USING EVIDENCE TO EXPLORE BROAD TRENDS IN NEST FATE ASSESSMENTS OF THREATENED PIPING PLOVERS

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ABSTRACT OF THE THESIS

Using evidence to explore broad trends in nest fate assessments of threatened Piping Plovers

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Piping Plovers (*Charadrius melodus*) are federally threatened under the Endangered Species Act. These threatened shorebirds breed on New Jersey's beaches from April to August annually. They face many threats during this time, including habitat loss and human disturbance. One major threat to Piping Plovers is nest predation by a suite of predators, causing approximately half of nest losses annually. Understanding the fate of nests can help better direct Piping Plover management. The objectives of my research were to 1. Determine the composition and level of occurrence of predators in each site and island in New Jersey between the years 2005-2013, 2. To understand if predator type and frequency change throughout the nesting season and throughout the age of the nest or across years and 3. To use this information to create a practical training manual and guide to common predators to better inform managers, biologists, and field personnel conducting nest fate assessments. Results show that some predators, such as Eastern Red Fox (*Vulpes vulpes*), Northern Raccoon (*Procyon lotor*), Ghost Crabs (*Ocypode quadrata*), crow (*Corvus*) and gull (*Larus*) species occurred most often nearby the nest (66%), and caused 88% of nest losses. The highest levels of predators occurred during peak Piping Plover hatching, but nests were most vulnerable to predation during the first seven days of nest initiation. Each major predator had different activity timelines and geographical distribution throughout the state of New Jersey. Results suggest that

different management strategies should be considered for each nesting area and predator type.

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Chapter 1: Understanding Nest Fate Assessments to Determine the Timing and Composition of Predators to Piping Plovers (*Charadrius melodus*)

Introduction

Piping Plovers (*Charadrius melodus*) are a small shorebird endemic to the United States. There are three subpopulations of Piping Plovers, one in the Great Lakes, one in the Great Plains, and one on the Atlantic Coast (Miller et. al. 2009). The Atlantic Coast subpopulation (*Charadrius melodus melodus*, hereafter referred to as Piping Plover) breeds on sandy mainland beaches and barrier island strands from Canada to North Carolina (Elliot-Smith and Haig 2004). Throughout its Atlantic Coast range, the Piping Plover is federally listed as threatened (Endangered Species Act of 1973, Species at Risk Act of 2002).

Piping Plovers breed on the Atlantic Coast between late April and the beginning of August. During this breeding season, the monogamous pair lays a clutch of approximately four eggs directly on the ground in a scraped nest. This nest is typically located between the high tide line and the primary dune system, or in backshore areas characterized by overwash fans. On barrier island strands, Piping Plovers will often nest behind the primary dune, using the alternate foraging areas of the back bays as their primary home range during the breeding season (Loegering and Fraser 1995, Maslo et. al. 2011). Incubation, performed by both male and female, lasts an average of 28 days from the date the last egg is laid (Cairns 1977). Precocial chicks hatch almost synchronously, and can move and forage on their own as soon as four hours after hatching (Cairns 1977). Parental care in the form of brooding and defense against predators continues at least until the chicks are 25-35 days old, upon which point the chicks are considered to be fledged, or capable of sustained flight (Wilcox 1959). Some level of parental care can continue for several weeks past this point (Cairns 1977). Though renesting attempts are often made in the cases of egg or very early chick failure, the breeding season ends by late July or early August, when migration to the wintering grounds in the southern Atlantic Coast and the Bahamas Islands begins (Elliot-Smith and Haig 2004).

Status of Breeding Piping Plovers in New Jersey

New Jersey's beaches serve as important breeding and migratory staging grounds for the Piping Plover. One hundred and fifteen (115) pairs bred in New Jersey in 2016 (Pover and Davis 2016). Though this number fluctuates somewhat from year to year, this figure represents approximately five percent of the total Atlantic coast population (USFWS 1996). Piping Plovers hold an Endangered conservation status listing in the state of New Jersey (E.N.S.C.A. 23:2A). Since the listing of Piping Plovers under New Jersey statutes in 1984, and the subsequent federal listing in 1986, actions required by these listings have been undertaken by land managers in New Jersey to protect this species. Each management action is decided and dictated by the direct land manager, with direction and guidance from the federal Endangered Species Act and the statewide guidelines set forth by the New Jersey Division of Fish and Wildlife, Endangered and Nongame Species Program (hereafter referred to as NJENSP). These actions addressing threats to the

Piping Plover include setting productivity and recovery goals, participating in regular and standardized monitoring, and conducting predator management (USFWS 1996).

Plovers face many challenges reaching productivity goals on the breeding grounds in New Jersey, such as habitat loss and degradation, coastal flooding, development, and increased human usage of the beach during the peak nesting season (USFWS 2007). The increased visitation to beaches leads to heightened disturbance by humans in the form of foot and vehicular traffic, which could crush nests directly or serve to keep plovers from incubating or caring for young (USFWS 2007). All of these threats are exacerbated by a variety of nest and brood predators, including human associated pets such as dogs or feral cats. Indirect impacts of development also include the increase of the number and variety of predators on barrier island strands, which are often attracted to areas where a high human population density creates foraging opportunities in the form of trash cans, roadkill, and other human created food sources.

Management and Monitoring of Threats in New Jersey

Human impacts are mitigated by a variety of management actions in New Jersey (USFWS 2016). Some areas, such as two beaches owned by Edwin B. Forsythe National Wildlife Refuge, are completely seasonally closed to the public for the entirety of the nesting season, and some of the pre- and post-nesting season (USFWS 2015). On the other end of the spectrum lie municipally owned beaches. On these beaches, land managers use symbolic string and post fencing to surround the nesting areas, while generally keeping the tideline and non-nesting areas of upper beach open to public access. The intent of this fencing, which also includes signage to notify visitors about the closure, is to allow the birds to roam freely, but represent a barrier where people should not enter (USFWS 2016). This management action is often used in conjunction with the presence of paid or volunteer personnel in order to mitigate human disturbance. In some cases, municipal codes allow for fines of persons caught violating the boundaries of the symbolically fenced areas. Other state-owned and federal properties combine symbolic fencing, sectional beach closures, or other strategies in order to provide a balance between protecting Piping Plover and other beach-nesting birds, and provide a recreational beach for human visitors (USFWS 2016). A full list of nest sites, and their management actions, is located in Table 1. By providing a buffer between humans and nesting Piping Plovers, the threat of predation is diminished but not eliminated.

Land managers often work year-round in order to protect Piping Plovers against the impacts of predation during their incubation and chick-rearing stages via many predator management strategies. Predators of Piping Plovers and other ground-nesting birds that cohabitate the barrier beaches are multitudinous and varied. Predators take eggs, kill adults and chicks, and can disrupt normal breeding behavior through increased vigilance by nesting adults. While a large number of species are potential Piping Plover predators, a small subset of potential predators constitute the majority of issues for plovers on New Jersey’s beaches. Nearby nesting gull species, including Great Black-Backed (*Larus marinus*), Laughing Gull (*Leucophaeus atricilla*), and Herring Gulls (*Larus smithsonianus*), all serve as predators of Piping Plover nests. The other main avian predators are American and Fish Crows (*Corvus brachyrhynchos* and *Corvus ossifragus*, respectively). The most common mammalian predators in New Jersey are Eastern Red Fox (*Vulpes vulpes*), Northern Raccoon (*Procyon lotor*). Finally, Ghost Crabs (*Ocypode quadrata*) predate Piping Plover chicks, and occasionally eggs. These species create the majority of the predatory issues for Piping Plover but many others occasional include plovers in their diet; a full list of known or suspected predators tallied during nest observations in the state are listed in Table 2.

All of the above-mentioned major predators are classified as generalist predators. Generalist predators feed opportunistically on a variety of food sources in response to available resources (Pulliam 1974). Specialist predators, on the other hand, eat only a small variety of prey items. A generalist strategy allows these predators to target plovers during the height of the Piping Plover breeding season while seamlessly switching to other food sources at other times, and likely, due to their scarcity, plovers do not provide the primary food source at any time of year. To exacerbate the problem, many generalist predators, such as Eastern Red Fox, Raccoon, and Striped Skunk (*Mephitis mephitis*) did not co-evolve with Piping Plovers on barrier island strands (Statham et al. 2012). Therefore, Piping Plovers have likely not had the opportunity or time to adapt to their pressure. Additionally, these generalist predators often benefit by living near human habitations (Gompper and Vanak 2008), which is a feature common to virtually all habitats on New Jersey's barrier islands. The increased access that human development grants these generalist predators, combined with the direct loss of habitat, create one of the most pressing problems facing Piping Plovers in New Jersey and those attempting to manage these threats.

Much like beach closures vary across different management schemes, predator management strategies vary considerably depending on the landowner. While all are required to follow management guidelines set forth by the United States Fish and Wildlife Service (hereafter referred to as USFWS), different managers vary in their budget and personnel limitations, political constraints, and specific challenges faced by plovers on specific beaches. Trapping of nonnative or nuisance mammals, which is the most common predator management strategy, can be controversial requires an enormous up-front cost and effort (Cohen et. al. 2009). All trapping efforts hinge upon the availability and willingness of a knowledgeable local trapper. If these two criteria are met, challenges such as permitting, timing and placement of trapping operations still exist (T. Pover, personal communication, 2015). Under these constraints, it is especially important not to disturb the nesting birds or unduly harm the trapped mammal. All trapping arrangements require the agreement of the local officials who work jointly to manage the beaches themselves. Despite these difficulties, trapping efforts are a recurring need, as recruitment of new predatory individuals onto the nesting habitat can occur throughout the season and year to year.

In addition to traditional trapping methods, many predator management strategies also are in use, such as the use of nest exclosures, small wire fencing with netting on top, designed to allow plovers to walk on and off the nest freely, while excluding large birds and mammals from approaching the nest (Rimmer and Deblinger 1990, Hardy and Colwell 2008, Beaulieu et. al. 2014, Murphy et. al. 2003, Maslo 2010). Beyond widely-used exclosures, other strategies have also been implemented in a smaller subset of nests, such as oiling, addling, or destroying eggs of nearby nesting gull and crow species (Olijnyk and Brown 1999), electrified fencing (Larson et. al. 2002, Ivan and Murphy 2005, Mayer and Ryan 1991, Murphy et. al. 2003). Predator deterrent methods include hazing (Blackwell et. al. 2002), effigies (Forys et. al. 2015), electrified (Velasco 2015) and toxic (Maguire et. al. 2009, Neves et. al. 2006, Avery and Decker 1994) decoy eggs. Most of these strategies are employed with the intent of deterring avian predators, though toxic eggs and electronic eyes may serve to deter mammalian predators as well.

