan(a)*\sin(90+ \theta_1))/\sin(90- \theta_1- \theta_2)$	neither end of the birds' flight path is at the post line, bird does not cross post line during flight
20	L	L	L	L	$d/\cos(\theta_2) - (a*\tan(a)*\sin(90+ \theta_1))/\sin(90- \theta_1- \theta_2)$	neither end of the birds' flight path is at the post line, bird does not cross post line during flight
21	R	L	L	R	$d/\cos(\theta_2) - (a*\sin(\theta_1))/(\sin(90- \theta_1+ \theta_2))$	neither end of the birds' flight path is at the post line, bird does not cross post line during flight
22	L	L	L	R	$d/\cos(\theta_2) - (a*\sin(\theta_1))/(\sin(90- \theta_1+ \theta_2))$	neither end of the birds' flight path is at the post line, bird

						does not cross post line during flight
23	R	R	L	R	a*cos(θ_2) + (d-a*tan(θ_2))/sin(θ_2)	bird's flight path crosses the post line
24	L	L	R	L	a*cos(θ_2) + (d-a*tan(θ_2))/sin(θ_2)	bird's flight path crosses the post line
25	R	L	R	R	d/(sin(θ_2)) - (a*sin(θ_1))/sin(180- θ_1- θ_2))	bird's flight path crosses the post line
26	L	R	L	R	d/(sin(θ_2)) - (a*sin(θ_1))/sin(180- θ_1- θ_2))	bird's flight path crosses the post line

E = the side of the filming zone the bird entered; R = right (same side as referee), L = left (opposite from referee)

S_1 = from the point of view of the referee sitting at the right post, did the bird enter the filming zone on her right side, left side, or at the center over the post itself (enter an R, L, or C)

S_2 = from the point of view of the referee sitting at the right post, did the bird exit the filming zone on her right side, left side, or at the center over the post itself (enter an R, L, or C)

O = orientation of the flight relative to where you measured the flight angle (did you measure the angle on the Left side of the protractor, the Right side, or down the center), L, R, or C

B = angle of flight in degrees, measured on the protractor

a = distance from right post to where the bird crossed the right side of the filming zone (where it entered or exited, depending on the direction it flew), in meters

CHAPTER 3. AUTOMATED TELEMETRY FOR MONITORING NOCTURNAL MOVEMENTS OF BREEDING PIPING PLOVERS ON THE ATLANTIC COAST

Abstract

As the focus on clean energy continues globally, collisions of birds with wind turbines in coastal areas poses a potential threat that could affect populations of imperiled or declining species. Assessing flight behaviors of beach-nesting birds during times of poor visibility can help to evaluate the potential threat of turbine construction at or near breeding areas because birds may be most susceptible to collision with turbines during the breeding season when they make frequent foraging commutes. We placed automated telemetry receivers near the nests of radio-tagged female piping plovers, a federally-threatened species, at six study sites in Massachusetts and New Jersey and determined the number of transitions between presence and absence and time spent out of range. Transitions to locations out of detection range would likely have been made by flying. Female piping plovers transitioned out of range an average of 35.91 ± 15.61 (SE) times during the day and 18.28 ± 2.59 times at night. Female piping plovers with a nest spent 63.7% ± 4.5% of the time out of detection range at night and 31.5% ± 6.2% of the time out of range during the day (MRBP, Test statistic = -3.261, $P = 0.011$). Our results suggest that, as has been found in other breeding populations, Atlantic Coast piping plovers make frequent flights at night. These movements could put them at risk of encounter with human-erected structures such as wind turbines at a time when visibility and thus the ability to avoid collision is low.

Keywords: automated telemetry, *Charadrius melodus*, Massachusetts, New Jersey, nocturnal behavior, piping plover

Bird mortality due to collisions with wind turbines is one of the major ecological concerns associated with wind farm development. As the focus on clean energy continues in the United States, the development of wind power in coastal areas poses a potential collision threat to beach nesting shorebirds and seabirds that could counteract recent recovery successes gained through protection and management. The Atlantic coast population of piping plovers (*Charadrius melodus*) was listed as threatened under the Endangered Species Act in 1986. Atlantic coast piping plovers nest on open, sandy beaches from North Carolina to Nova Scotia, and depend on the Atlantic coast for the remainder of their annual cycle (migration and wintering) (USFWS 1996). Since listing, the population has recovered from 790 pairs to more than 1898 pairs in 2012 (USFWS 2012). Recovery of the species can be attributed to an intensive effort across the breeding range to protect habitat, minimize anthropogenic disturbance, and reduce predator pressures in order to maximize survival and productivity. Wind turbines have the potential to counteract this recovery effort, and the effects of wind power development should be assessed prior to construction.

There is high potential for wind power development in shallow waters along the Atlantic coast. The U.S. Fish and Wildlife Service's Five Year Review (2009) for the recovery of the piping plover identifies 4 multi-turbine projects built and 11 proposed in the Atlantic Coast piping plover's breeding range; however, the magnitude of the threat posed by turbine collisions cannot be evaluated with current data because we lack information on behaviors that affect collision risk. Current models have demonstrated that wind power-related collision mortality is affected by rotor diameter and speed, bird speed, flight height, and avoidance behavior (Chamberlain et al. 2005). Poor weather or lighting (night-time, fog, and overcast skies) also influence bird behavior and ability to detect and avoid structures such as wind turbines that are within their flight path (Avery et al. 1977). In a study designed to evaluate potential collision risk with offshore wind turbines, Hüppop et al. (2006) found terrestrial birds to be attracted to illuminated, offshore obstacles in large numbers especially under conditions of poor visibility. Strikingly, more than half of all potential bird collisions that happened during the study period occurred on just two nights that were characterized by poor weather and poor visibility (Hüppop et al. 2006).

Piping plovers are known to be diurnally active, highly territorial, and have relatively small home-ranges; however, little is known about nocturnal activity levels on the Atlantic Coast, except that piping plovers forage at night (Staine and Burger 1994). Most avian behavior studies have focused on tracking individuals during the day due to the logistical difficulties of tracking birds at night; however, a number of recent studies have focused specifically on nocturnal bird behavior, recognizing that activity levels may actually increase at night. Ward et al. (2014) discovered that both male and female yellow-breasted chat (*Icterina virens*), another diurnally active and territorial species, are active outside of their territories at night, with fertile females being the most likely to engage in extraterritorial behavior. Sherfy et al. (2012) examined movements of piping plovers and least terns nesting on the central Platte River, Nebraska and found that piping plover movements increased between 20:00 and 04:00. Because birds appear to be more at risk of collision during times of poor visibility, and bird activity levels have been shown to increase at night, the need to study Atlantic coast piping plover nocturnal behavior has become increasingly apparent.

Because of the difficulty of sighting animals during periods of low visibility, obtaining behavioral information can be challenging. Radio-telemetry offers a method of locating an animal without seeing it. By attaching a frequency-specific transmitter which emits an electromagnetic pulse to the study animal, researchers can use specialized antennas to receive the pulse signals that are being broadcast and track the animal of interest. Triangulation is a common way to determine the exact location of an animal at a given point in time. Triangulation works by calculating the location of an individual using two or more directional bearings (Lee et al. 1985). This process can be performed both manually and through the use of an automated system where information is logged for long periods of time. Allocating resources dedicated to manual means of conducting both nocturnal and diurnal behavioral observations can be logistically difficult; therefore, the use of automated telemetry to study animal behavior over extended periods of time is increasing (Kays et al. 2011, Ward et al. 2013). Such automated telemetry receiving systems can be placed in high use areas to detect animals and log presence-absence data as well as provide information about the times of the day when piping plovers are most active, helping to evaluate behaviors that may increase collision risk.

Our objectives were to determine periods in the diel cycle when nesting female piping plovers were most active, to examine the amount of time that females spent away from the nest over a 24-hour period, and to examine movement frequency of female piping plovers at times of poor visibility. This information can provide better insight into the nocturnal behavioral characteristics of female piping plovers, at a time of increased risk of collision. Our results can be used by resource agencies to evaluate permit requests for turbine construction in piping plover breeding areas.

METHODS

Study Areas

A total of six study sites were selected for the 2013 field season (Fig. 3.1). Three study sites were located in southern New Jersey: Avalon, Stone Harbor Point, and Strathmere. Three study sites were located on Cape Cod, Massachusetts: Spring Hill Beach, Sandwich; Chapin Beach, Dennis; and Dead Neck/Sampson's Island, Barnstable. Chamberlain et al. (2006) suggested that data for the collision risk model should be derived from localities as similar as possible to the locations under consideration, and bird collision probabilities have been shown to depend on topographic features (de Lucas et al. 2008). Therefore, study sites were chosen to represent a variety of habitat configurations that consisted of differing arrangements of nesting habitat that may or may not be contiguous with desirable foraging habitat. We also gave consideration to sites that have historically supported samples sizes of at least 5 breeding pairs of piping plovers to obtain a sample size big enough for statistical inferences.

Avalon-Dunes, Avalon, New Jersey (N 39.079176, W -74.732010) was located in the southern part of the state on the northern portion of a barrier island along the Atlantic Ocean called Seven Mile Island. The site consisted of sparsely vegetated areas and open, sandy areas on the berm of the beach below the dune, which provided suitable nesting habitat for piping plovers. Foraging areas contiguous with nesting habitat for both adults and chicks was limited to the ocean side intertidal zone and wrack line given that access to bayside foraging was obstructed by coastal development.

Stone Harbor Point, Stone Harbor, New Jersey (N 39.028307, W -74.777536) was located at the southern-most end of Seven Mile Island at the Hereford Inlet. The site consisted of low-lying, open sand and cobble areas and sparsely vegetated dunes, which provided suitable nesting habitat for piping plovers. Ample bayside and oceanside foraging existed and corridors between bayside and oceanside were maintained by frequent washover events that occurred during strong storms and monthly high tides. An additional foraging area for piping plovers was created on the northern end of the site and included an artificial pond (contained dredge facility) that was tidally influenced.

Strathmere Natural Area, Strathmere, New Jersey (N 39.202334, W -74.651514) was located on the northern portion a barrier island known as Ludlam Island at Corson's Inlet. The site consisted of sparsely vegetated areas and open, sandy areas on the berm of the beach below the dune, which provided suitable nesting habitat for piping plovers. Depending on nest location and territory size, foraging areas contiguous with nesting habitat may have been limited to the oceanside intertidal zone and wrackline or may have contained corridors between bayside and oceanside foraging habitats.

Spring Hill Beach (N 41.762756, W -70.477318) was located on Cape Cod Bay, on the north side of Cape Cod in Sandwich, MA. The site contained a barrier spit with a rocky/cobble/sand-mixed beach on the north side and an extensive marsh system on the south side. The areas of the study site extending 0.88 km east of the tip of the barrier spit were free of coastal development, and private homes were distributed within the dune system for the remaining 1.2 km. The nesting habitat was varied, including sparsely vegetated, sandy areas below the toe of the dune, open cobble areas on the berm of the beach, and sparsely-vegetated and open washover areas to the west. Bayside foraging access for chicks was obstructed by coastal development to the east, but the bay side was easily accessible to the west through washover corridors.

Chapin Beach (N 41.72780, W -70.23870) was located on Cape Cod Bay on Cape Cod in Dennis, MA. The site contained a barrier spit free of coastal development that extends southwest toward Barnstable Harbor. Open sandy areas and sparsely vegetated dunes provided nesting habitat for piping plovers. Ample bayside and oceanside foraging areas existed, and corridors between the bayside and oceanside were maintained by frequent washover events that occur during strong storms and monthly high tides.   Due to extreme tidal fluctuations, additional foraging areas for piping plovers included the extensive sand flats exposed at low tide both on the ocean side and bay side. A single wind turbine was proposed at this site for the Aquacultural Resource Center, which was located on the bay side, behind the dune system.

Dead Neck/Sampson’s Island (N 41.60627, W -70.42130) was located on Nantucket Sound, on the south side of Cape Cod in Barnstable, MA. This site was constructed primarily of dredge materials, which were been deposited at both the east and west ends of the island. This study focused efforts on the east end (Dead Neck) due to ease of access and concentrations of nesting birds in 2012; however, the banding and research efforts were extended in the 2013 field season to include the west end (Sampson’s Island). A variety of nesting habitats existed on the island: sparsely vegetated, sandy areas below the toe of the dune occurred towards the center of the island and open cobble areas and sparsely-vegetated areas became more frequent to the east where the dredge materials were deposited. Foraging habitats included the intertidal zone on the bayside and large accumulations of wrack that occurred on the oceanside. Additionally, a tidally fed pond served as foraging habitat for piping plovers nesting towards the center of the island.

Field Methods

We uniquely marked piping plovers with leg bands and attached radio transmitters to a subsample in order to obtain individual-specific data on flight paths and flight characteristics. We captured adult plovers on their nests using walk-in funnel traps (Cairns 1977). We marked adults individually using colored Darvic bands (yellow, dark green, dark blue, light blue, black, gray, red, or orange).   At study sites in Massachusetts, each marked individual received a single color-band on each upper leg. At study sites in New Jersey, each individual was marked with two color-bands on each upper leg. In addition to color-banding, we fitted a subset of females and fledglings with radio transmitters prior to release.