To measure reproductive outcomes and assess the impacts of predators and other threats to Piping Plovers, most known nests are monitored with a high degree of regularity (USFWS 1996), and virtually all of the historic and available breeding habitat is surveyed at the height of the breeding season (Haig et. al. 2005). Attempts to assign nest-fate to a specific predator is a standard tactic used across monitoring plans on the Eastern seaboard (USFWS 1996), though these data are not gathered in the same way by every monitor or manager throughout New Jersey. Attempts to assess nest fate evidence at plover nests are usually made by monitors in the field. Monitors are generally trained to write down or make judgments on the evidence presented at the nest site upon failure. Collected field data, while potentially valuable, can be highly variable based on the experience, skill, and training of individual monitors. Differences between monitors and data collection methods serve to introduce bias into nest fate assessments. One commonly cited flaw in predator assessment of evidence in monitoring plans has typically been the introduction of bias based on non-standard determination parameters (Mabee 1997). Adding to these difficulties, no range-wide standardization of data collection methods to assess predator evidence has been implemented.

A long-term monitoring protocol is in place for the State of New Jersey that allow data to be compared by site, or beach, regardless of management strategies and land ownership types. At a minimum, managers, or monitors from NJENSP devote personnel and effort to finding Piping Plover nests, and contribute to this dataset by monitoring those nests to fledge or failure. Each check of the nest is recorded, along with its status on that date. Data are also collected on the level of human disturbance, predator pressure, and types of management strategies that are used to protect the nest and surrounding areas (e.g. symbolic fencing of nesting area or nest exclosures and electric fencing around the nest itself). See Figure 2 for a datasheet listing variables collected. Data have been collected in this standardized format at all sites since 2000, and on a subset of sites since the early 1990's (C. Davis, personal communication, 2015).

Research Objectives

With the apparent difficulties in assessing predator evidence in determining nest fate, combined with limited resources to manage for predators to Piping Plover nests and young, it is important to understand the composition and distribution of predators across the landscape and between sites. The variability of predator composition across differently managed beaches also matters, as composition can dictate mitigating management actions. The first objective of this research is to determine the composition and level of occurrence of predators in each site and island in New Jersey between the years 2005-2013. Fortunately, the large dataset, maintained by NJENSP, provides the opportunity to mine data to elucidate trends.

The second objective of this research is to understand if predator type and frequency change throughout the nesting season and throughout the age of the nest, or across years 2005-2013, using the dataset provided by NJENSP. Understanding the timing of the risks posed by predators could impact management actions affecting Piping Plovers. Phenology can affect predation rates throughout the nesting cycle (Creswell 1997), across-year survival productivity (Colwell et al. 2007, Harris et al. 2005), daily survival rates of Piping Plover chicks (Brudney et. al. 2013), and be impacted by weather (Dinsmore 2008).

Declines in overall reproductive success as a nesting season progresses have been documented in several studies of Piping Plovers (Brudney et al. 2013, Knetter et al. 2002, Harris et al. 2005). Many reasons are possible for this decline, such as parental age and experience, or increased human visitation of many busy beaches in the summertime, but some studies suggest that this can be at least partially due to a change in predation pressure throughout the nesting season (Kruse et al. 2001). Predator and prey phenology, and how timing impacts New Jersey’s nesting Piping Plovers, is not currently considered in management plans. Understanding the impact of phenology of predators on New

Jersey's barrier islands could help target trapping or other management efforts to the times when such management actions would have the highest impact and allow for a more efficient use of existing resources.

Methods

Datasheets, and a comprehensive database, were obtained from NJENSP, spanning the years of 2005-2013 and encompassing all known nesting sites in New Jersey during that timeframe. Datasheets used for nest monitoring already include an assessment of nest fate. When a nest is relocated in subsequent visits and altered in some way, a field monitor makes a best-case assessment of the nest fate based on available field evidence. For example, if the age has been calculated to be at or after the hatching date, the monitor then spends a significant amount of time searching for the parents or chicks. If, however, no chicks are found, or the nest has been found to disappear before the projected fledge date, other cues are used to determine the fate of the nest. If the eggs are intact, but the parents are clearly not using it, the nest is tentatively coded as abandoned pending further checks. For all other occurrences and timing, the monitor uses individual judgment in order to assess nest fate.

The possibilities for nest fates are Hatched, Abandoned, Failed, and Unknown. If the nest was considered failed, a further sub-classification is used to categorize the reason for failure: avian predation, mammalian predation, flooding, human destruction, over-incubation of eggs, sand-covering. In the cases where the field monitor decides that he or she cannot confidently determine a cause, the fate is recorded as an undetermined cause.

In order to manage and analyze these data on a statewide level, these nest datasheets are compiled into a Microsoft Access database that includes all of the aforementioned parameters. They are standardized amongst sites, though variation in field methodology still exists (T. Pover, personal communication, 1 Mar 2014). I then added Julian dates to the date the nest fate was determined for all nests failed in order to compare across years.

Each nest check, including the nest status and any unusual observations, was handwritten onto a datasheet, and entered into a comprehensive database managed by NJENSP. Ultimately, these notes were not included in the Access database. I transcribed these handwritten notes from each datasheet whenever records of predators, or evidence from predators, were written down by monitors. I eliminated nests from the dataset for several reasons. First, nests were eliminated if any information was not complete. Nests were also eliminated from the dataset if they were found at the brood stage, meaning no eggs were ever seen in order to limit any analysis determinant upon nest fate. Finally, nests were eliminated when there was a gap in visitation between the last visit and nest-fate determination of greater than eight days. Nests classified under the statewide database of "Unknown" were changed to "Undetermined Destruction" when the nest age was known and under 25 days of age (the earliest amount of time taken for an average nest to hatch). The final sample size included in analysis was 1,228 nests.

Because it is well documented that Piping Plovers, and other precocial species, exhibit significant variation in survival probability between years (Colwell et al. 2007, Harris et al. 2005), data transcribed from handwritten field notes were pooled across years between 2005 and 2013. Each predator occurrence, defined as any note taken by the monitor in the field noting a predator or evidence of a predator (including predator tracks, scat, eggshells, dead adults or young), was annotated. Occurrences of predators were summarized across two geographic scales: site, as dictated by the land manager and listed in Table 1, and by the 12 separate geographically designated islands in New Jersey. Predator occurrences were also summarized across temporal variables, when the occurrence could be narrowed down to a particular date (n=560). Despite expected year-to-year variability, predator occurrence was also summarized across years to provide a visual representation of the composition of major predators in each year. In addition to predator occurrence data, nest fates classified as flooded and predated were also graphed to explore temporal effects.

I also classified land use types into several categories (Table 1). Individual sites are dictated by land managers, and thus highly variable in length and plover density (Kisiel 2009). The most common land use type in New Jersey is Municipal Beaches. These beaches are characterized by a high use of symbolic fencing in areas where Piping Plover territories and nests are observed. They also largely operate under a “share the beach” approach, where human use and recreation is considered at least of equal importance to beach nesting bird management. These beaches are also dependent on widely variable management plans that differ by individual municipalities, and seasonal staff and stewards hired under a centralized entity. There are approximately 20 miles of coastline and 17 nesting sites that fall under this classification. The second type of land use is Visitor Parks. These parks, while still allowing visitors during the beach nesting bird season, have biologists or seasonal stewards on site who play some role in Piping Plover management. They also have management plans that exist under a higher level of organization. There are approximately 20 miles of coastline and six nesting sites that fall under this classification. The third type of land use is Wilderness Beaches. Under this classification, visitors are not allowed to use the beach during the height of the beach nesting bird season. In addition, these beaches have personnel specifically dedicated to the management of beach nesting birds. There are approximately 12 miles of coastline and four sites that fall under this classification. Coastlines were mapped using the distance measurement tool in ArcMap 10.1. Each barrier island was also mapped in ArcMap (Figure 3).

Results

Predator Composition and Occurrence

Across the entire dataset, there were 673 occurrences of predators or predator track and sign. This includes occurrences with and without dates of observation attached. Data are summed across years, 2005-2013. The major predators that emerged were crow species (to include both Fish Crow and American Crow), Eastern Red Fox, Ghost Crab, gull species (to include Laughing Gull, Herring Gull, and Great Black-backed Gull), and Raccoon. There were 448 occurrences of these five species. These data are summarized in Table 3 by island, organized from north to south. A map of the islands in New Jersey is located in Figure 3. A list of predators known to cause nest failure, and predators observed throughout the nesting season broken down by management site is described in Table 2.

Predator occurrence was tallied regardless of nest fate. There were 541 occurrences of predators where monitors listed a species (or higher level taxon) as being present nearby the nest when checked on nest visits. These data only include observations when a date was attached. A full list of all species documented is listed in Table 2. The major species that emerged from this list are Eastern Red Fox (n=201), gull Species (Herring Gull, Great Black-backed Gull, and Laughing Gull, n=82), Northern Raccoon (n=51), crow species (either American Crow or Fish Crow, n=40), and Ghost Crab (n=38). In addition, known, suspected, or threatened predation was also documented by grackle species (Either Common Grackles [*Quiscalus quiscula*] or Boat-tailed Grackles [*Quiscalus major*] n=24), Red-winged Blackbirds (*Agelaius phoeniceus*) (n=19), Domestic Dogs (*Canis lupus*) (n=10), American Oystercatchers (*Haematopus palliatus*) (n=8), Domestic Cats (*Felis catus*) (n=8), American Minks (*Neovison vison*) (5), Coyotes (*Canis latrans*) (n=4), Peregrine Falcon (*Falco peregrinus*) (n=4), Striped Skunk (n=4), River Otter (*Lontra canadensis*) (n=2), White-tailed Deer (*Odocoileus virginianus*) (n=1), and snake species (n=1). Partial or complete nest destruction by humans was also documented 11 times.