We fixed radio transmitters to the intrascapular region of both adult females and fledglings. Methods of tag application to adult females evolved throughout the course of the 2012 field season as we attempted to improve retention time of radio transmitters. From 11 May 2012 to 15 May 2012, we plucked a small patch of feathers in the intrascapular region to expose the skin of the bird, applied cyanoacrylate superglue to the transmitter, glued the transmitter directly to the skin of the bird, and then held the transmitter in place for 1 – 2 min prior to release of the bird. Between 23 May 2012 and 28 May 2012, we used two different methods for applying radio transmitters. The first method was to use Osto-bond (Montreal Ostomy, Quebec, Canada) medical glue, which has been formulated for the attachment of medical devices to human skin. The Osto-bond glue was applied in the same manner as previously stated; however, this glue required a longer drying time, and we placed the birds in a soft-shelled holding cage for 5 minutes prior to release. In the second method, we clipped feathers down to 1 – 2 mm of stubble in the intrascapular region using fingernail scissors (no feathers were plucked), and applied the transmitter to the stubble using cyanoacrylate superglue. We held the transmitter in place for 60 – 90 seconds until the glue was firm, and then the adult was placed in a soft-shelled holding cage to allow the glue to dry further. Radio transmitters were applied to all fledglings by spreading the feathers to reveal a patch of skin and attempting to glue directly to the skin and feather bases. Only cyanoacrylate superglue was used to affix radio transmitters to fledglings, and no feathers were clipped or plucked from fledgling piping plovers.

For transmitter attachment during the 2013 field season, we employed the “clipping” method which proved to be successful in 2012. For this method, we clipped feathers down to 1 –

2 mm of stubble in the intrascapular region, and the radio-tag was applied to the stubble using cyanoacrylate superglue. We held the tag in place for 60 – 90 sec until the glue was firm, and then the adult was placed in a soft-shelled holding cage to allow the glue to dry further prior to release of the bird.

From May to July 2013, we employed the use of automated telemetry stations known as SensorGnomes (sensorgnome.org, Nova Scotia, Canada). Each unit was made up of a circuit board (BeagleBone, Richardson, TX) with a microSD card, which housed the software, and a USB port, which connected the circuit board to a USB hub. A 3-element or 5-element Yagi antenna (ATS, Isanti, MN) was used to receive the signal from the bird antenna and was mounted 1 m to 2 m above the ground on a tripod. The Yagi antenna was connected to a FUNcube dongle (AMSAT-UK, Blanford, United Kindom) via a coaxial cable, and the FUNcube dongle could then be plugged into the USB hub for connection to the circuit board, making the computer a radio receiver. Also plugged into the USB hub was a 1 GB storage device and a GPS unit, which logged a time stamp for each signal that was received. The unit was powered by a 12-volt deep cycle marine battery that was recharged on a daily basis via a solar panel.

The stations were positioned where we had observed radio-tagged female piping plovers flying from nesting sites to foraging sites during the daytime, and left for 24 h to 72 h to record the presence of birds within detection range continuously. If a bird was within range of the automated telemetry unit, a signal would be logged every 1 sec to 3 sec. On 4 occasions, we ground-truthed the automated receiver using handheld ATS R410 receivers (ATS Inc, Isanti, MN) and a 3-element Yagi antenna.

We ground-truthed automated telemetry logged data by conducting 1-hr day-time behavioral observations of radio-tagged females. The start and end time of each behavioral observation was recorded and the bird was followed throughout the course of the observation. If a flight occurred during the course of the observation, the time of the flight was documented to determined and compared to logged data from the automated telemetry units.

Data Processing and Analysis

We looked at the temporal pattern of radio detections by the automated telemetry units. Due to recognized issues with changes in signal strength and bird proximity during ground-truthing periods, we determined birds to be out of range if a detection did not occur over the period of one minute or longer. During behavioral observations, it was noted that when a bird's antenna was oriented parallel to the ground and facing the observer, a remarkable drop in signal strength was observed despite the fact that the bird was located in close proximity to the observer. This could occur, for instance, when a bird was incubating; however, we also noted that birds often shifted on the nest during these stationary periods. For this reason, any periods where a bird was out of range for less than one minute, could have been due to a stationary bird that was "within range" that was not detected by the telemetry unit.

After identifying periods where a bird was out of range, we summed the number of minutes that each individual female spent out of range of the automated receiver. We considered diurnal periods to be between 06:00 – 20:00 and nocturnal periods to between 20:00 – 06:00 (Sherfy et al. 2012). Multi-Response Randomized Block Procedure (MRBP) with individual birds as blocks was used with Blossom Statistical Software (Cade and Richards 2005) to determine whether percent time out of ranged differed between day and night.

RESULTS

Ground-truthing results indicated that the automated telemetry units were reliably logging detections of birds within range of the receiving antenna (Fig. 3.2). A total of 15,542 detections were logged from 10 female piping plovers using automated telemetry units in 2013 (Table 1). Female piping plovers at all study sites made more transitions in and out of range during the day than at night. We documented a total of 839 transitions out of range during the day and 512 transitions at night. Females in New Jersey transitioned out of range 298 times during the day and 210 at night whereas females in Massachusetts transitioned out of range 541 times during the day and 302 at night. Female piping plovers transitioned out of range an average 35.9 ± 15.6 times during the day and 18.3 ± 2.6 times at night.

Female piping plovers with a nest spent more time out of range at night than during the day (MRBP, Test statistic = -3.261, $P = 0.011$) (Fig. 3.3 – 3.4). The average percent of time that female piping plovers with a nest spent out of range during diurnal periods was 31.5 percent (SE ± 0.04); in contrast, the average amount of time that female piping plovers with a nest spent out of range during nocturnal periods was 63.7 percent (SE ± 0.44).

DISCUSSION

Many studies have documented nocturnal behavior of what is typically believed to be diurnally active bird species. Ward et al. (2014) discovered that both male and female yellow-breasted chat (*Icterina virens*), are active outside of their territories at night, with fertile females being the most likely to engage in extraterritorial behavior. Kostecke and Smith (2003) found that wintering American avocets (*Recurvirostra american*) in southern Texas spent more time foraging (62%) and less time resting (20%) during the night than during the day (45% and 37.5%, respectively). Sherfy et al. (2012) found that piping plover movements away from nesting areas occurred almost exclusively between the hours of 20:00 and 05:00 (n = 113; 86 percent), demonstrating a nocturnal increase of 2.45 times the diurnal movements. We found that Atlantic coast female piping plovers with a nest spend more time at the study site in the vicinity of their nest during the day and less time at the study site at night. We also found that transitions out of range were lower during nocturnal periods likely because females leave the site at night and do not return for longer periods of time, whereas day time transitions indicate more frequent incubation swaps between males and females. While we cannot confirm that piping plovers are more active at night than during the day with these data, we can confirm that they are quite active at night both within and outside of the typically delineated breeding site, when avoidance of structures in their flight path could be difficult.

The risk of collision with anthropogenic structures is high during times of poor visibility. Deng and Frederick (2001) documented that waterbirds flying at night were less likely to react to a 550v transmission line in an open, flat landscape than during the day. On overcast nights the number of migrants observed at a 366 m transmission tower in North Dakota was significantly greater than the number seen at a towerless location (Avery et al. 1976). More than half of all bird collisions at an off-shore platform in the German Bight of the North Sea occurred on just two nights that were characterized by poor weather and poor visibility (Hüppop et al. 2006). Because birds experience the highest collision risk during times of poor visibility such as rain, fog, overcast skies, and at night, it is vitally important to continue to pursue piping plover night time behavior as an area of concern for risk of collision with wind turbines. Our study confirmed that female piping plovers are nocturnally active; however, we were unable to examine nocturnal behavior of males due to limitations in the number of radio-transmitters we could deploy.

Female piping plovers might be at more risk than males of collisions with anthropogenic structures at night. On several occasions during the 2012 field season, observers attempted to conduct behavioral observations of females but had a difficult time locating the females at night using radio-telemetry. On one occasions, observers were concerned that the nest might be unattended, approached the nest carefully with a flashlight and binoculars, and confirmed the presence of the male incubating the eggs. A study examining black tern (*Childonias niger*) incubating behavior at two colonies in the Netherlands found that during the day, females incubated eggs 60% of the time whereas at night, males completely took on the role of incubation while females spent the night at a communal roost more than 3 km away from the breeding colony (van der Winden 2005). Furthermore, a study of common ringed plover (*Charadrius hiaticula*) in southwest Sweden found that males incubated the nest more at night (58%) than females, demonstrating another *Charadrius* species with predominately male nocturnal nest attendance (Wallander 2003). Due to limitations in the number of transmitters deployed during our study, we tagged only females; however, a future study that would allow radio-tagging of both males and females could examine the differences in diurnal and nocturnal nest attendance between the sexes. During 2012 nocturnal behavioral observations, when females were not detected using manual telemetry, we anecdotally confirmed that male piping plovers were incubating by approaching the nest with binoculars and a flashlight to clearly read the band combination of the incubating bird.

Radio telemetry allows biologists to examine population parameters such as survival, home range/territory size, and movement frequency. However, reliability of radio-telemetry, especially with automated stations, may decrease as the size of the study animal becomes small. The additional interaction between the receiving antenna and the transmitting antenna is dependent upon their orientation relative to one another. Anecdotally, we found that when a bird was facing towards the observer with an antenna, the signal strength dramatically decreased. Transmitting antennas can undergo changes in frequency due to increases in temperature and humidity, causing the signal to “drift” and requiring a user to manually locate the signal. Additionally, because Yagi antennas are highly directional, they are most useful in pinpointing an individual wearing a dipole (omni-directional) antenna. The use of multiple Yagi antennas in conjunction with an automated telemetry unit datalogger would provide a clearer picture of the direction of movement as a bird leaves a study area, in addition to a wider (not longer) range of detection, whereas our study was limited to presence/absence from a study site with the use of a single Yagi antenna at each automated telemetry unit. Nonetheless, our results show promise that an enhanced automated telemetry array might provide detailed information on nighttime flight behaviors.

Table 3.1. Number of detections and transitions out of range during the day and at night by ten female piping plovers using three automated telemetry units, 2013.

Unit Location	Day Transitions	Night Transitions	Total Detections
Massachusetts (1)	467	419	6884
Massachusetts (2)	372	93	2666
New Jersey	298	210	5992
Total	1137	722	15,542

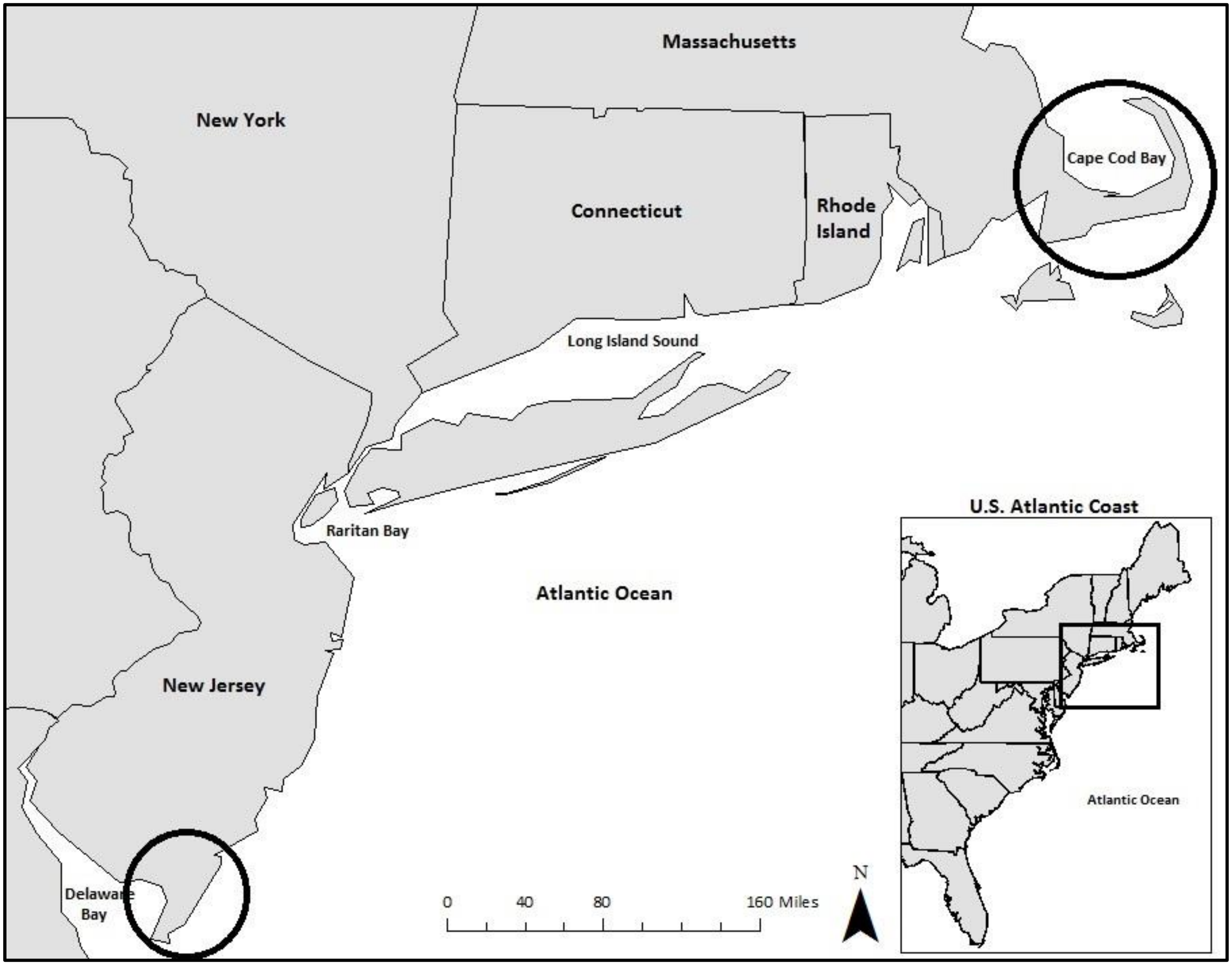


Figure 3.1. Location of study sites for piping plover flight characteristic study in southern New Jersey and Cape Cod, Massachusetts, 2012-2013.

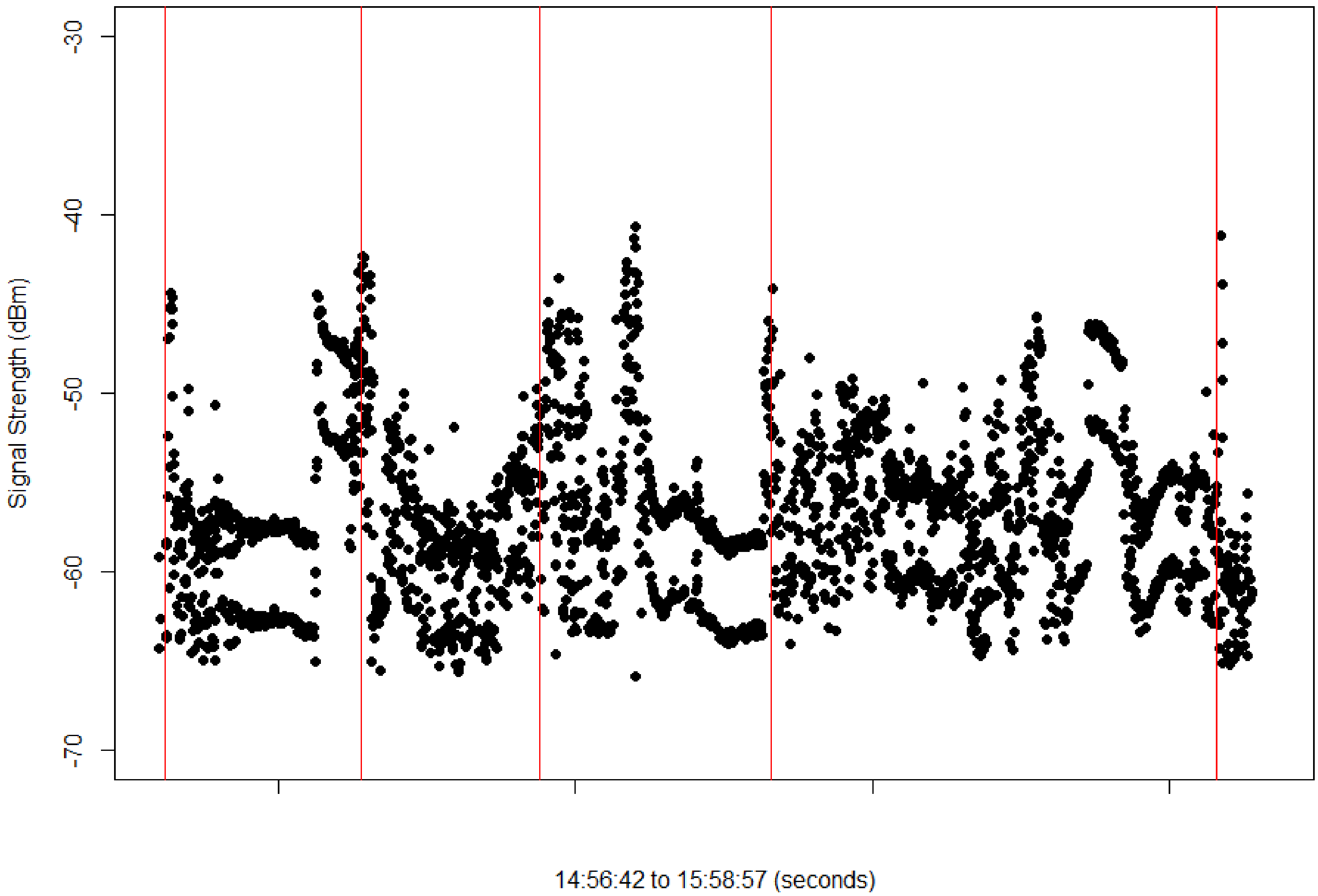


Figure 3.2. Example of ground-truthing of the automated telemetry unit with manual radio-telemetry for piping plover, Massachusetts 2013. Black dots indicate signal detections, lines indicate observed flights. Periods where the signal strength is stationary (flat areas) are likely times when the bird was incubating. Periods with no signal strength readings indicate absence of the bird from the detection range of the automated receiving station, although the bird was within range of the automated telemetry unit during the entirety of all ground-truthing periods.

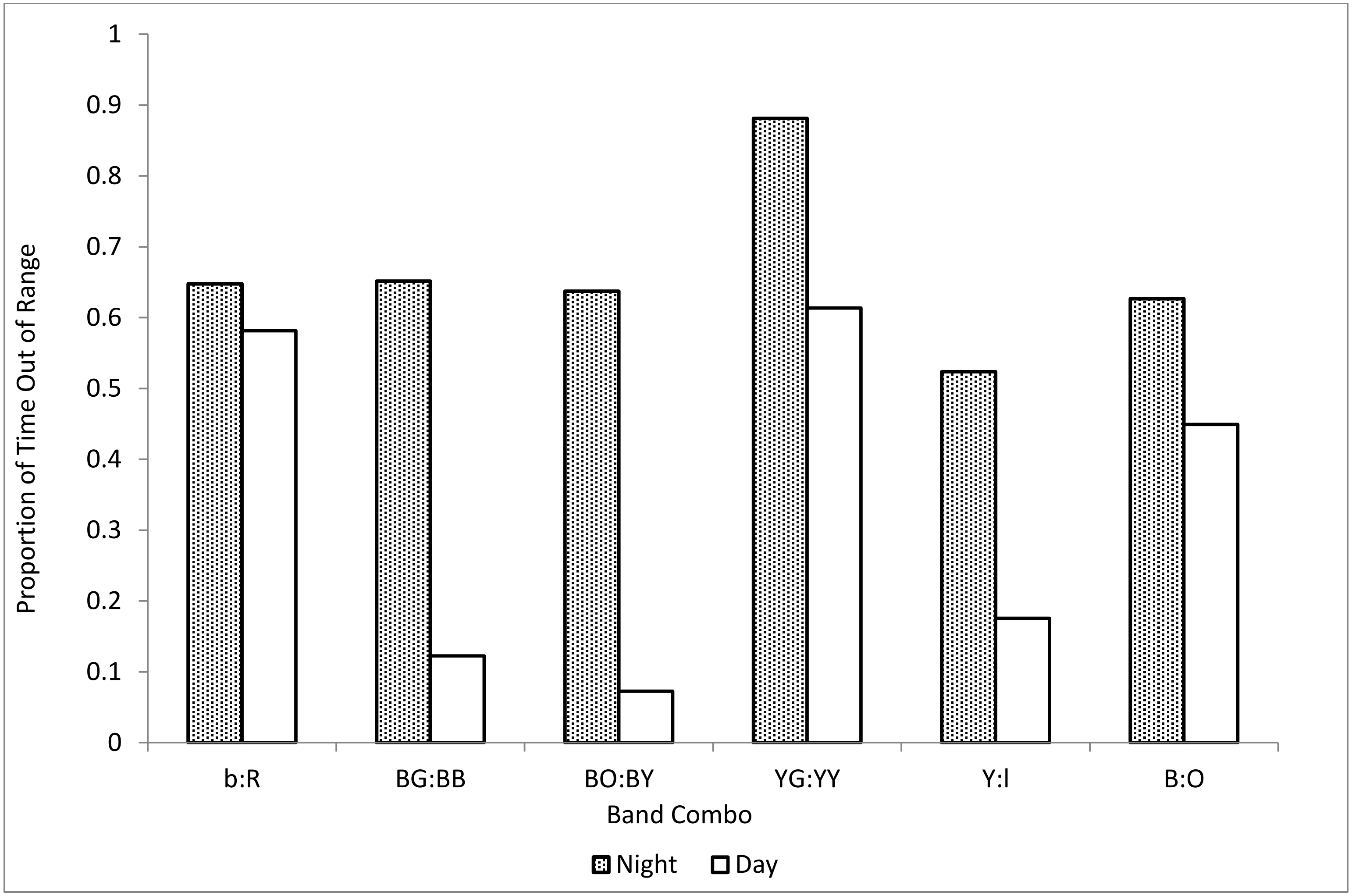
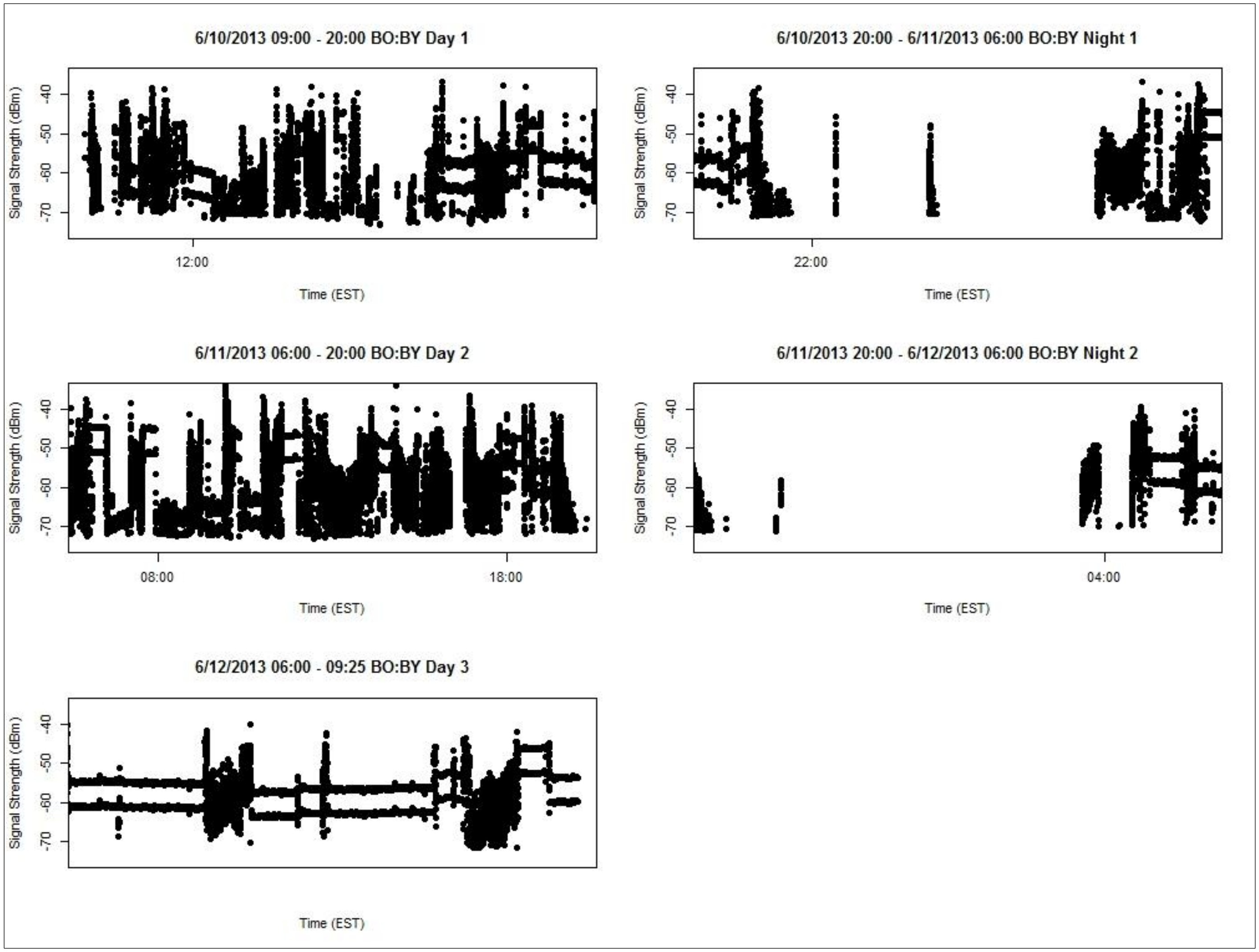


Figure 3.3. Proportion of time female piping plovers with nests spent out of range of automated telemetry receivers, MA and NJ, 2013. Mean time spent out of range was greater at night than during the day (Multiresponse Blocked Permutation Procedure, Test statistic = -3.261, *P* = 0.011).


6/10/2013 09:00 - 20:00 BO:BY Day 1

6/10/2013 20:00 - 6/11/2013 06:00 BO:BY Night 1

6/11/2013 06:00 - 20:00 BO:BY Day 2

6/11/2013 20:00 - 6/12/2013 06:00 BO:BY Night 2

6/12/2013 06:00 - 09:25 BO:BY Day 3

Figure 3. 4. Example signal detection plots for a radio-tagged piping plover at Avalon, NJ, 2013. Daytime observations are on the left, night observations are on the right. Black dots indicate signal detections. Periods where the signal strength is stationary (flat areas) are likely times when the bird is incubating. Periods with no signal strength readings indicate absence of the bird from the detection range of the automated receiving station.