Predator Occurrence Phenology

These occurrences were graphed across two temporal scales: by year (Figure 4) and Julian date for all seasons (Figure 5). The top five major predators were also broken down by Julian date in Figure 6. Year-to-year variability was high, with some years showing a much higher occurrence of some species than others across all geographical scales. Within the nesting season, when all data was combined throughout years, the data show that predator occurrences are at the highest in late May and throughout June, coinciding the peak of the Piping Plover hatching period (Figure 5). The five major predators showed differences in occurrences throughout the season. Fox were most prevalent in the middle of the season (from Julian dates 151-175, approximately May 31-June 24). Gulls, on the other hand, showed a high level of occurrence from approximately June 10-June 29, with another peak July 10-July 19, annually. Crows showed a low, but more or less seasonally consistent, presence until June 30th, when their occurrences drop off substantially. Likewise, Raccoons are present consistently throughout the season until July 20th, but with the highest levels of occurrence registering in late May. Ghost Crabs are also omnipresent, with occurrences lowering on July 10th of each year.

Nest Fate

Nest Fate Assessments

Of 1,228 nests included in the analysis, 439 were considered destroyed. Causes of destruction included predation (182), flooding (179), sand-covered eggs (9), and intentional or inadvertent human destruction (3). Six (6) nests were also documented as "overincubated", indicating eggs that exceeded the predicted hatch date that did not hatch. Sixty (60) additional nests were deemed to be destroyed, but with not enough evidence to determine the cause of destruction (Table 4). For the purposes of this analysis, nests that were flooded and predated were broken down by Julian date (Figure 7). Predated nests were further broken down into causes of avian, mammalian, and crab predation. It is important to note that predation causes denote the cause of failure of the entire clutch of eggs, not the loss of a single egg. Nest fates based on these determinations include only nests that failed prior to their predicted hatch date. This distinction differentiates these results from occurrence data, which records any predator observation, regardless of its impact on the entire clutch.

Of 182 predated nests, 99 were attributed to mammalian predators, 54 to avian predators, and one to ghost crabs. Twenty-eight (28) additional nests were determined to be predated, but with no evidence indicating the possible predator. Ninety-eight (98) predated nests were determined down to the species level. The majority (88%) of these were evidence-based determinations with evidence found on the same day used to make the fate call. A breakdown of these species-level predators is in Figure 8.Statewide-standardized protocols measuring predator pressure also were recorded for each nest. The pressure rating indicates how many times a predator was seen at each nest before either hatching or failure, and is recorded by the field monitor that is most familiar with each individual nest. See Table 5 for a complete list of results. Avian and mammalian pressure is tallied separately. Regardless of whether a nest was hatched or destroyed, mammalian evidence was rated as a zero at approximately the same rate (37% to 41%, respectively). This indicates that 37% of hatched nests, and 41% of destroyed nests, never recorded any sign of mammals or predators at nest checks throughout the life of the nest. The same pattern was seen with avian predators. 36% of hatched nests, and 41% of destroyed nests, were recorded as never having a predator in the close vicinity of the nest. However, when only nests that failed due to predation were calculated, the percentage of nests that had never seen a predator prior to predation was 6% (mammalian) and 13% (avian).

Nest Fate Phenology

Monitors could age 153 of the predated nests at the time of initial discovery. Half (77) of these nests were predated within the first seven days, while the other half (78) were assessed as depredated when the nest was between 8 and 34 days old. When breaking down this data by type, differing patterns emerge. Avian predators, consisting of gull and crow species, caused more depredations (32) when the nest was less than seven days old, as opposed to when the nest was older (22 nests). The opposite pattern holds for mammalian predators, with more nests depredated later in the incubation stage (26 nests under 7 days of age, 50 above). The average age of hatching for all nests was 32 days when nest age could be calculated (n=454 nests), from the date that the first egg was laid. The data show two peak hatching dates, one in the last week of May and the other in the third week of June (Figure 9).

When looked at across years, some seasonal trends begin to be further elucidated. One such result is that predator occurrences, and nests that are failed as a result of predation, both peak in the month of June (Figures 5 and 7), specifically just before the peak hatching dates. For the top five major predators, fox are shown to have the most impact during this time (Figure 8), causing 62 nest failures. High levels of predation occur throughout June, when predation rates, and hatching rates, drop off considerably.

Discussion

Predator Composition

A true understanding of predator composition on a geographic scale cannot yet be elucidated with the data given. The data show that foxes are a major predator, shown by their high number of occurrences and high number of nest depredations attributed to them, in a few select sites, such as Sandy Hook, Long Beach Island, and Seven Mile Island (Tables 2, 3, and 5). On its face, all of these islands are similar in the sense that they have large areas of natural dune system environments situated on inlets. These dune systems allow for close proximity to fox denning. Large areas in which management practices include reducing or eliminating visitation, development, and off-road vehicles characterize these beaches. Ghost crabs, another predator of Piping Plovers, also benefit from management practices such as mature dune systems and reduction of off-road vehicles, which could crush their burrows (Lucrezi and Schachler 2014). One would expect that ghost crabs would also rate highly with predator occurrences at beaches characterized by these features as well, but this was only seen on Long Beach Island. Virtually all raccoon occurrences are restricted to a single site, Little Beach in Ocean County. Perhaps unsurprisingly, gull and crow species show up in small numbers almost everywhere, regardless of any obvious defining feature.

These patterns, or lack thereof, are potentially illustrative of the fact that conclusions drawn by the data are confounded by a difference in how data are recorded and what recorders choose to record on their daily notes on the datasheet. Another limitation of using nest data to find predator occurrences over-represents the islands where lots of plovers nest, while potentially incorrectly inferring the severity of risks unique to one site across all sites. Additionally, islands and sites are of varying sizes throughout the state, which is not accounted for in data analyses. The question as to whether there are more predators in areas where high densities of plovers nest is not answered by the dataset. Further work is needed in order to understand the composition of predators. Ideally, this model would include a standardized methodology of surveying all potential nesting habitat irrespective of the density of nesting pairs. Standardized methodology, such as that proposed in Chapter 2 of this work, can help to better understand the relative impacts of the suite of important predators to Piping Plover nesting habitat.

Phenology- Nest Age

Nest age can only be determined when the monitor found the nest at less than full clutch, defined as the final number of eggs a nest obtains before hatching or predation. As such, of all predated nests, only a subset (153) of those nests could be aged. Nests are infrequently attended during the laying stages, which constitute the first five to seven days of the nest. Only when a nest is at full clutch do Piping Plovers incubate and attend almost constantly (Cairns 1977). Results show that during this first week of less frequent attendance, avian predators caused more depredations than they did during the last three weeks of the nest age. The danger to nests from avian predators drops even more significantly after the second week, with only 8 of 50 known depredations occurring after that time. This pattern is especially interesting when you consider the result that avian predators are not tallied as frequently in occurrences during the early part of the season, when the nest laying stages by Piping Plovers is most prevalent. These data suggest that nests during the laying stage are more vulnerable to avian predation. Additionally, due to the abundance of avian predators on the beach during the latter part of the nesting season, nests that are initiated later could potentially be more vulnerable than nests initiated earlier.

Mammalian predators, on the other hand, were shown to depredate nests at double the rate after this first seven days. When looked at on a weekly basis, however, one third (26) of depredations occur during the first seven days, with each subsequent week holding an equal chance of mammalian predation. This suggests while young nests are still vulnerable, actively incubated nests are still very more vulnerable than young nests. One possible explanation for the difference in risk for Piping Plovers could lie within the behavior of these predators. Many mammalian predators use scent as a means to finding Piping Plover nests, as opposed to avian predators, who tend to use more visual cues. Future analyses with a larger sample size of known-age, known-fate nests should include exclosure presence as a criteria, as this could change the results considerably.

Phenology- Seasonal and Annual

The understanding of predator phenology on barrier islands in New Jersey is based on predator observations at Piping Plover nests, rather than any surveys to record animal movement and beach use independently. As such, data are currently limited to the timeframe in which Piping Plovers have initiated laying nests through when chicks are fledged, approximately late April to early August. When looked at across the years of 2005-2013, the variability is apparent, as is the variability in the methods used by monitors in the field and different management scenarios (Figure 4). For example, based on predator occurrences as recorded by field monitors in daily notes, data in 2011 show that the predator occurrences were low. However, the rate of nests attributed to predation, as well as the predator density tallies, was approximately equal to other years.

A less biased method that could allow for more robust analyses in the future could involve collecting data on predator presence as soon as Piping Plovers start courtship on the beaches, and continue to collect that data through the end of the chick fledging on a site-by-site or regional basis. Analyses of seasonal trends are similarly limited by a lack of standardization of recording and effort, and the lack of information that could act as controls in areas where Piping Plover nests are limited or nonexistent.

The results obtained by this effort have implications for further study. Future work should be conducted to understand the site-specific phenology of predator and prey relationships in coastal ecosystems, beyond recorded occurrences around Piping Plover nests, in order to understand the impact to Piping Plovers breeding on these beaches. Enhanced understanding of the other prey items in the diet of Piping Plover predators could also impact management. For example, female Diamondback Terrapins emerge from the marsh water bodies in order to nest in large numbers on the beaches and surrounding marshes (Brennessell 2006). Terrapins have a highly predictable nesting phenology of late May-early July (Brennessel 2006). While exact figures are not known, when the nests are predated, up to 95% of these predation events occur in the first 24 hours of the nest being laid (Brennessel 2006). Not surprisingly, their main predators are some of the major predators of Piping Plover nests as well, such as Eastern Red Fox, Raccoon, Skunk, and crow and gull species (Brennessel 2006). This influx of prey items in the form of Diamondback Terrapin eggs to the coastal ecosystem could perhaps release some of the predation pressure on plovers during the peak hatching and young chick-rearing stages, when the birds are at their most vulnerable.

Understanding the phenology of the predator and prey bases in the specific systems also can have predator management impacts. Ghost crabs can act as a prey item for mesopredator species such as foxes and raccoons, or as a predator on Piping Plover eggs or young chicks. However, their life cycle phenology on the New Jersey coastline shows that they are not very active on beaches until late May or early June (R. Boerner, personal communication) and thus perhaps present a much larger predation risk for plover nests initiated later in the nesting cycle. Additionally, larger ghost crab burrows, built by adult ghost crabs, are found further away from the high tide lines and into dune structures (Lucrezi and Schachler 2014), overlapping areas where plovers nest. Burrows, and therefore ghost crabs, are most successful where off-road vehicles are not crushing burrows (Lucrezi and Schachler 2014). Off-road vehicle restrictions imposed upon passenger vehicles, construction equipment, and beach rakes, are a common management strategy designed to protect beach-nesting birds such as the plover. However, these restrictions provide ancillary benefits to ghost crabs. This overlap in habitat suitability, both in site selection and management strategy, could present a greater predation risk to plovers in their proximity to these burrows. In addition to understanding this potential direct risk, further work is needed to see if mesopredators such as fox, raccoon, and skunk seek out ghost crab burrows. If this is the case, plovers could suffer from the chance encounter of mesopredators seeking out ghost crabs, and instead finding plover nests or young.