CHAPTER 4. ESTIMATING APPARENT WEEKLY SURVIVAL, DETECTION AND BREEDING STATUS TRANSITIONS OF ATLANTIC COAST PIPING PLOVERS

Abstract

Understanding the effects of newly introduced threats to wildlife of conservation concern requires estimation of baseline demographic rates. We used a multi-state mark-recapture model incorporating information on sex, breeding status, and study site to estimate apparent survival of Atlantic coast piping plover (*Charadrius melodus*) adults from six study sites in Cape Cod, Massachusetts and southern New Jersey, accounting for imperfect detection and heterogeneity among phases of the breeding cycle. Piping plovers were more likely to leave our population after losing their first nests attempt than other phases of the breeding cycle and were not likely to leave prior to their first nest attempt. We found differences in detection probability among study sites, reflecting differences in observability and temporary emigration among habitat areas, and birds were more difficult to detect after loss of a nest or when tending a brood than when incubating a nest. Estimating baseline weekly survival and detection probability for piping plovers at sites with varying habitat configurations can provide information on what would be expected of the population at a site prior to construction of a wind turbine. Although the apparent survival rates we estimated are highly dependent on emigration, any significant drop after construction of wind turbines could indicate a negative response by piping plovers, either through site abandonment or increased mortality. .

Key words: apparent survival, Atlantic coast, *Charadrius melodus*, multistate model, piping plover, wind turbine.

Bird mortality due to collisions with wind turbines is one of the major ecological concerns associated with wind farm development (Smallwood and Thelander 2008, Krijgsveld et al. 2009, Shaub 2012). As the focus on clean energy continues in the United States, the development of wind power in coastal areas poses a potential collision threat to beach nesting shorebirds and seabirds that could counteract recent recovery successes gained through protection and management. The Atlantic coast population of piping plovers (*Charadrius melodus*) was listed as threatened under the Endangered Species Act in 1986 (USFWS 1996). Atlantic coast piping plovers nest on open, sandy beaches from North Carolina to Nova Scotia, and depend on the Atlantic coast for the remainder of their annual cycle (migration and wintering)(Elliot-Smith and Haig 2004). Since listing, the population has recovered from 790 pairs to more than 1,800 pairs in 2008 (USFWS 2010). Recovery of the species can be attributed to an intensive effort across the breeding range to protect habitat, minimize anthropogenic disturbance, and reduce predator pressures in order to maximize survival and productivity (USFWS 1996).

Conservation of migratory birds relies on managing factors that limit survival and reproduction during all phases of the annual cycle (Newton 2013). Major causes of decline and continued threats to the recovery of the piping plover population include habitat loss and degradation of breeding habitat, anthropogenic disturbances, and increased rates of predation compared to pre-settlement times (Wilcox 1959, Burger 1994, USFWS 1996). Predation events result in direct mortality, and predators of Atlantic coast piping plover eggs and chicks 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 sp.*), great-horned owl (*Bubo virginianus*), feral cat (*Felis catus*), and Atlantic ghost crab (*Ocypode quadrata*)

(Patterson et al. 1991, CACO 1993, Loegering and Fraser 1995, USFWS 1996). Collisions with wind turbines or avoidance of habitat associated with them represent a potential additive stressor to these predation threats, resulting in direct mortality.

A population viability analysis demonstrated that Atlantic coast piping plover populations are sensitive to small changes in adult survival (Melvin and Gibbs 1994, Plissner and Haig 2000). The mean annual survival of piping plovers nesting on Long Island, NY was estimated to be 0.703 (Cohen et al. 2006), and MacIvor et al. found that piping plovers on Cape Cod, MA had an annual survival rate of 0.74 (USFWS 1996). Estimating baseline weekly survival and detection probability for piping plovers at sites with varying habitat configurations can provide information on what would be expected of the population at a site prior to construction of a wind turbine which can then be used as a comparison post-construction to determine if survival has changed after the turbine is placed into operation. Periods of temporary emigration from the study site could place piping plovers more at risk of collision; therefore, estimating differences in survival and detection among different breeding stratum was the goal of our analysis. We hypothesized that piping plovers with a nest and with a brood would have a higher apparent weekly survival rate and higher detection probability than piping plovers without a nest or brood.

METHODS

Study Areas

A total of five study sites were selected for the 2012 field season, and a sixth study site was added in 2013 (Fig. 4.1). Three study sites were located in southern New Jersey: Avalon-Dunes, Avalon, Stone Harbor Point, Stone Harbor and Strathmere Natural Area, Strathmere (2013). Three study sites were located on Cape Cod, Massachusetts: Spring Hill Beach, Sandwich; Chapin Beach, Dennis; and Dead Neck/Sampson’s Island, Barnstable. Chamberlain et al. (2006)

suggested that data for the collision risk model should be derived from localities as similar as possible to the locations under consideration, and bird collision probabilities have been shown to depend on topographic features (de Lucas et al. 2008). Therefore, study sites were chosen to represent a variety of habitat configurations that consisted of differing arrangements of nesting habitat that may or may not be contiguous with desirable foraging habitat. We also gave highest consideration to sites that have historically supported samples sizes of at least 5 breeding pairs of piping plovers to obtain a sample size big enough for statistical inferences.

Avalon-Dunes, Avalon, New Jersey (N 39.079176, W -74.732010) was located in the southern part of the state on the northern portion of a barrier island along the Atlantic Ocean called Seven Mile Island. The site consisted 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. Foraging areas contiguous with nesting habitat for both adults and chicks was limited to the ocean side intertidal zone and wrack line given that access to bayside foraging was obstructed by coastal development. The site experiences relatively moderate levels of anthropogenic disturbance from beach visitors; however, off-road vehicle use and dogs were not permitted.

Stone Harbor Point, Stone Harbor, New Jersey (N 39.028307, W -74.777536) was located at the southern-most end of Seven Mile Island at the Hereford Inlet. The site consisted of low-lying, open sand and cobble areas and sparsely vegetated dunes, which provided suitable nesting habitat for piping plovers. Ample bayside and oceanside foraging existed and corridors between bayside and oceanside were maintained by frequent washover events that occurred during strong storms and monthly high tides. An additional foraging area for piping plovers was created on the northern end of the site and includes an artificial pond (contained dredge facility) that is tidally influenced. The site experienced relatively low levels of anthropogenic disturbance from beach visitors, and off-road vehicles and dogs were not permitted.

Strathmere Natural Area, Strathmere, New Jersey (N 39.202334, W -74.651514) was located on the northern portion a barrier island known as Ludlam Island at Corson's Inlet. The site consisted of sparsely vegetated areas and open, sandy areas on the berm of the beach below the dune, which provided suitable nesting habitat for piping plovers. Depending on nest location and territory size, foraging areas contiguous with nesting habitat may have been limited to the oceanside intertidal zone and wrackline or may have contained corridors between bayside and oceanside foraging habitats. The site experienced high levels of anthropogenic disturbances from beach visitors; however, off-road vehicle use and dogs were not permitted.

Spring Hill Beach (N 41.762756, W -70.477318) was located on Cape Cod Bay, on the north side of Cape Cod in Sandwich, MA. The site contained a barrier spit with a rocky/cobble/sand-mixed beach on the north side and an extensive marsh system on the south side. The areas of the study site extending 0.88 km east of the tip of the barrier spit were free of coastal development, and private homes were distributed within the dune system for the remaining 1.2 km. The nesting habitat was varied, including sparsely vegetated, sandy areas below the toe of the dune, open cobble areas on the berm of the beach, and sparsely-vegetated and open washover areas to the west. Bayside foraging access for chicks was obstructed by coastal development to the east, but the bay side was easily accessible to the west through washover corridors. Human access to the site was restricted to private property owners; therefore, the site experienced relatively low levels of anthropogenic disturbance.

Chapin Beach (N 41.72780, W -70.23870) was located on Cape Cod Bay on Cape Cod in Dennis, MA. The site contained a barrier spit free of coastal development that extended southwest toward Barnstable Harbor. Open sandy areas and sparsely vegetated dunes provided nesting habitat for piping plovers. Ample bayside and oceanside foraging areas existed, and corridors between the bayside and oceanside were maintained by frequent washover events that occurred during strong storms and monthly high tides. Due to extreme tidal fluctuations, additional foraging areas for piping plovers included the extensive sand flats exposed at low tide both on the ocean side and bay side. The site experienced high levels of anthropogenic disturbance prior to nest hatching, primarily due to off-road vehicle traffic. A single wind turbine was proposed at this site for the Aquacultural Resource Center, which was located on the bay side, behind the dune system.

Dead Neck/Sampson's Island (N 41.60627, W -70.42130) was located on Nantucket Sound, on the south side of Cape Cod in Barnstable, MA. This site was constructed primarily of dredge materials, which have been deposited at both the east and west ends of the island. This study focused efforts on the east end (Dead Neck) due to ease of access and concentrations of nesting birds in 2012; however, the banding and research efforts were extended in the 2013 field season to include the west end (Sampson's Island). A variety of nesting habitats existed on the island: sparsely vegetated, sandy areas below the toe of the dune occur towards the center of the island and open cobble areas and sparsely-vegetated areas became more frequent to the east where the dredge materials were deposited. Foraging habitats included the intertidal zone on the bayside and large accumulations of wrack that occurred on the oceanside. Additionally, a tidally fed pond served as foraging habitat for piping plovers nesting towards the center of the island. This site experienced high levels of anthropogenic disturbance, entirely due to recreational boating.

Field and Analytical Methods

We captured adult plovers on their nests using walk-in funnel traps (Cairns 1977). We marked plovers individually using colored Darvic bands (yellow, dark green, dark blue, light blue, black, gray, red, or orange). At study sites in Massachusetts, each marked individual received a single color-band on each upper leg. At study sites in New Jersey, each individual was marked with two color-bands on each upper leg.

We attempted to resight all color-banded birds at each study site once per week. Two observers would survey 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 and the band combination of the individual. We used multi-state models (Hestbeck et al. 1991, Brownie et al. 1993) in Program MARK to estimate apparent weekly survival rates, detection probability, and transition rates among the different breeding statuses: In 2012, we could only resight birds during or after the incubation period, because we had to band them on the nest, so we could only model strata 2 to 4. Because piping plovers banded in 2012 returned to nest at all study sites in 2013, we were able to begin resighting surveys prior to nest initiation and to include all 4 strata.

We ran models for survival, detection, and transition probabilities that included combinations of covariates for site, sex, and breeding status and interactions among them. We ranked the models based on Akaike's Information Criterion adjusted for small sample size (AIC_c) and selected the best model based on the lowest AIC_c value (Burnham and Anderson 2002). AIC_c is a measure used to aid in the selection of the best fitting model that uses the fewest possible parameters to fit the data (Burnham and Anderson 2002). We considered all models with a likelihood of <0.125 to have some support, and if there were several supported models we calculated model-averaged predicted values for the whole model set (Burnham and Anderson 2002).

RESULTS

We trapped and banded 61 piping plovers in the 2012 nesting season at study sites in Massachusetts and New Jersey out of 77 piping plovers estimated to be present. We trapped and banded 37 piping plovers during the 2013 nesting season at study sites in Massachusetts and New Jersey. Including marked birds that returned from 2012, there were 56 banded plovers in our study areas in 2013 out of 82 piping plovers estimated to be present. We spent 95 hours conducting weekly resighting surveys in 2012 and 210 hours in 2013.

Of 560 candidate models, the best-fitting model in 2012 was the null model indicating that there were no differences in weekly apparent survival, detection, or transition probabilities among study sites, breeding statuses, or the sexes (AIC_c weight = 0.154). The second best model, and the only other model to have some support based on our criteria, contained a sex covariate for transition rate (AIC_c weight = 0.148). Although it appeared that piping plovers that had lost their nest had lower apparent survival than those with nests or broods (Fig. 4.2 and 4.3) and lower detections probabilities (Fig. 4.4 and 4.5), we lacked the power to detect a difference. Weekly transition rates among breeding statuses were generally <10%, except for transition from nest to no nest, which was between 10% and 15% depending on the site (Fig. 4.6).

Of 560 candidate models, the best-fitting model for 2013 included an interaction between breeding status and sex for weekly apparent survival, an additive effect of status, site, and sex on detection, and an effect of site on weekly transitions among breeding statuses (AIC_c weight = 0.444). The second best model contained an interaction between breeding status and sex and an additive effect of site for weekly apparent survival, an additive effect of status, site, and sex for detection, and an effect of site on weekly transitions among breeding statuses (AIC$_c$ weight = 0.211). The last model to have some support based on our criteria included additive effects of breeding status and site for weekly apparent survival, an additive effect of status and sex for detection, and an additive effect of status and site on weekly transitions among breeding strata (AIC$_c$ weight = 0.151).

Apparent weekly survival in 2013 was higher for males and females prior to the first nest attempt and during incubation than after nest loss or during brood tending, based on overlap in prediction intervals (Figs. 4.7 and 4.8) . At Spring Hill and Avalon, detection rate was higher for males and females with nests or broods than those without (Figs. 4.9 and 4.10). Weekly transition rates between from having a nest to having no nest was generally higher than weekly transition probability from having a nest to having a brood (Fig. 4.11).

DISCUSSION

Birds were more likely to leave the site after their first nest attempt failed and were most likely to remain at the site from week to week prior to their first nest attempt. Because piping plovers are arriving at breeding territories for the purpose of nesting and piping plovers are highly site faithful (Weins and Cuthbert 1988, Cohen et al. 2006), it would be expected that a bird that has yet to make its first nest attempt has a higher apparent survival than a bird that has lost a nest or brood. Our results for apparent weekly survival ranged from 0.71 – 0.99, where males and females without a nest or brood demonstrated a lower apparent weekly survival rate likely as a result of temporary emigration from the study site. Roche et al. (2010) found that Atlantic coast populations of piping plovers had an apparent breeding season survival rate of 0.58 – 0.66 for piping plovers in Long Island, NY and Atlantic Canada, which translates to an estimated apparent weekly survival of 0.989 – 0.992.

Differences in detection probability between pairs of piping plovers at Spring Hill and pairs at Avalon reflect differences in habitat configuration. Piping plovers at Spring Hill are required to fly from the oceanside nesting areas to the marsh in order to access ideal foraging habitat. In these cases, it is more difficult to locate a bird within an extensive marsh system, especially at low tide. In contrast, piping plovers nesting at Avalon are restricted to oceanside foraging within the wrack and intertidal zone, increasing their likelihood of detection. Differences in detection probability in relation to habitat type have been demonstrated in other bird species. Pacifici et al. (2008) found that detection decreased as the number of leaves on the trees increased, and detection was higher in mixed pine-hardwood forest than in deciduous forest. Similarly, Darrah and Krementz (2009) found that sites with a greater cover of tall, emergent vegetation resulted in decreased detection probability. The decreased detection probability at sites where birds are required to fly to access optimal foraging habitat also indicates that habitat configuration may be an important factor when evaluating requests for wind turbines at or near piping plover breeding areas. Detection rates were high if birds were tied to a nest or brood and low otherwise. It is likely that detection was confounded with temporary emigration, as birds without a nest or brood could spend more time foraging away from the nest site. Piping plovers were observed foraging 87 percent of the time at bayside and tidal pond intertidal zones prior to egg laying (Fraser et al. 2005), indicating that when piping plovers are not incubating a nest or tending a brood, they are more likely to travel further distances and spend more time away from their territories for foraging than when they do have a nest or brood.

Plovers that have lost their nest or brood may therefore be at increased risk of collision with wind turbines if they move between their territories and foraging sites more often than birds with a nest or brood. Furthermore, during seasons when reproductive success is poor, piping plovers may spend more time flying between nesting and foraging areas, further increasing the risk of collision. Furness et al. (2013) noted that flight activity for seabirds tends to increase during the chick rearing season. Additionally, common murres (*Uria aalge*) and thick-billed murres (*Uria lomvia*) without nests were found more than 100 km from nesting colonies in the Chukchi Sea, yet murres continuously feeding chicks were found between 50 – 80 km from colonies (Hatch et al. 2000), demonstrating that transition rates and foraging behaviors of other species also differs with breeding status. A multistate model that examines transition rates between nesting and foraging areas and their relationship to breeding status would be a useful avenue of research for understanding movement-related risk.

FIGURES

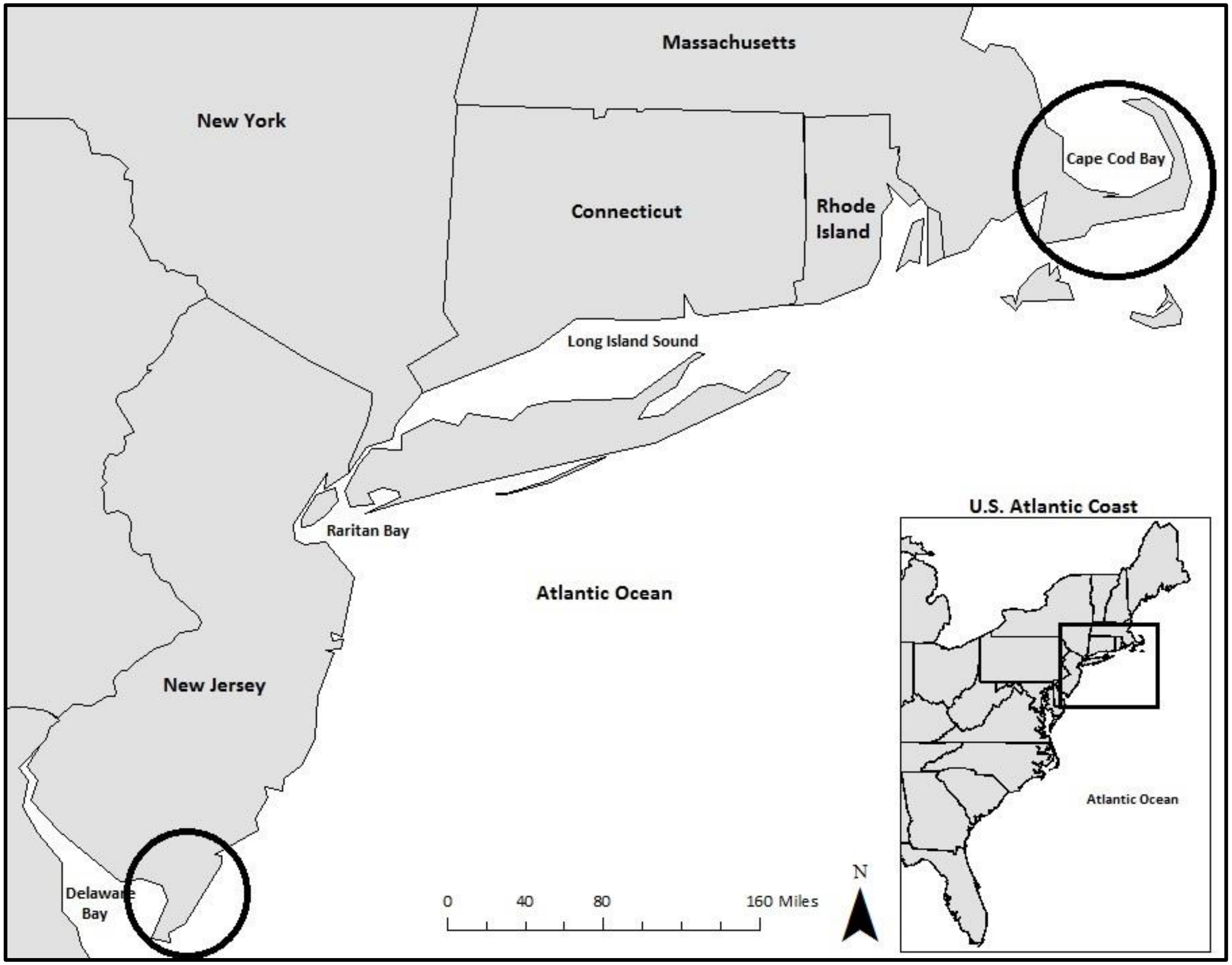


Figure 4.1. Location of study sites for piping plover weekly survival study in southern New Jersey and Cape Cod, Massachusetts, 2012-2013.

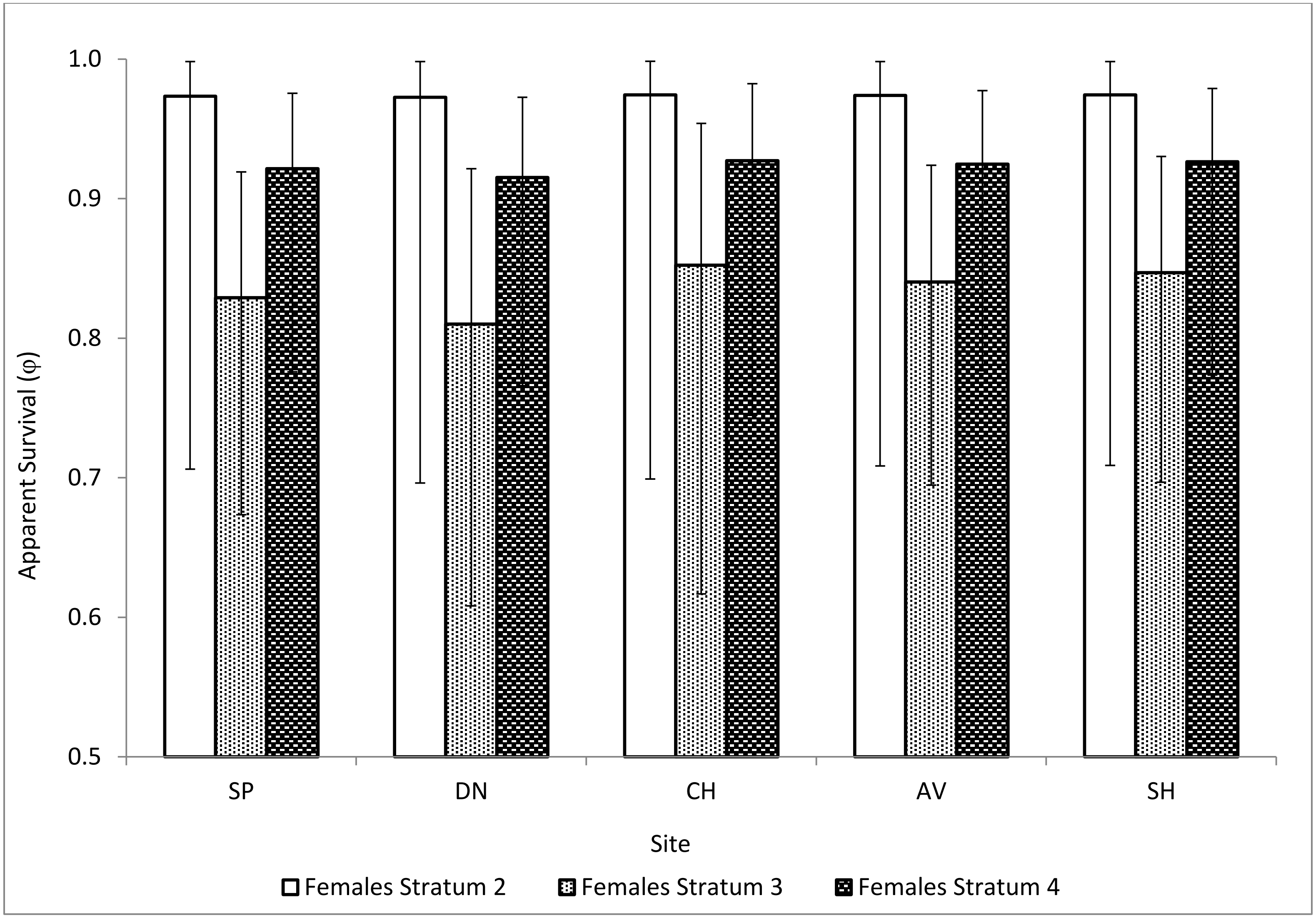


Figure 4.2. Apparent survival of female piping plovers in 3 different breeding statuses, MA and NJ: 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2012

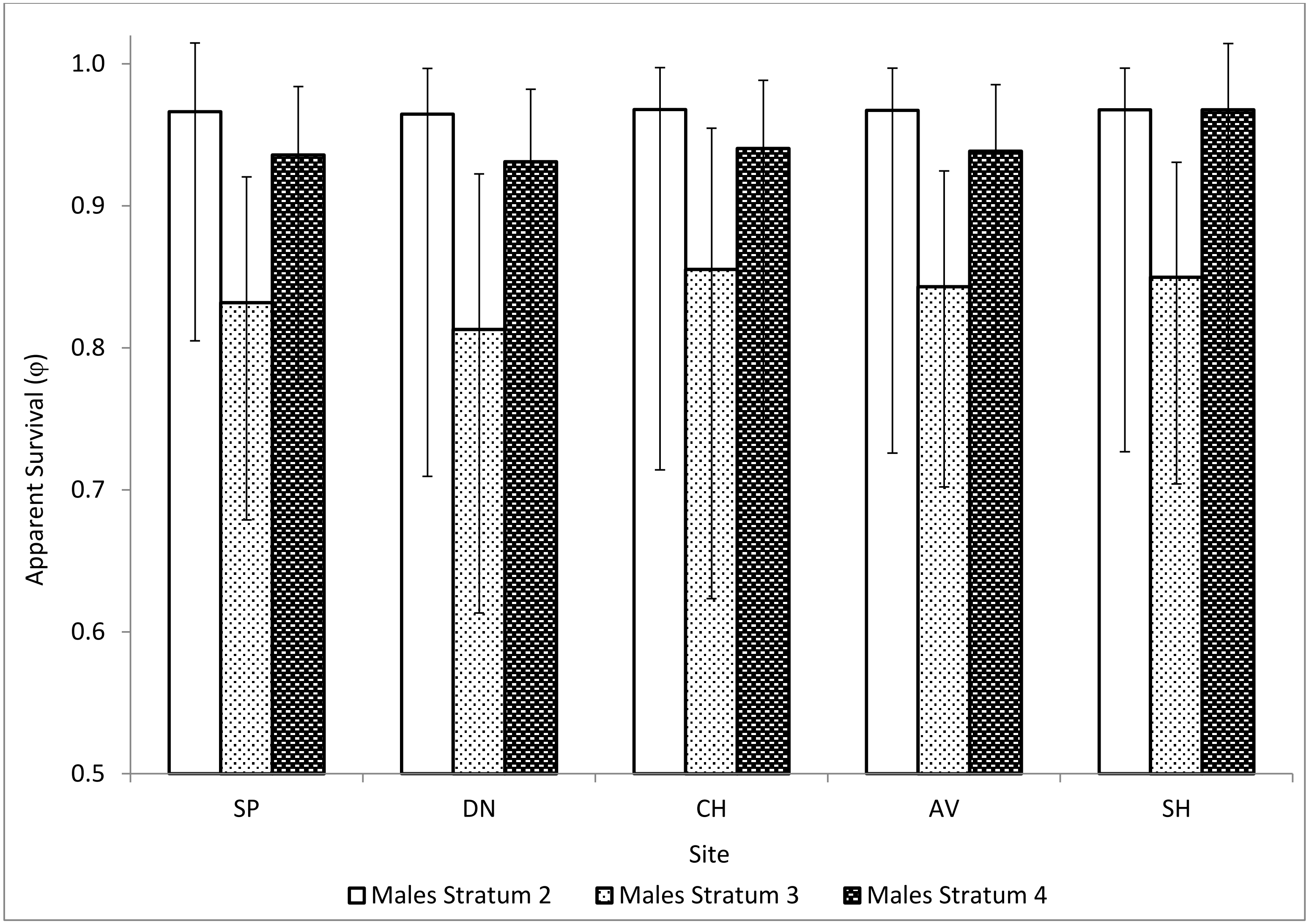


Figure 4. 3. Apparent survival of males among 3 different strata: 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood 2012.