Gull phenology data are suggestive as well. Figure 6 shows a peak in gull occurrences around May 1-May 5 each year, which is immediately prior to peak egg laying of gull species in New Jersey (Burger 1978, Montevecchi et. al. 1979). A period of low gull occurrences recorded by Piping Plover nest monitors lasts throughout gull incubation, until another peak of high activity, which lasts from June 10th to July 19th. This period coincides with the height of the chick-rearing period for nesting nearby gulls (Burger 1978, Montevecchi et. al. 1979). These occurrence data suggest that management actions targeted at reduction of gull predation might not be as successful during the nesting phase of plovers, and that gulls could potentially impact plover chick survival more than nest survival.

Management Implications and Conclusions

Monitoring Piping Plover nests is a challenging task. Resources and training opportunities are limited, and frequently monitors need to monitor many beaches and nests in a day of a variety of nesting bird species, including, but not limited to, Piping Plovers. These time and resource considerations may not allow a careful study of all available evidence during each visit to a nest. While recording data throughout the life of the nest can be valuable, time and resource limitations could supersede the importance of careful assessment of the nesting area at each visit. However, nest-fate assessments, made at the time of hatching or failure, should be made extremely carefully regardless of the amount of time and resources it might take. Striving to find this balance in order to capture the most information possible to understand the threats and possible solutions to the myriad difficulties facing Piping Plovers is of utmost importance for the continued recovery of the species.

Ultimately, predator observations are difficult to assess for their impact to nest fate. Even with standardized surveys, there can be bias. Bias can be behavioral; for example, gulls tend to loaf on the beaches, which can cause them to be counted more frequently than a ghost crab, which might move through very quickly and cryptically, even if numbers and presence are similar. Another potential source of bias is between observing nocturnal versus diurnal predators. Nocturnal predators can only be assessed by field monitors via track and sign evidence, or by cameras pointed at each nest, an expensive and potentially risky option. Track and sign evidence, while important, can be ephemeral and not captured on regular monitoring surveys. On the other hand, diurnal predators, such as gulls, crows, and domestic dogs, are easily observed in the field during regular monitoring.

Another area of improvement in nest-fate assessments is regarding the potentially very valuable information gained by eggshell evidence. Fragments or whole broken eggshells were listed in monitor notes 19 times, with no guess or assumption as to the cause of destruction. However, details of the appearance of the eggshell were usually listed in great detail. This indicates a need for further field monitor training in the use of eggshell evidence to accurately assess predators. Mabee (1997) illustrates the potential knowledge that can be gained from assessing eggshell evidence. Eggshell fragments can also be found during hatching (Mabee 1997), further compounding the importance of eggshell fragments in nest fate assessments.

In order to properly use all of this evidence in order to understand the effect of predators on Piping Plover nesting success, standardized and regular predator assessments should be made by trained and qualified monitors. Occurrence data, while useful, are not standardized and are just noted occasionally when a field monitor visits the nest. Due to increasing human scent and tracks to the nest, as well as considering stress to the plovers, it is not recommended that field monitors approach the nest on each visit (T. Pover, personal communication, 2015). Therefore, track evidence near the nest would be harder to distinguish. Many methods exist to assess predator composition. One standardized method of assessing predator composition using track evidence away from the nest structure is outlined in Chapter Two. In addition to these processes, occurrence data should continue to be made on the daily nest checks.

Standardized survey and occurrence data can also be used to continue to understand the phenological patterns exhibited by predators and prey on New Jersey's beaches. Trapping efforts are expensive and time-consuming, and potentially cause disturbance to nesting birds. However, the benefits of removing predators from a site can outweigh these challenges. In order to make trapping the most effective, with the least harm given, as much should be understood about the targeted predator and their interactions with their Piping Plover prey. Phenological patterns can be used to direct predator mitigation efforts in a more targeted manner. For example, fox trapping should occur at the dens before mid-March when the adults and pups are more reliably present in that location. Working with the individual municipalities or land managers to provide extra trash removal can help to mitigate some gull activity on the beaches. Using collected data, these efforts should be focused during the chick-rearing stage, when gull occurrences are higher. Finally, further data collection on raptor occurrences, combined with mammalian density and impact can help to influence decisions on where and when predator exclosures should be placed to manage adult mortality and nest failures.

In-depth Piping Plover monitoring is a challenging job, made more difficult by limited resources, budgets, and time by land managers. The recovery metrics listed in the Piping Plover Recovery Plan (USFWS 1996) for the Atlantic Coast population emphasize reproductive goals as a major driver in success of species recovery. Any successful strategy to improve accuracy of assessments of nest fate will help inform these reproductive metrics put forth by the Recovery Plan. There has never been a systematic, evidence based, data driven framework applied equally by all managers. It is my hope that the information provided in Chapter Two will be a step in this direction. Standardized surveys will only enhance and improve those nest-fate assessments, and shed further light to our understanding of coastal ecosystem processes. Reducing variability amongst monitors and decision managers, standardizing data obtained, and relying on multispecies management approaches will help to direct and guide management efforts to protect Piping Plovers.

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Table 1. Sites and Management Classification, 2005-2013.

Site Name	***Site Classification***	***Abbreviation***	***Miles***
Sandy Hook	Visitor Park	SH	7.3
Sea Bright North	Municipal Beach	SBN	2.0
Monmouth Beach	Municipal Beach	MON	1.8
Seven Presidents Park	Visitor Park	7P	.9
Sea Girt Wreck Pond	Municipal Beach	SGW	0.6
Island Beach State Park	Visitor Park	IB	9.6
Barnegat Light	Municipal Beach	BN	1.8
Holgate	Wilderness Beach	HG	3.8
Little Beach	Wilderness Beach	LB	4.1
North Brigantine Natural Area	Visitor Park	NB	1.5
Seaview Harbor Marina	Municipal Beach	SM	.53
Waverly	Municipal Beach	WV	1.1
Ocean City	Municipal Beach	OC	.75
North Corson's Inlet	Visitor Park	NC	0.7
South Corson's Inlet	Visitor Park	SC	0.6
Strathmere Natural Area	Municipal Beach	STM	0.6
Strathmere Upper Township	Municipal Beach	STU	0.9
Whale Beach	Municipal Beach	WH	1.7
Townsends Inlet	Municipal Beach	TI	0.5
Avalon	Municipal Beach	AVD	2.6
Champagne Island	Municipal Beach	CI	.3
Stone Harbor Point	Municipal Beach	STH	1.7
North Wildwood- Hereford Inlet	Municipal Beach	NWH	.75
Coast Guard North	Wilderness Beach	CN	.6
Coast Guard South	Wilderness Beach	CS	3.6
Cape May Meadows	Visitor Park	CM	.8
Cape May Point State Park	Visitor Park	CP	.5

Table 2. Causes of nest failure (when due to predation) and the known cause. Predators seen: Known or potential predators tallied by field monitors throughout the nest and brood stage of each individual nests. Data are pooled across years (2005-2013). AO- American Oystercatcher, BB- Red-winged Blackbird, CA- Domestic Cat, CR- Crow species, DE- Deer, DG- Domestic Dog, FX- Eastern Red Fox, GB- Great Black-backed Gull, GC- Ghost Crab, GR- Grackle, GU- Gull Species, HG- Herring Gull, LG- Laughing Gull, MN- Mink, OT- Otter, SK- Skunk, SN- Snake, RA- Raptor, RC- Raccoon

Site Name	***Nests lost due to:***	***Predators seen:***
Sandy Hook	CR, FX, GU	AO, BB, CA, CR, DE, DG, FX, GC, GR, GU, RA
Sea Bright	CR, FX	CA
Monmouth	--	CR, DG, FX, GU, RA
Seven President's Beach	CR	CR, DG, FX
Sea Girt Wreck Pond	CR	CR, DG, GU
Island Beach State Park	FX	FX
Barnegat Light State Park	CR	CA, CR, FX, GR, RA
Holgate	FX, GR	FX, GB, GC, GR, HG, LG, PF, RC
Little Beach	AO, FX, RC	FX, GB, GC, GR, LG, OT, RA
North Brigantine Natural Area	FX, GU	BB, CR, FX, GU, PF, RC
Seaview Harbor Marina	--	--
Waverly	--	--
Ocean City	GU	BB, FX, LG, GC, GR
Corsons Inlet	FX	FX, LG
Strathmere Natural Area	--	LG
Townsends Inlet	--	--
Avalon Dunes	FX, SK	CA, CR, DG, FX, GC, GR, SK
Champagne Inlet	--	--
Stone Harbor	FX, GU, LG, MN, SK	CR, FX, LG, GB, GC, DG, MN, SK
Two Mile (Coast Guard North)	GR	CA, CO, CR, GC, GR
Coast Guard South	--	CR
North Wildwood	--	CA, CR, FX
Cape May Meadows	--	CO, CR, GC, SN
Cape May Point State Park	--	CO, CR

Table 3. Total number of predator occurrences of the top five most abundant species, listed by barrier island in New Jersey between 2005-2013. Islands (12) are organized from north to south. These data are pulled from all nests, regardless of fate.

	Crow	*Fox*	*Ghost Crab*	*Gull*	*Raccoon*
Sandy Hook Island	9	93	3	27	3
Shark River Area	12	16	0	2	0
Barnegat Bay Island	0	2	0	0	0
Long Beach Island	3	41	17	31	5
Little Beach Island	0	34	6	25	41
Brigantine Island	1	8	0	2	1
Absecon Island	0	0	0	0	0
Peck's Beach Island	0	5	1	5	0
Ludlam Island	0	0	0	1	0
Seven Mile Island	2	18	4	7	0
Five Mile Island	3	0	2	0	0
Cape Island	12	0	5	1	0

Table 4. Nest fates by site, 2005-2013.