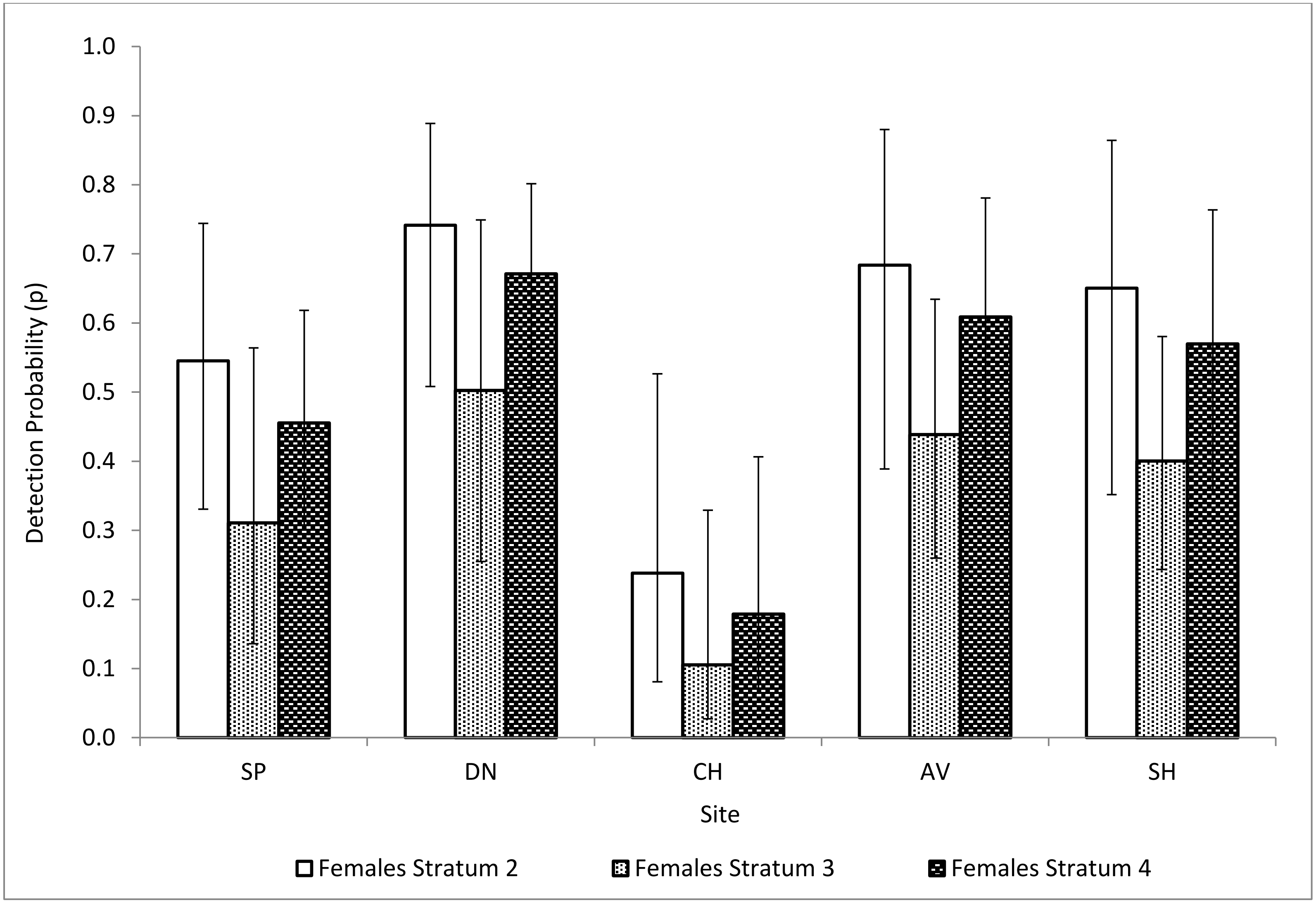


Figure 4.4. Weekly detection probability of females among 3 different strata: 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2012.

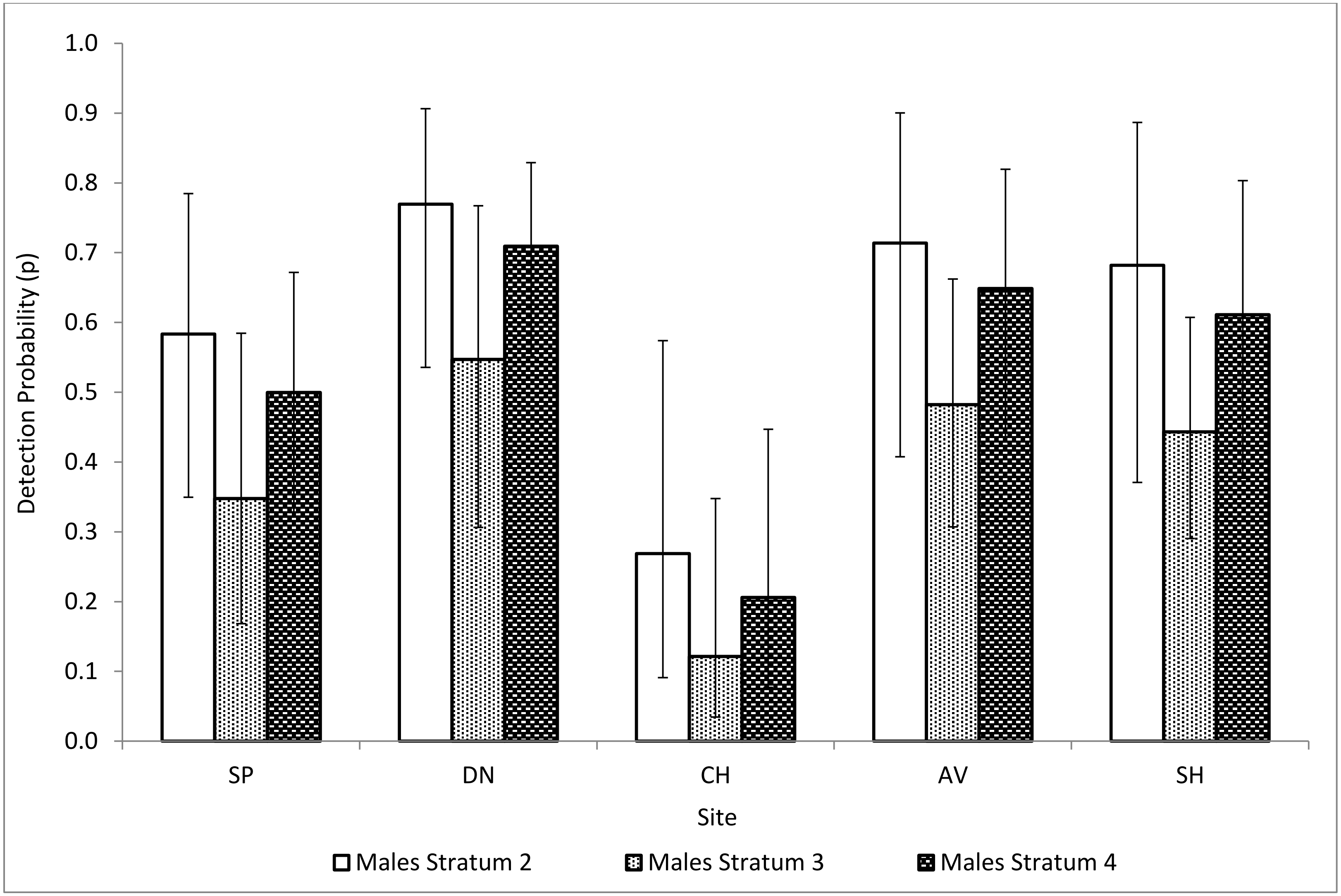


Figure 4.5. Weekly detection probability of males among 3 different strata: 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2012.

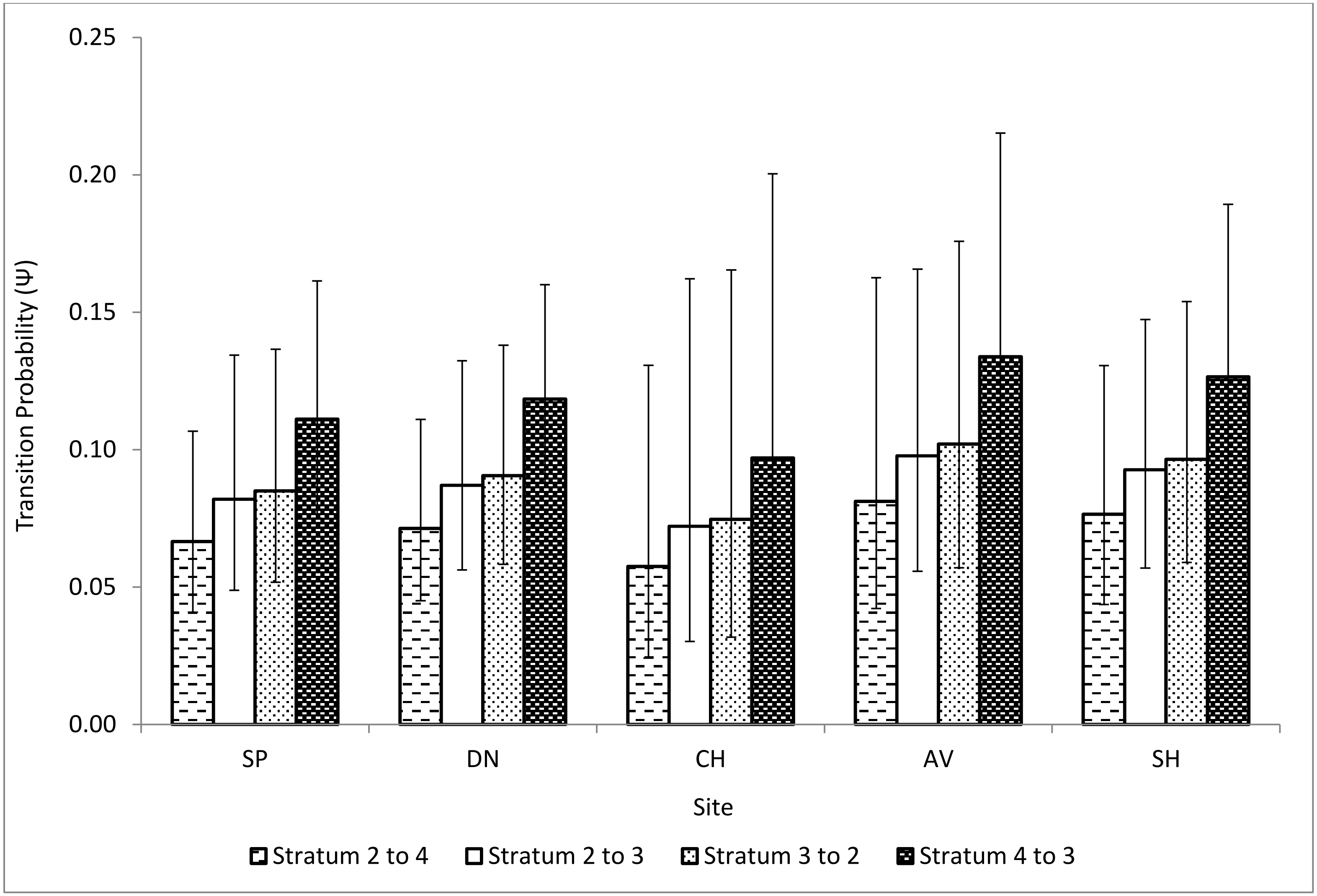


Figure 4. 6. Weekly transition rates of male and female piping plovers among 3 phases of the breeding cycle, MA and NJ, 2012: 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2012.