Site	***Disturbance***	***n=***	***Abandoned***	***Destroyed***	***Hatched***	***Unknown***
Seven President's Beach	Medium	17	1	4	12	0
Avalon Dunes	High	49	9	16	24	0
Barnegat Light State Park	High	24	1	8	14	1
Champagne Inlet	Medium	5	0	3	2	0
Two Mile (Coast Guard North)	Low	7	0	3	3	1
Cape May Point State Park	Medium	33	3	6	24	0
Coast Guard South	Low	9	2	2	5	0
Holgate	Low	107	6	33	68	0
Island Beach State Park	Medium	4	1	3	0	0
Little Beach	Low	133	2	73	52	6
Monmouth	High	14	4	2	8	0
North Brigantine Natural Area	Medium	81	9	44	27	1
North Wildwood	High	24	7	7	10	0
Ocean City	High	26	10	3	12	1
Sea Bright	High	51	8	18	24	1
Corsons Inlet	Medium	14	0	7	6	1
Cape May Meadows	Medium	44	3	5	36	0
Sea Girt Wreck Pond	High	5	1	2	2	0
Sandy Hook	Medium	411	69	96	242	4
Seaview Harbor Marina	Medium	3	0	0	3	0
Stone Harbor	Medium	150	7	99	41	3
Strathmere Natural Area	Medium	5	0	2	3	0
Strathmere- Upper Township	High	7	1	0	6	0
Townsends Inlet	High	2	0	1	1	0
Whale Beach	High	1	0	0	1	0
Waverly	High	2	0	2	0	0
Totals		***1,228***	***144***	***439***	***626***	***19***

Table 5. Predation pressure as measured by statewide protocols. Numbers represent the number of times evidence of a predator was tallied around the nest by field monitors throughout the life of the nest and brood.

Mammal Pressure Rating					***Avian Pressure Rating***				
	0	**1**	**2**	**3+**		**0**	**1**	**2**	**3+**
Hatched	37%	27%	6%	30%	Hatched	36%	19%	5%	40%
Abandoned	31%	17%	6%	46%	Abandoned	40%	12%	5%	43%
Destroyed	41%	31%	7%	21%	Destroyed	41%	31%	4%	24%
Unknown	42%	53%	5%	0%	Unknown	53%	32%	10%	5%
Average	38%	32%	6%	24%	***Average***	43%	24%	6%	28%
Only predated nests (mammal) (n=99)					Only predated nests (avian) (n=54)				
	0	1	2	3+		0	1	2	3+
	6%	53%	15%	26%		13%	57%	7%	22%

Table 6. Coastal Phenology for predators on New Jersey's barrier islands.

Predator Phenology

	Fish Crow	**Laughing Gull**	**Herring Gull**	**Great Black-backed Gull**	**Fox**	**Raccoon**
Early April	Nest building	Colony occupation		Nest building	Cubs are born	Young are born
Mid April	Nest building		Nest building	Peak laying		
Late April	Nest building			Incubation	Cubs emerge from den	
Early May	Peak laying	Egg laying begins	Peak laying	Incubation		
Mid May	Incubation		Incubation	Peak hatching	Cubs are weaned	Adult females leave den
Late May	Peak hatching	Peak laying	Incubation	Chick rearing	Hunting in family groups	
Early June	Chick rearing	Incubation	Peak hatching	Chick rearing	Hunting in family groups	Young leave den
Mid June	Chick rearing	Peak hatching	Hatching/chick rearing	Chick rearing	Hunting in family groups	Mothers and young out
Late June	Chick rearing	Chick rearing	Chick rearing	Chick rearing	Hunting in family groups	Mothers and young out
Early July	Chick rearing	Chicks fledging, remain near colony	Chick rearing	Chick rearing	Hunting in family groups	Mothers and young out
Mid July	Peak fledging		Chick rearing	Chick rearing	Hunting in family groups	Mothers and young out
Late July			Chicks fledging	Chicks fledging	Hunting in family groups	Mothers and young out
August		Adults and young on beaches	Adults and young on beaches	Adults and young on beaches	Hunting independently	Mothers and young out
September		Migration	Adults and young on beaches	Adults and young on beaches	Hunting independently	Mothers and young out

Table 7. Coastal Phenology for prey on New Jersey's barrier islands.

Prey Phenology

	Piping Plover	Diamondback Terrapin	Fiddler Crab	Ghost Crab*
Early April	Arrive on territory			
Mid April				
Late April				
Early May			Increase activity	
Mid May	Peak egg laying		Increase activity	
Late May	Incubation	Begin nesting	Increase activity	Increase activity
Early June	Incubation/Chick rearing	Nesting	High activity	Increase activity
Mid June	Incubation/Chick rearing	Nesting	High activity	High activity
Late June	Incubation/Chick rearing	Nesting	High activity	High activity
Early July	Chick rearing	Nesting	High activity	High activity
Mid July	Fledged chicks on beach	Nesting	High activity	High activity
Late July	Fledged chicks on beach		High activity	High activity
August	Adults begin to migrate		High activity	High activity
September	Adults and fledglings migrate	Hatchlings emerge	Reduce activity	Reduce activity

**in this system, ghost crabs act as predators of Piping Plover nests as well as prey for many other predators.*

Figure 1. Nest sites used by Piping Plovers, 2005-2013. n=27.

Figure 2. Datasheet used by NJENSP to assess nest fate.

NEST FATE

Date Determined ___/___/___ Last observed incubating ___/___/___

__Hatched Maximum # chicks ever observed ____ # Eggs remained unhatched _____

__ Failed (all eggs missing) Probable cause:

- __ predation
  - __ avian
  - __ mammalian
- __floods
- __undetermined
- __people
- __other __________ (eggs buried, etc)

__Abandoned (eggs intact, adults gone)

__Unknown

Clutch reduction (eggs lost before hatching) ? ___Yes ___No Date(s) and # lost ____________________________

Regardless of nest outcome, did any evidence of the following exist within 10 meters of the nest on any nest check?

Give level of occurrence: **1** (evidence observed 1-3 times) **2** (4-6 times) **3** (7-10 times)

mammalian predator____________ avian predator________________ ghost crab______________

people brief___________________ people extended_______________ flooding_________________

ORV________________________ beach scraper________________ severe storm______________

Figure 3. Barrier islands in New Jersey used by Piping Plovers for nesting, 2005-2013.

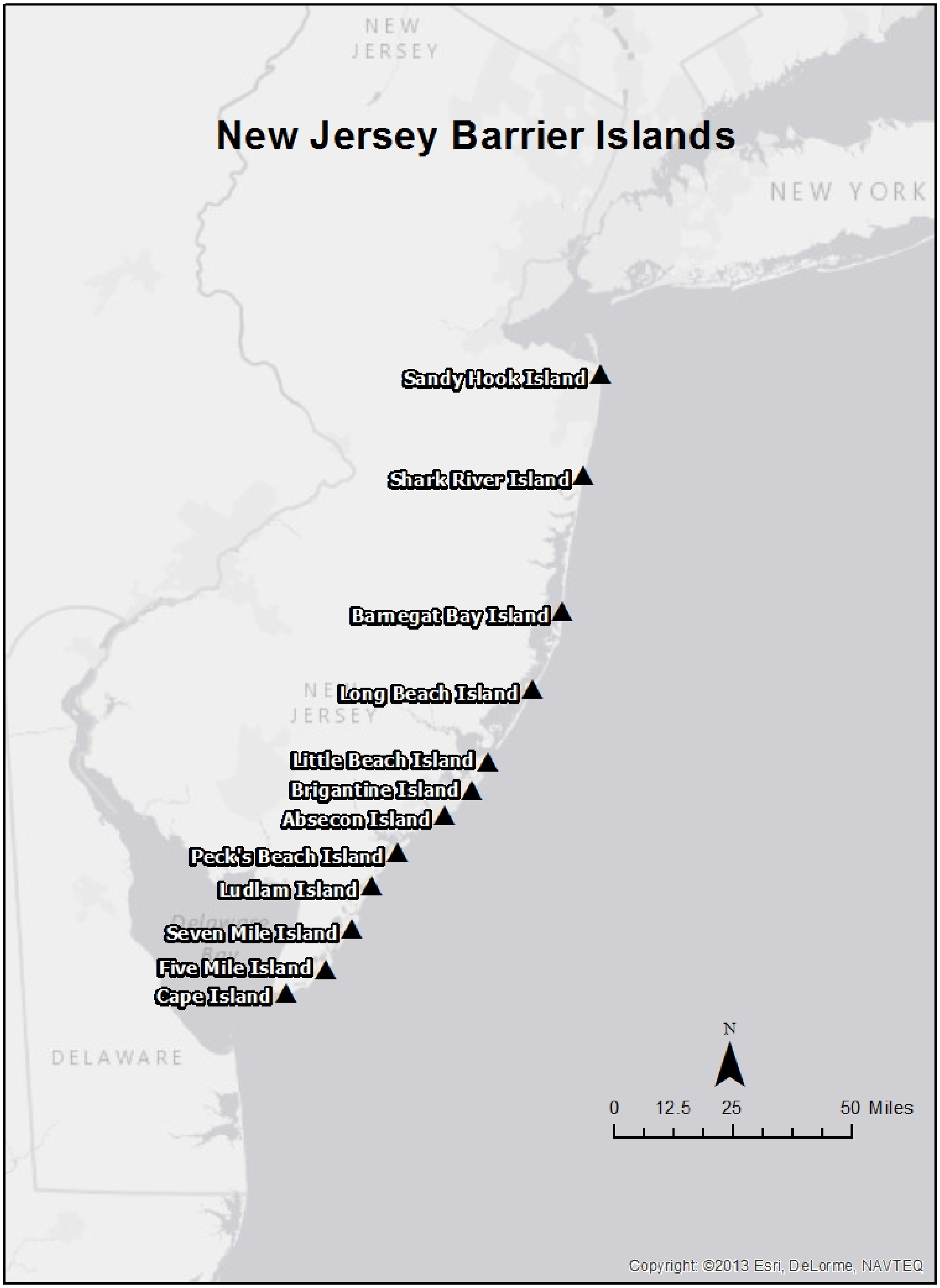


Figure 4. Occurrences of the top five major predators (412 occurrences) that were noted with dates corresponding to the sighting, separated by year.