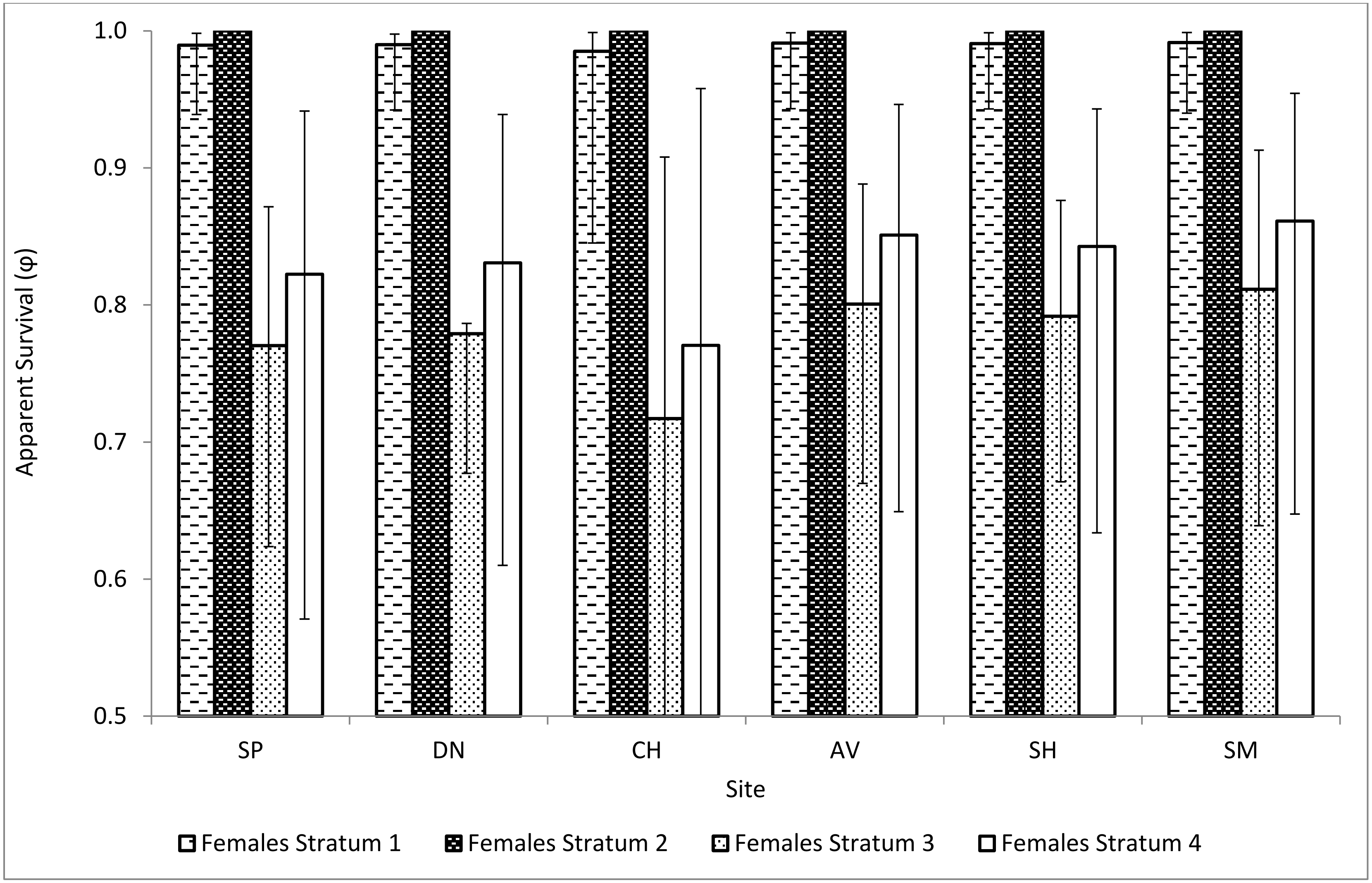


Figure 4. 7. Apparent survival of female piping plovers in 4 breeding statuses, MA and NJ: 1) adult prior to the first nest attempt, 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2013.

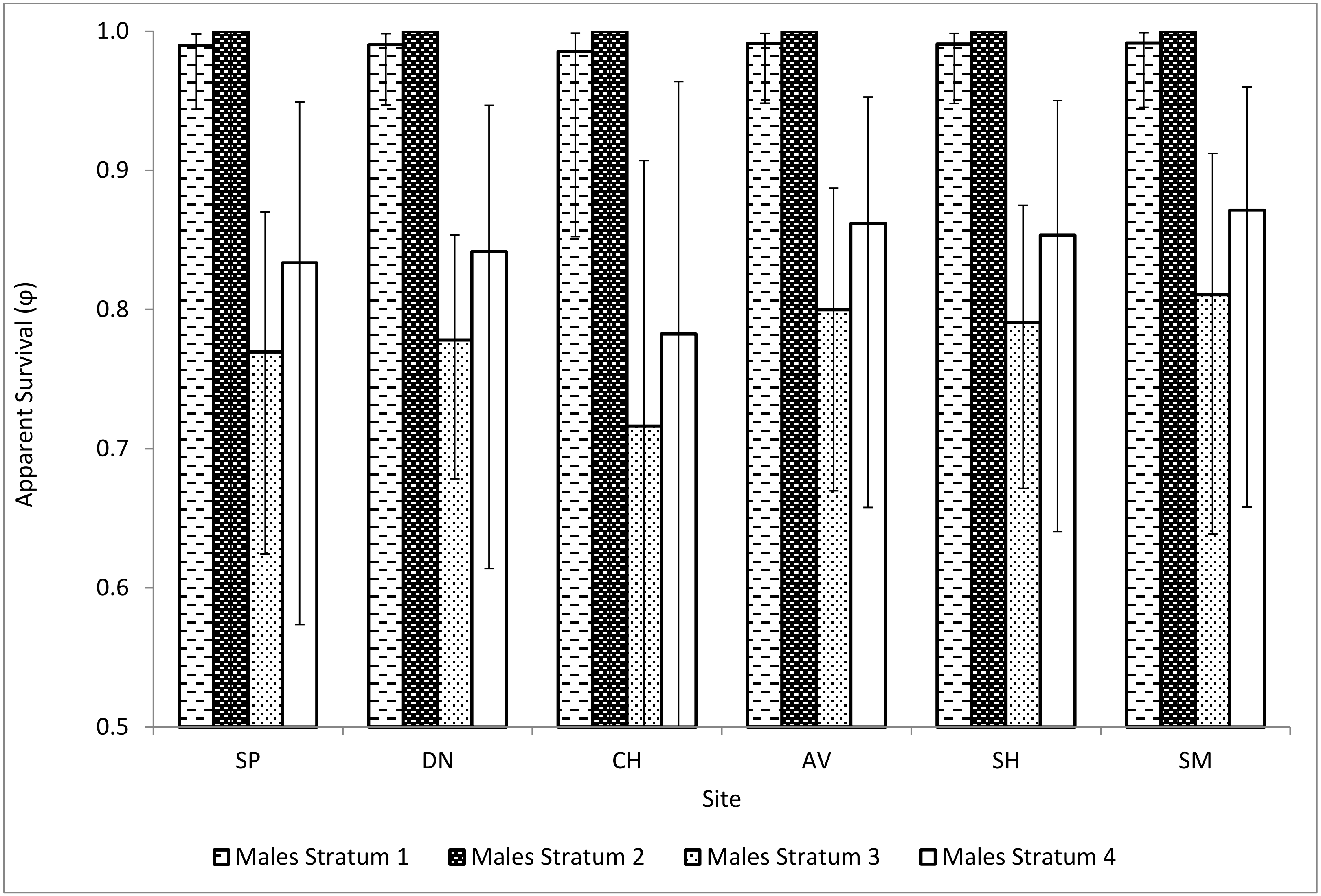


Figure 4. 8. Apparent survival of males among 3 different strata: 1) adult prior to the first nest attempt, 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2013.

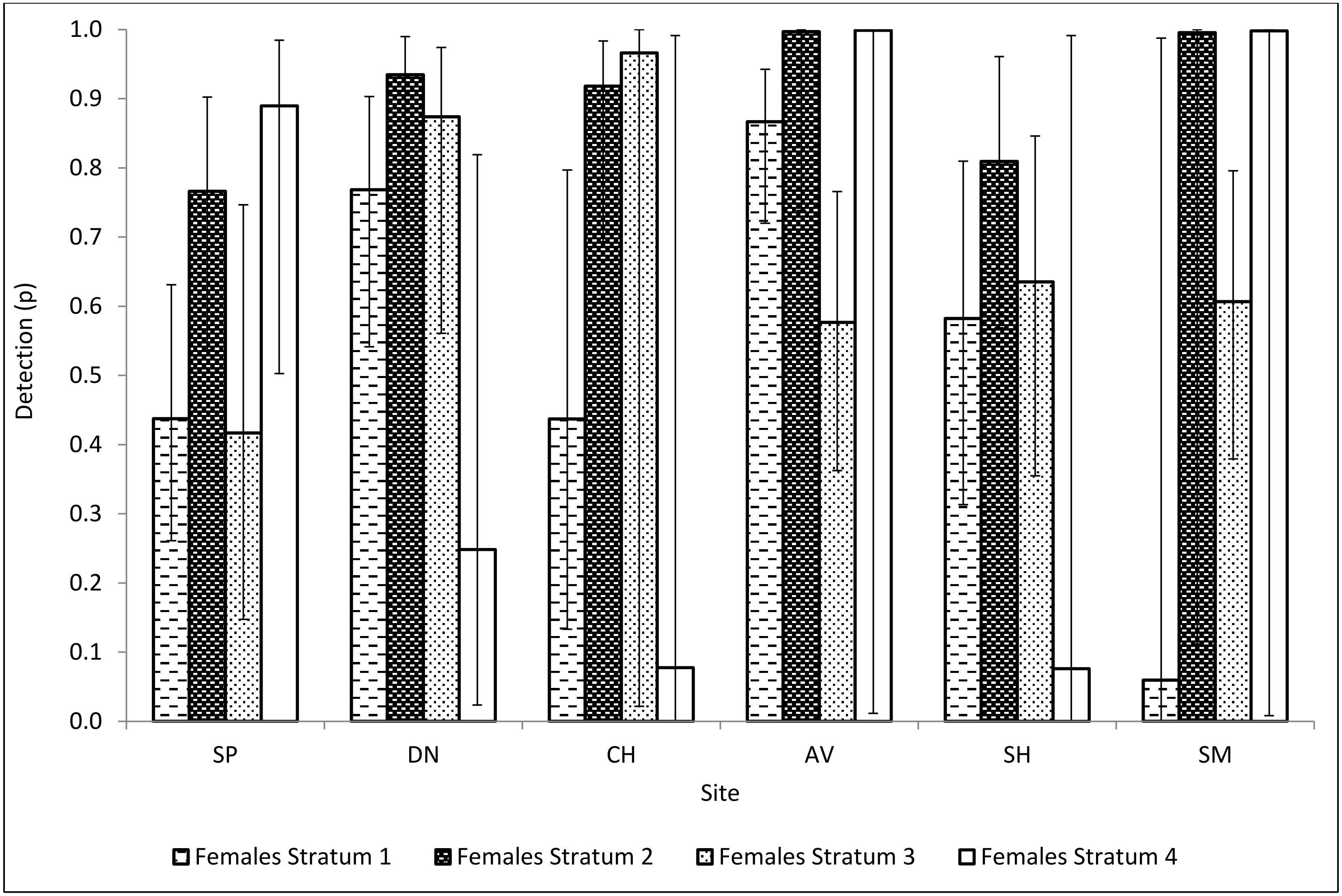


Figure 4. 9. Weekly detection probability of females among 3 different strata: 1) adult prior to the first nest attempt, 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2013.

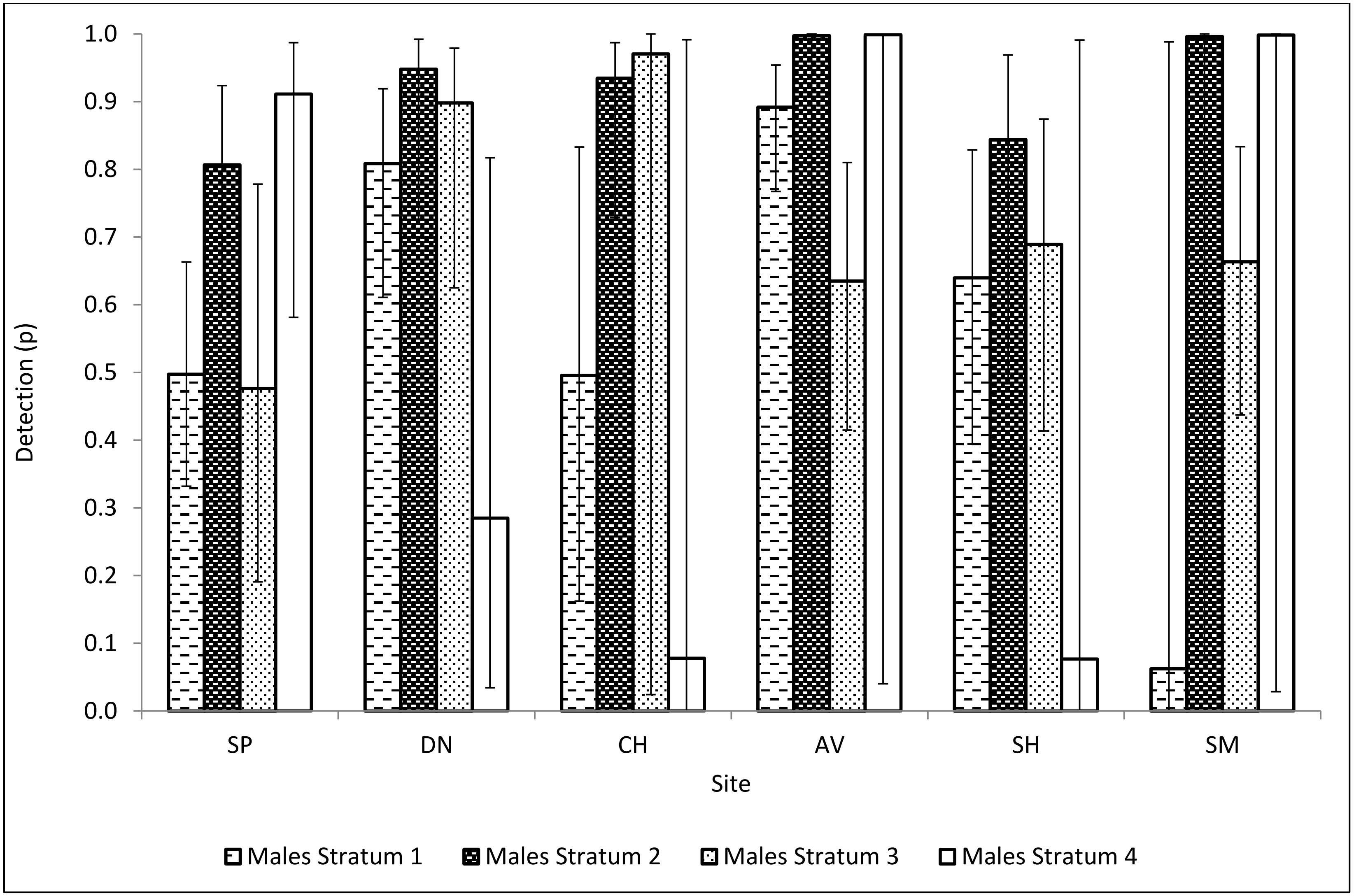


Figure 4. 10. Weekly detection probability of males among 3 different strata: 1) adult prior to the first nest attempt, 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood, 2013.