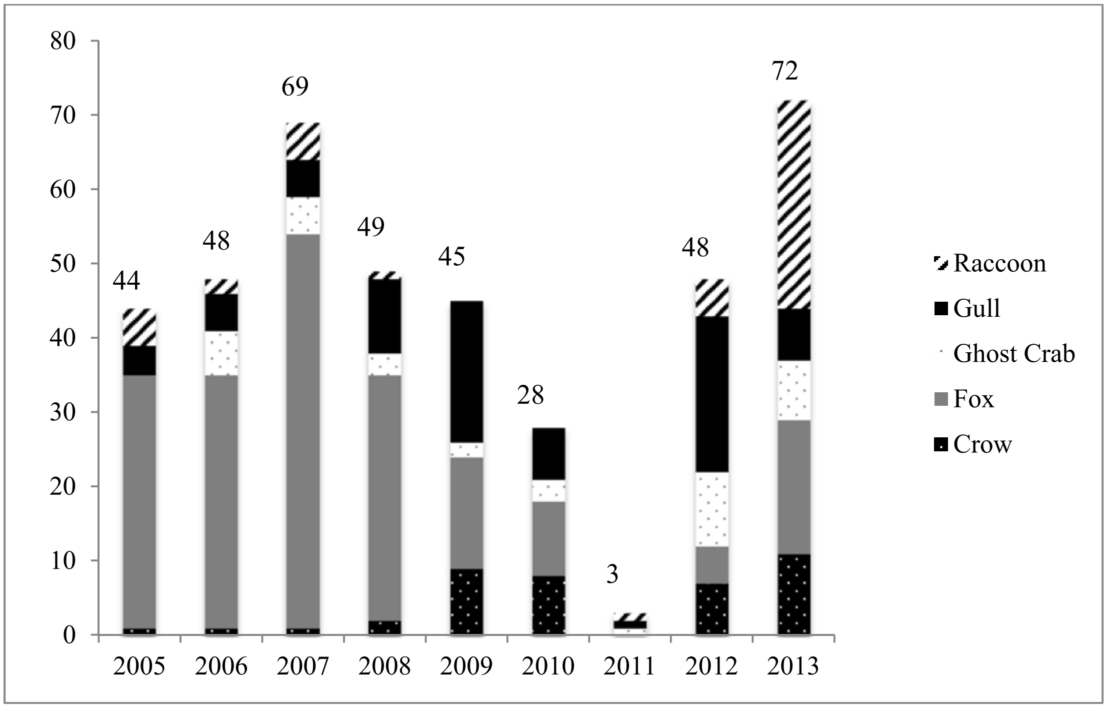


Figure 5. Occurrences of all predators (541 occurrences of 19 predator species) that were noted with dates corresponding to the sighting. Data are combined across 2005-2013 and listed by Julian date. Two peak hatch dates were also calculated from the data and incorporated.

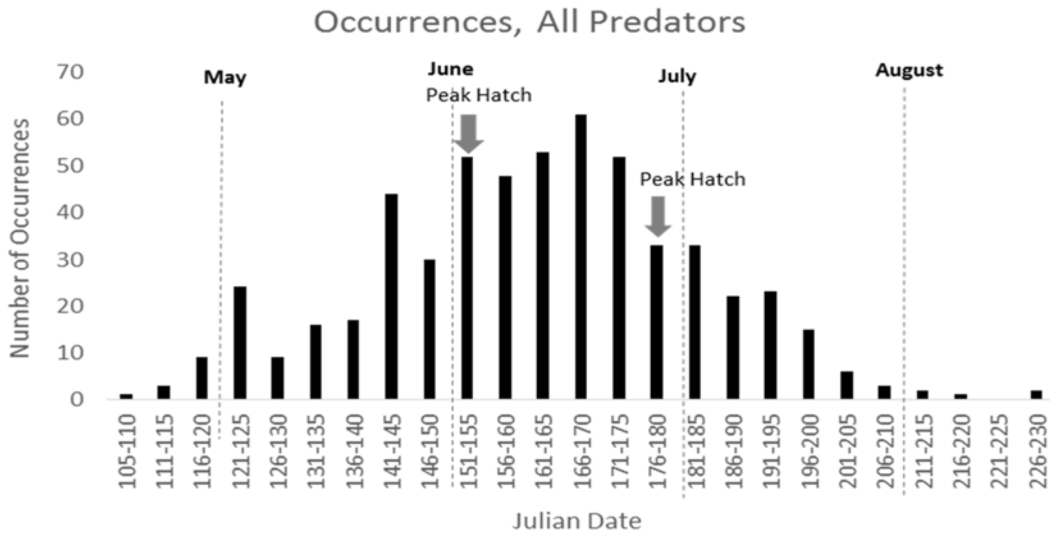


Figure 6. Occurrences of the five most abundant predators (412 occurrences) that were noted with dates corresponding to the sighting. Data are combined across 2005-2013 and listed by Julian date.

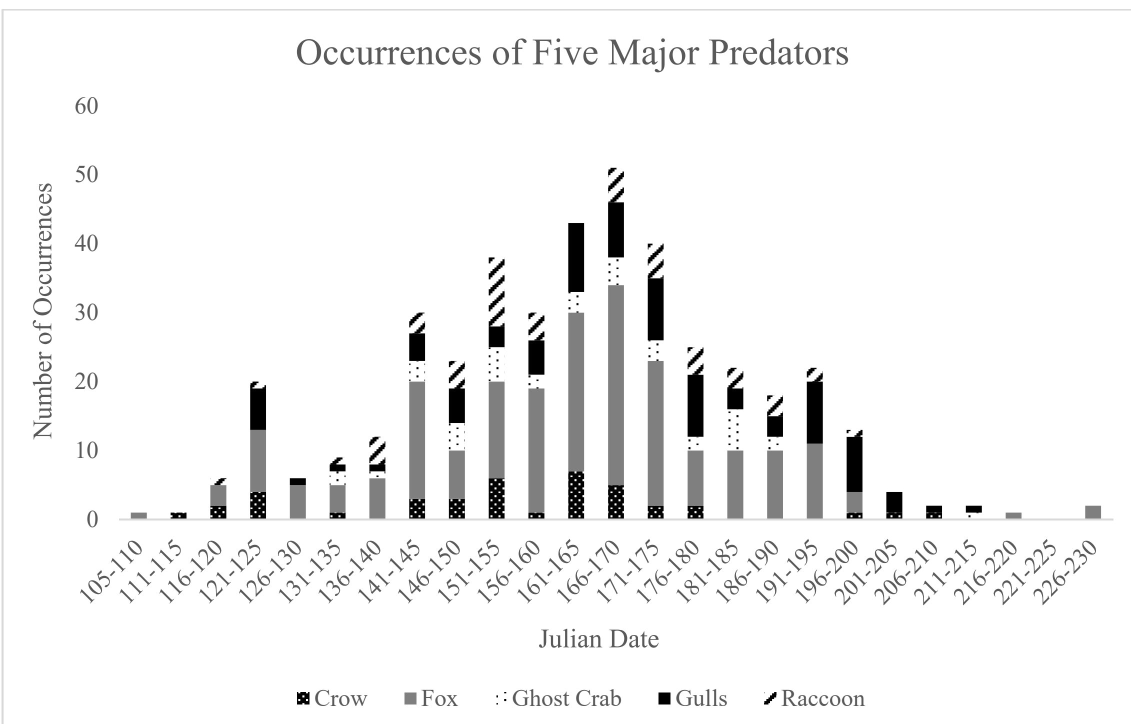


Figure 7. Nest failures of flooded and predated nests by date, pooled across seasons (2005-2013).

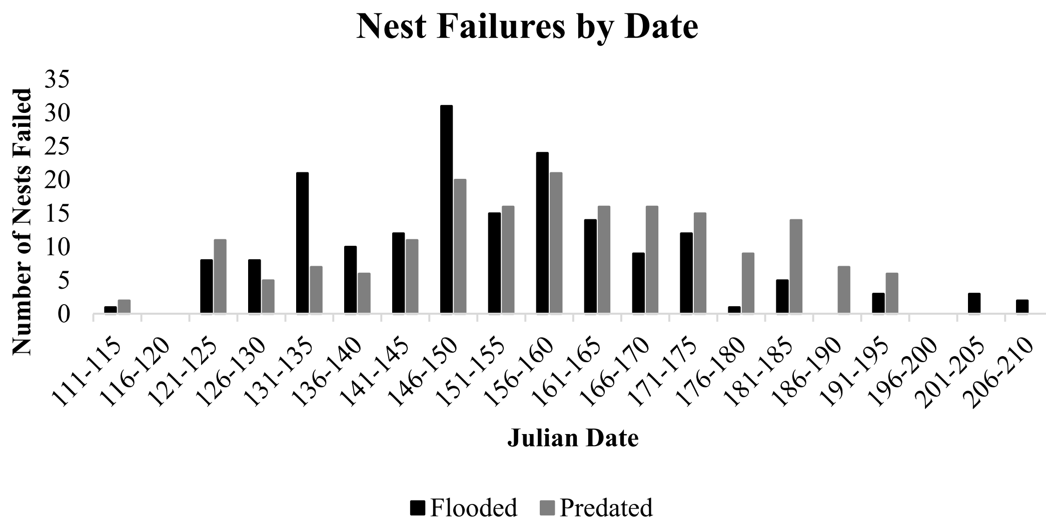


Figure 8. Nest failures of predated nests, pooled across seasons (2005-2013) and broken down by predator.