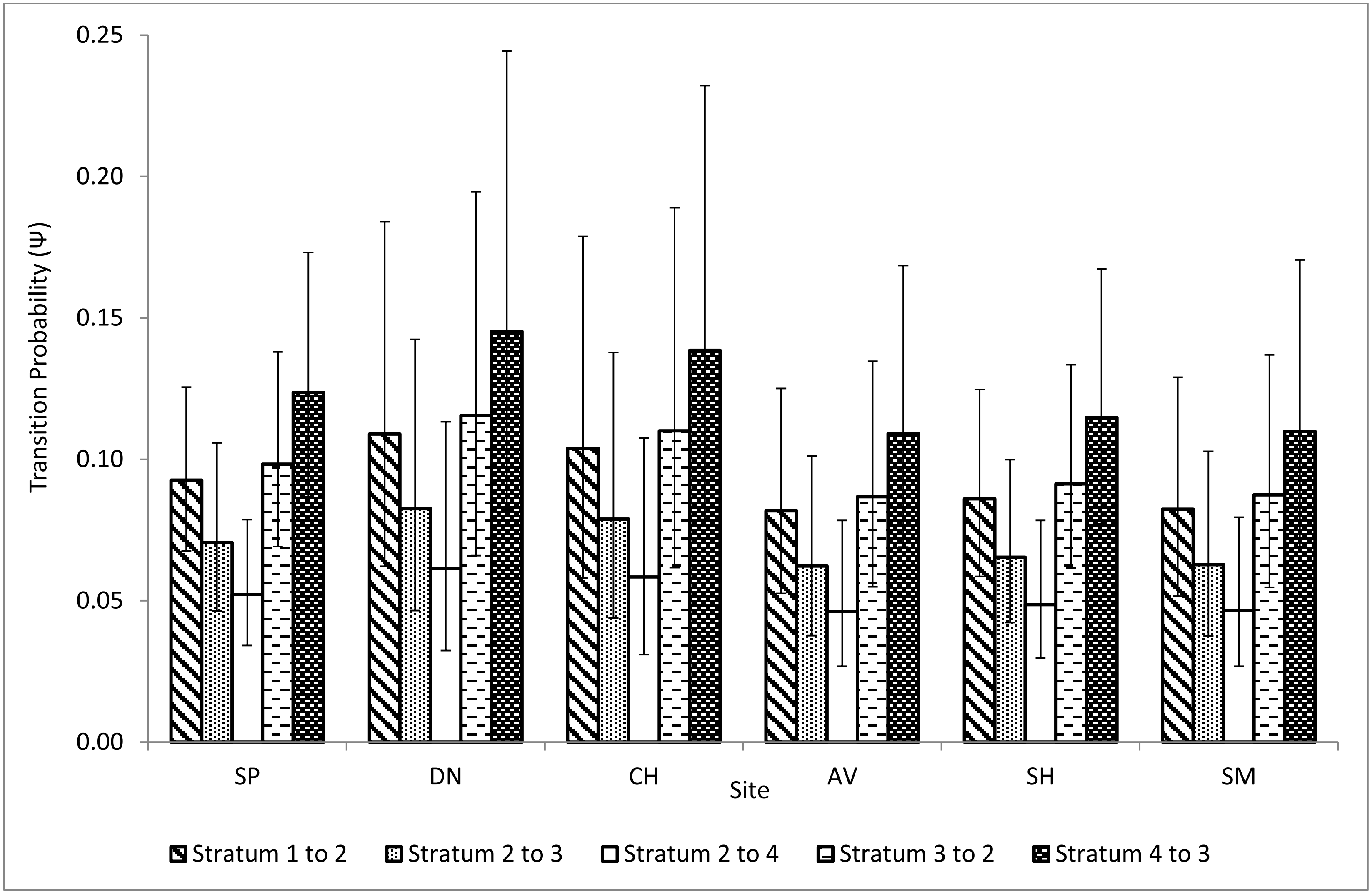


Figure 4. 11.Weekly transitions of piping plover in 4 breeding statuses: 1) adult prior to the first nest attempt, 2) adult with nest, 3) adult without a nest or brood, and 4) adult with brood and, MA and N, 2013.

CONCLUSIONS

The Atlantic coast piping plover population has experienced great recovery progress through protection and management, but wind power development could counteract the coast-wide effort towards recovery. The population is highly sensitive to changes in productivity and adult survival (Melvin and Gibbs 1994), and the Atlantic coast piping plover population is among the least able to sustain mortality due to collisions with wind turbines among different shorebirds (Watts 2010). We used an existing collision risk model (SNH 2000) to predict the number of piping plovers potentially killed per year at each site given flight parameters, varying wind turbine specifications, and numbers of wind turbines on the landscape.

We have provided information regarding piping plover flight behaviors such as flight speed, flight height, and flight frequency that have not been previously documented. We have demonstrated that flight frequency is dependent upon habitat configuration, and habitat characteristics are an important consideration when evaluating site for potential wind power development. In addition to considering habitat characteristics, turbine specifications are also an important consideration when evaluating permit requests at or near piping plover breeding areas, where turbines with a larger diameter, wider chord width, and faster rotation period result in a higher probability of collision as well as a higher number of collisions per year. Piping plovers nesting at sites where birds are required to fly from oceanside nesting territories to bayside foraging habitat, especially in the case of large wind turbines, are at a higher risk of collision than piping plovers nesting on beaches where foraging habitat is contiguous with nesting habitat and restricted to the oceanside intertidal zone and wrack line.

We confirmed that female piping plovers spend a significant amount of time away from breeding sites at night. We found that transitions out of range were greater during the day and fewer at night, likely because females leave the site at night and do not return for longer periods of time. Nocturnal behavior is logistically difficult to study, but due to the increased collision risk, it is an area of future concern. Automated telemetry receivers show promise for providing detailed information on night time behavior of nesting piping plovers.

Differences in weekly apparent survival between piping plover pairs prior to the first nest attempt and pairs without a nest or brood indicate that birds were more likely to leave the site after their first nest attempt failed and were most likely to remain at the site from week to week prior to their first nest attempt. Differences in detection probability between study sites may reflect differences in habitat configuration. Plovers that have lost their nest or brood may therefore be at increased risk of collision with wind turbines if they move between their territories and foraging sites more often than birds with a nest or brood.

A multistate model that examines transition rates between nesting and foraging areas and their relationship to breeding status would be a useful avenue of research for understanding movement-related risk.

We found that large, fast spinning wind turbines can lead to a high number of collisions/yr relative to the size of many local breeding populations. If the number of collisions/yr is greater than 2 individuals at a study site, the pair occupying the territory containing a wind turbine will be lost, leading to a decrease in adult survival in addition to the reproductive consequences of losing breeding adults. Many nesting sites along the Atlantic coast continue to experience continued habitat loss and increased predator pressures, and the placement of wind turbines within nesting areas could lead to yet another threat to the recovery of the Atlantic coast population of breeding piping plovers.

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RESUME

Michelle L. Stantial

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Education

Master of Science Candidate — March 2012 to December 2014
SUNY-ESF, Environment and Forest Biology — Syracuse, New York
Focus: Fish and Wildlife Biology and Management
“Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines”

Bachelor of Science — Major: Biology — Minor: Chemistry
Marietta College — Marietta, Ohio — Graduated August 2005

Work Experience

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, trapping (Potter traps), banding, productivity monitoring, and post-breeding resighting (13 pairs)
- Common Tern (7000 pairs) productivity monitoring, trapping (Potter traps), 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 submissions for Roseate Tern, American Oystercatcher, and Northeastern Beach Tiger Beetle projects
- 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
- Tagged and processed 500+ spawning Horseshoe Crabs
- Finalized 2009 and 2010 Annual Field Season Reports for 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 other healthy 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
Field Supervisor — March 2010 to August 2010
March 2009 to August 2009

- 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
- 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 Technician — November 2009 to February 2010

- 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 Technician — August 2009 to October 2009

- 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 residents
- Assisted with locating nests and banding of Northern Harrier chicks

Publications

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

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

Ellis, J.C., S.J. Courchesne, V.I. Shearn-Boschler, and M. Stantial. "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, 2010.

Awards/Grants

38th Annual Meeting of the Waterbird Society — La Paz, Mexico
Student Travel Award $200.00 — November 2014

26th International Ornithological Congress — Tokyo, Japan
Student Travel Award $1000.00 — August 2014

37th Annual Meeting of the Waterbird Society — Wilhelmshaven, Germany
Best Student Paper Presentation — September 2013

37th Annual Meeting of the Waterbird Society — Wilhelmshaven, Germany
Student Travel Award $100.00 — September 2013

Garden Club of America New York, New York
Francis M. Peacock Scholarship $4500.00 April 2013
“Automated Telemetry for Tracking Piping Plover Movements: A Novel Approach for Evaluating Risks of Wind Turbine Collision on the Breeding Grounds”

Goldenrod Foundation Plymouth, Massachusetts
Small Equipment Grant $1500.00 February 2013
“Automated Telemetry for Tracking Piping Plover Movements: A Novel Approach for Evaluating Risks of Wind Turbine Collision on the Breeding Grounds”

Bird Conservation Conference of the Northeast Plymouth, Massachusetts
Student Travel Award $80.00 October 2012

Professional Presentations

38th Annual Meeting of the Waterbird Society La Paz, Mexico
15 Minute Oral Presentation November 2014
“Using a Collision Risk Model to Assess Potential Impacts to Breeding Piping Plovers along the Atlantic Coast”

26th International Ornithological Congress Tokyo, Japan
Poster Presentation August 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”

37th Annual Meeting of the Waterbird Society Wilhelmshaven, Germany
15 Minute Oral Presentation September 2013
“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”

Northeast Fish and Wildlife Conference Saratoga Springs, New York
20 Minute Oral Presentation April 2013
“Flight Behavior of Breeding Piping Plovers: Implications for Risk of Collision with Turbines and Other Human Structures”

Bird Conservation Conference of the Northeast — Plymouth, Massachusetts
Poster Presentation — October 2012
"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 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"

Volunteer Experience

Mass Audubon — Wellfleet, Massachusetts
Wellfleet Bay Wildlife Sanctuary Volunteer — October 2008 to Present

- Conducted stranded sea turtle beach surveys
- Helped with special event setup, coordination, and breakdown
- 5-10 hours per month

Cape Cod Natural History Museum — Brewster, Massachusetts
MAPS Bird Banding Program Volunteer — October 2008 to August 2010

- Retrieve captured birds from mist nests
- Take measurements of captured birds
- Record data for Master Bander
- 10-40 hours per week

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
- 40-50 hours per week

Computer/Other Skills

ArcGIS, SAS, R, Microsoft Excel, Access, Word, PowerPoint and Publisher, Prezi, eBird, Adobe Photoshop, Bandit, FileMakerPro, Outboard Motor Operator (13ft – 23ft power boats)

Professional Memberships

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 and Graduate Student Advisor to the Undergraduate Chapter at SUNY-ESF

Certifications

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 Professional Lifeguard, Red Cross CPR for the Professional Rescuer, Red Cross First-Aid, Red Cross Water Safety Instructor, Red Cross Small Craft Safety and Rescue, ACCT Certified Challenge Course Lead Instructor (NE Adventure, Inc.)

Languages

English (primary), French (beginner)

Travel Destinations

International: Costa Rica, 2005, 4 weeks; India, 2012, 4 weeks; Europe (England, France, Germany), 2013, 2 weeks; Iceland, 2013, 1 week; Nova Scotia, 2013, 1 week; Japan, 2014, 2 ½ weeks; Mexico, 2014, 1 week; 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

Personal Interests

Knitting, music, cooking, gardening, reading, home-brewing, hiking, camping, bird watching, falconry, crossword puzzles, painting, glass blowing, pottery