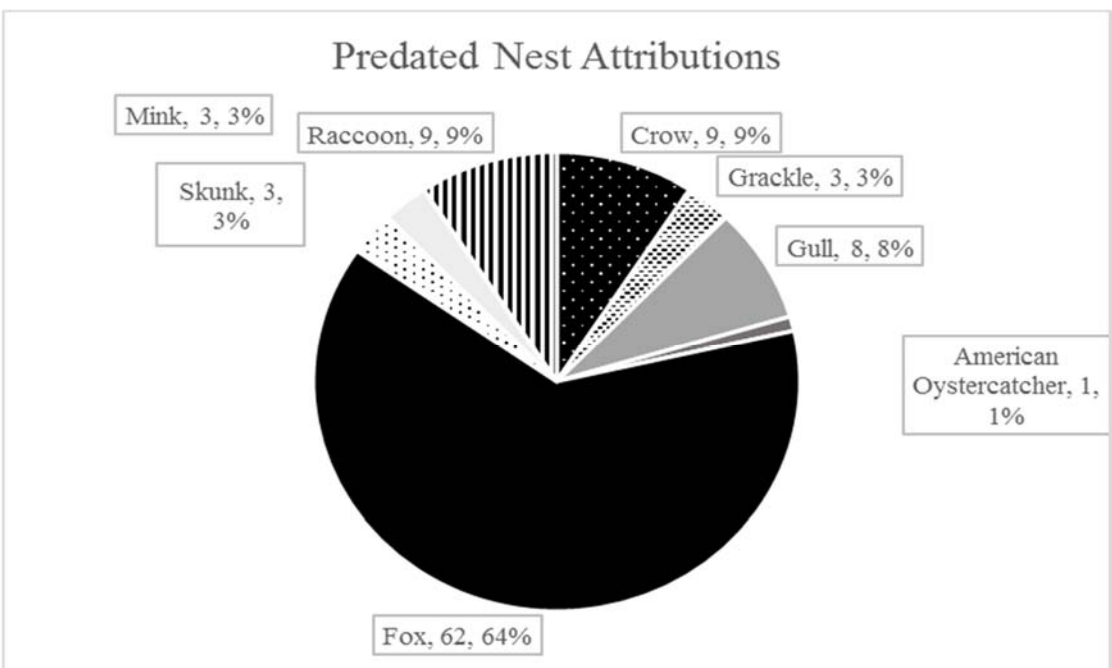
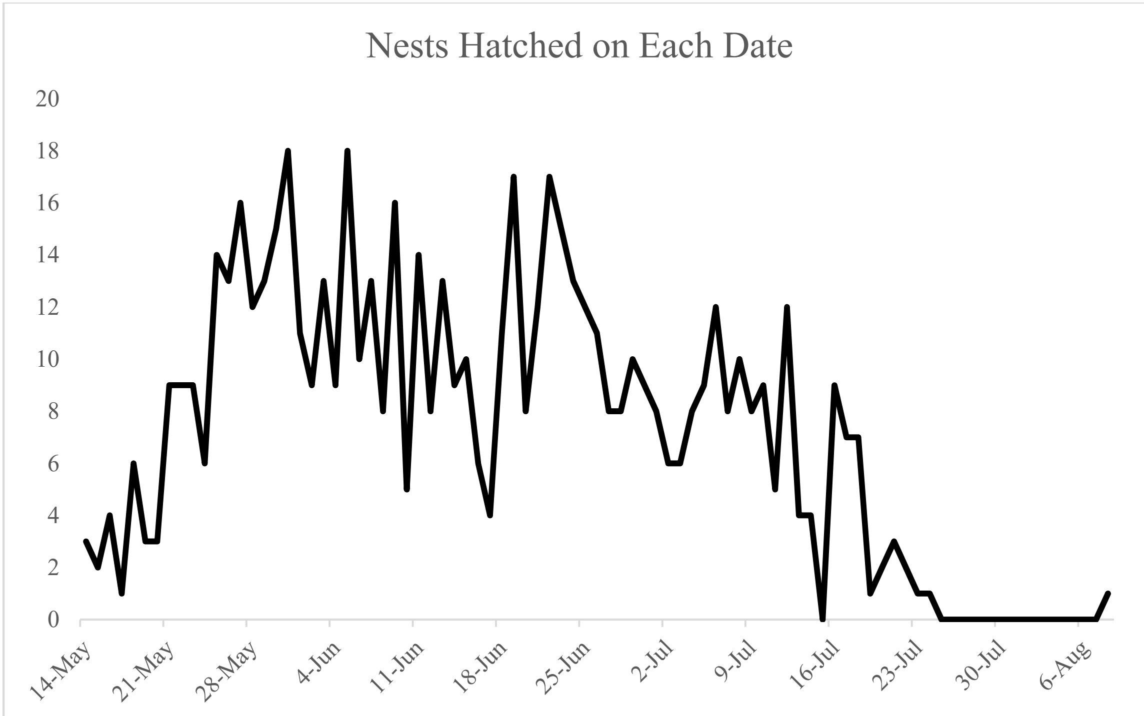


Figure 9. Nest hatching date for each aged nest included in the analysis (n = 626).



Nests Hatched on Each Date
20
18
16
14
12
10
8
6
4
2
0
14-May
21-May
28-May
4-Jun
11-Jun
18-Jun
25-Jun
2-Jul
9-Jul
16-Jul
23-Jul
30-Jul
6-Aug

Chapter 2: A Recommended Field Protocol and Reference Manual for Assessing Predator Evidence to Determine Nest Fate

Introduction

Long-standing and well-established field practices exist for beach nesting bird management throughout New Jersey, but no such statewide-standardized protocol exists for assessing predator evidence (T. Pover, personal communication). Most observers, hereafter referred to as monitors, are trained on the ground by full-time staff or more experienced seasonal field technicians. While on-the-ground training from more experienced monitors is vital, this material seeks to provide background information, a reference guide, and suggested management practices in order to more accurately assess predator evidence regardless of skill or experience.

This review is particularly timely because of ongoing and renewed effort to evaluate many aspects of data collection by beach monitors. A surge of funding has allowed for more in-depth analyses than previous annual efforts. One such example impacting predator studies is the recent efforts to evaluate the effectiveness of exclosures, or predator exclusion cages, in a more structured manner (Cohen et. al. 2016). These cages are placed around Piping Plover nests and seek to keep mammalian and avian predators from depredating the nest, while still allowing the plover to incubate and move freely ((Rimmer and Deblinger 1990, Hardy and Colwell 2008, Beaulieu et. al. 2014, Murphy et. al. 2003, Maslo 2009). Exclosures are currently being reviewed in many locations in recent years, including ones located in New Jersey (Cohen et. al. 2016). While exclosures are by most accounts an effective way of increasing the hatch success of Piping Plovers (Murphy et al. 2003, Maslo and Lockwood 2009), some studies show that exclosures increase adult mortality rates (Cohen 2009, Murphy et. al. 2003, Roche et. al. 2010). One solution proposed by several authors is to use exclosures only at sites where predator dynamics and species composition are well known entities (Mabee and Estelle 2000). Especially with active experimentation currently going on in New Jersey regarding the effects of exclosures, it is imperative to understand all aspects of predator dynamics and species composition at management sites. An enhanced understanding of predator dynamics can help feed data to decision tools regarding the use of exclosures or other novel forms of predator mitigation in order to increase Piping Plover populations.

Training manuals and background materials on bird identification, nest-searching, and conservation messaging to beach visitors are currently in use (Canale 1998), and this work does not seek to replace those efforts. Instead, the suggested changes and added information will focus on monitoring activities specifically as they relate to predator presence or absence and density throughout the breeding season, as well as how to make nest-fate, and in a larger sense, management decisions throughout the incubation period. It is intended for use by Piping Plover biologists, field monitors, academic researchers, or any other stakeholder responsible for drawing conclusions about the success or failure of Piping Plover nests in New Jersey.

Suggestions for Monitoring Methods

After a nest has been located, it is imperative to avoid direct approach to the nest on subsequent visits whenever possible. Many predators could perhaps smell human scent or see human tracks, and follow these cues to see where they lead. While the practice of remote nest observation does not allow for assessment of predator activity in the immediate vicinity of the nest, the safety of the nest and incubating adults is of utmost importance.

The nest should not be marked in any way. Monitors should take handheld Global Positioning System (GPS) coordinates, take meticulous notes, and take a photo from a set angle such as facing away from the tideline of the microhabitat surrounding the nest, ensuring any defining features are captured in the image. Handheld GPS units should be carried in the field any time a new nest could be discovered.

Monitors should visit the nest every 1-3 days to get the best, most up-to-date information possible. Nests can hatch early, flooding events can occur, and depredation evidence can be erased by winds and tides. Thus, a short interval between nest visits is critical to make the most accurate nest fate determination. A remote check using long-range optics such as binoculars or a spotting scope should be used whenever possible. If approaching the nest directly is necessary on any of these visits, monitors should take extreme caution that no avian predators are in the area that may be cued in to the nest from such an event. Upon approach, monitors should walk parallel to the nest, walking past the nest in a straight line and taking observations from the periphery. Footprints leading up to the nest bowl then going back in the same direction should be avoided at all costs so as to not attract predators that may cue into human tracks.

Datasheets should reflect which nest-checking approach was taken, remote or direct, to more accurately assess potential ramifications of monitor interactions with nests at a large scale. Remote checks can be defined as observing a nest from a close enough distance to ascertain nest status, but far enough away that the behavior of the nesting pair is not changed. If using direct observation, evidence about predator track or sign seen in the close vicinity of the nest should be recorded. Datasheets should also be altered with new columns to reflect known or suspected predator species, evidence type and species and the distance from the nest that this evidence occurred. New datasheet change suggestions are shown in Figure 1.

Track Surveys

When a nest is found, data are collected on many variables regarding micro and macro habitat and vegetation features (Canale 1998). Most predators of Piping Plovers travel parallel to the coastline (Loegering and Fraser 1995, Doherty and Heath 2011). As such, track surveys should be conducted perpendicular to the tide line, intersecting this line of travel. This methodology is confounded by some of the barrier island beach strands in New Jersey that serve as Piping Plover habitat, as the predators travel across both bayside and ocean side habitat (T. Pover, personal communication, 2015). In these scenarios, if possible, transects running across the entirety of the barrier island strand from ocean tideline to bayside would be the most effective. If the topography doesn't allow for transects from beach to bay, surveys should be conducted perpendicularly to whichever tideline is closer to the nest.

A suggested methodology for these transects has been described by Doherty and Heath (2011), Engeman and Allen (2000), and Engeman et al. (2005), and adjusted slightly for New Jersey's beaches. The steps are as follows:

Materials needed*:* coin, compass, rangefinder, rake (can be made of object found on beach, such as a piece of driftwood)

1. Upon discovery of a nest, pick a random direction north or south of the nest, determined by flipping a coin.
2. Walk 50 meters in the chosen direction. Observe the behavior of the Piping Plover to assess whether the pair is affected by your presence. If so, continue moving in the same direction in ten-meter intervals until the nest is not endangered by lack of adult attendance.
3. Starting at the beach or bay tideline (whichever is closer to the nest), rake a one-meter wide trail from the tideline to the base of the dense dune vegetation, tree line, or other major obstacle. If no such obstacle exists in the case of washover habitat from ocean to bay, sweep 100 meters inland.
4. Return the next day and count the number and species of each track line in the greatest detail possible. In the case of inclement weather between sweeping and survey, give an extra 24 hours.

5. Note weather conditions for that day, as well as any flooding or obvious wind effects.
6. At the time of the initial transect, complete another survey using the same methodology in a random placement along the tideline to serve as a control for the track survey completed. This control transect should be no closer than 30 meters from the track survey transect. In notes, label this transect "Control".

See datasheet (Figure 2).

Assessing Nest Fate

The best way to get accurate hatch dates is by locating the nest while it is still in the laying stages, before final clutch is achieved. Early detection of nesting attempts is vital to assigning nest fate. Hatch dates should be predicted using a standardized calendar (Canale 1998) (Figure 3). Generally, Piping Plovers hatch an average of 28 days after laying the final egg in the clutch. This allows for some predictability in the hatch prediction dates. However, there is some variability in these dates. When the nest is within three days of its predicted hatch date, it should be visited daily to increase the chances that an accurate nest fate will be assessed. When assessing if a nest hatched or failed, in the absence of any direct evidence in either direction, assume an unknown fate if it is plus or minus three days from the predicted hatch date.

Hatch date can only be predicted in scenarios where the clutch of eggs is discovered before the end of laying. If the nest is found at final clutch size, generally four eggs unless it is later in the season or a renest attempt (Wilcox 1959), then hatch dates cannot be back calculated by the date first laid. In these scenarios, visit the nest as often as possible to assess when the nest has hatched.

If the nest hatching has not been confirmed by the presence of chicks, it is imperative to approach the nest bowl to collect evidence to evaluate fate. Evidence should be evaluated if it is within ten meters of the nest in a circular radius (Figure 4). Using this standardized distance allows for year-to-year or site-to-site comparison of results, allowing for better analysis and management decisions in the future.

In prior years, distance measuring and use of judgment in making nest fate assessments has resulted in a variety of observations written down or excluded from analysis. All managers across the state of New Jersey have recorded a rating of predator pressure within ten meters of the nest, using evidence such as tracks, scat, or visuals, on a scale of 1-3 (0 = never, 1 = 1-3 times, 2 = 4-6 times, 3 = 7 or more times). These data are recorded regardless of nest age or number of visits to the nest. If a nest was only seen once before it was predated, then the predator pressure rating would be a 1. This can have the effect of skewing the data toward fewer predators seen.

While the predator intensity ranking system of 1-3 are important, this section provides only a coarse metric of what is happening at each nest and across a management area or site, and relies on the memory of many monitors to assess a pressure ranking. This section of the datasheet was recorded once the nest failed or hatched. Waiting to fill out these observations at the end of a nest cycle does not allow for adaptive management, or the ability to make decisions throughout the nesting stage. Finally, this metric encourages, and only takes into account, those visits which are a close approach to the nest.

In the 2016 Piping Plover nesting season, this system was changed to include a running tally filled out by monitors after each nest visit, which will improve this rating system by allowing for a weighted metric that takes into account the number of visits to a nest (C. Davis, personal communication, 2017). This system also ensures that a monitor assesses predator presence on each visit. However, it does not take into account whether a nest was visited by a monitor within ten meters, which could have the effect of undercounting cryptic evidence only visible at close range.

All datasheets have a notes section where the field monitor can write down any observations from the day that they deem important to the narrative. Nine years of handwritten datasheets (2005-2013, n= 1,077) were analyzed for content and the ease of making assessments of predator occurrence or cause of nest loss. In 696 records of nests where individual visits were analyzed, there were 10,779 individual visits to nests. Distance terminology used to notate any predator occurrence at the nest was only used 592 times. Of those 592 times, 71 different terms were used to describe these distances (see Table 1). Distance terminology is most useful when specific: “X number of feet away from the nest”, for example. More confusing phrasing was often used in these notes, such as use of the phrases “nearby” or “in vicinity”. In some cases, supported by personal observation, monitors may not write down evidence if they deem it to be not a factor in nest loss, such as fox tracks found in a nearby dune, for example. In addition to the confusion brought about by vague terminology, by not standardizing a distance surrounding the nest, the ability to study distance interactions is limited. Studies have shown that accurate perception of distance is limited after 2-3 meters, and even more challenging past 20 meters (He et al. 2004). Lack of accurate distance and explicit distance estimates can perhaps reduce careful observation of the nesting area, and eliminates standardization across field monitors, sites, and management practices.

These notes, when used during the nesting season, help to shed light on the number of predator interactions and understanding of what happened to each individual nest. However, a long-term understanding of a large dataset is limited due to the lack of comparability between individual monitors. Manual assessment of field notes to understand the long-term impacts of predators is time-consuming, hard to standardize, and can be hindered by the varying backgrounds and experience level of each field monitor.

Active predator management efforts across the range of Piping Plovers suggest that managers are well aware of the link between predator interactions and the danger to nesting birds. However, some studies have suggested that the presence alone of some predators can lead to increased abandonment or adult mortality of nests (Melstrom and Horan 2013, Hardy and Colwell 2008). The use of vague terminology, or excluding possibly important but misinterpreted observations, presents a major challenge to current and future understanding how predator interactions dictate success or failure.

n an effort to improve predator studies in these systems, a proposed standardized methodology for assessing nest fate is described below. A new datasheet is proposed in

Figure 1. This methodology is not intended to make final determinations of nest fate, or to minimize the judgment of on the field monitors. Instead, the purpose is to allow for robust future analysis and studies regarding predator interaction with endangered species such as the Piping Plover.

Assessing Nest Fate Using Predator Evidence in Piping Plover Nesting Habitat

Materials needed*:* String, tape, tent stake, and pin flag.

1. Cut a length of string 20 meters in length. Fold the string in half, and tie a ground stake to the middle, creating two ten-meter sections of rope.
2. Place a piece of tape around the string at a 1-meter distance from the center tent stake, on both sides of the string.
3. Put the tent stake in the location where the nest was.
4. Take one ten-meter section of string and run it straight out in any direction. Put a pin flag at the end of the string, ten meters away from the nest bowl. With the other length of string, run out a three-meter distance away from the first section, creating a pie-shaped wedge with the two strings.
5. Carefully assess any evidence within that wedge and document on the datasheet, ensuring separation between those observations occurring within one meter of the nest and those observations occurring two to ten meters from the nest.
6. Leaving the pin flag at the original location, take the first section of string, skip it over the second section of string, and repeat analysis with a second wedge of area.

Repeat this process, skipping each section of rope over the other in an alternating pattern, until you arrive back at the pin flag laid down on the first wedge.

This process allows the monitor to take a careful look at the surrounding nest area. The recording scheme will allow for analysis and standardization in future years. Photos should be taken and catalogue any track and sign present. See Figure 1 for details on how to fill out a datasheet and Figure 4 for a schematic of distance sampling.

Assessing Found Evidence

Eggshell evidence

If hatch or fail is in question due to the predicted hatch date timing, then look to the evidence. Mabee (1997) states that eggshell fragments, defined as being less than 4mm and not exhibiting any curvature of the top or bottom of the eggs, are often present in the hatched nest bowl, but usually not in failed nests. In addition, the fragments of unhatched eggs will have membranes that are still attached to the eggshell (Mabee 1997).

Some studies used small bits of membrane within the nest bowl to determine proof of hatching for Kentish plover (*Charadrius alexandrinus*) (Serrano and Lopez 2014). Since shorebirds usually discard hatched eggshells quickly after the nest has hatched (Sordahl 1994), the presence of larger sections of eggshell is not a good indicator of hatching success. Mabee (1997) has shown that determining nest fate by using eggshell evidence found at Snowy Plover (*Charadrius nivosus*), and Killdeer (*Charadrius vociferus*) nests can be correctly assessed for hatching versus predation 90-96% percent of the time. Each species account below will provide information on how to try to piece together eggshell fragments to help guide an accurate conclusion, if predators are suspected or the nest was not near its hatch date.

Track Evidence

In addition to tracks around or leading up to the nest bowl, it is important to know how each animal interacts with the beach environment. Despite its ephemeral nature, sand often provides a great substrate for track identification (see Figures 5 and 6). In all species accounts below, and how they affect Piping Plovers, are based on personal observation unless otherwise referenced.

Species Accounts of Selected Piping Plover Predators

Mammalian Predators

Domestic dog (Canis lupus)

In New Jersey, these animals are usually seen accompanying humans. They pose a danger to beach nesting birds on- or off- leash, but with greater harm potential to nesting or young birds when they are off-leash (USFWS 2007). When they encounter beach-nesting birds such as Piping Plovers, they tend to be destructive and exploratory (USFWS 2006). Their tracks, which can be highly variable in size dependent on breed, may be in circles without any discernable intent (USFWS 2006). If they predate a nest, the nest bowl usually has visible evidence of disturbance. The entire clutch is unlikely to be missing altogether. If all eggs are gone, look for eggshells nearby and broken eggs nearby. When trying to assess if domestic dog was responsible for predation, look for human tracks next to the dog tracks nearby. This may occur outside of the ten-meter radius.

Domestic Cat (Felis catus)

Cats are a major problem for beach nesting bird communities (USFWS 2006), but tend to be localized threats at a site-by-site level. Cat tracks are more compact than dog tracks, showing a large overlap between the toes and the pad (Murie and Elbroch 2005). Most notably, cat tracks usually do not show exposed claw marks, as opposed to the other mammalian predators (Murie and Elbroch 2005). If the tracks are eroded to the extent that you cannot see if claws are present, look for a rounder shape than that of domestic dog or fox (Murie and Elbroch 2005). They can be distinguished from mink tracks shape, and by four toes to the mink’s five (Murie and Elbroch 2005). Tracks are usually found in a specific direction, forming straight-line paths. Cats usually return along the same path that they went out on, forming a “highway” (Murie and Elbroch 2005).

Since cats are a predator on adult birds, chicks, and eggs, it can be fruitful to look for caches of bird wings in nearby dune systems. Wings are usually separated from the rest of the bird. If more of the body is present on birds, look for puncture wounds on the back of the bird, especially on the nape. Even if no individuals of the target species are missing, this can be a useful exercise to assess cat presence at your site. Cats will likely eat the eggs at the nest site, so look for some yolk, or perhaps broken eggshells, nearby.

Red Fox (Vulpes vulpes)

Fox are ubiquitous predators of the New Jersey barrier islands (Chapter 1, this work). Their tracks are smaller than those of coyote or domestic dog, and have a distinctive chevron shape of the heel pad (Murie and Elbroch 2005). Their tracks are usually directed, and the gait of front and back paws is in an almost straight line (Murie and Elbroch 2005). Fox will create their dens in mature dunes, directly into the sand or with plant roots supporting the den. Fox are quite intelligent and curious, and can use scent as well as visual cues left by monitors, such as following footprints up to a nest bowl or investigating nest markers. When they take eggs, they take them whole and eat them entirely away from the nest, leaving little evidence behind. They often come back several times until the entire clutch is predated. The nest bowl is usually undisturbed.

Coyote (Canis latrans)

On the East Coast, coyotes are often much larger than their western counterparts (Murie and Elbroch 2005). They are often difficult to tell apart from domestic dogs, especially larger dogs. They are often more secretive, sticking to dune vegetation when possible and walking in directed lines. This is as opposed to domestic dogs, which tend to leave tracks in looping or meandering patterns. Coyotes are usually in sites with easy access to forested areas with mature vegetation, such as bayberry (*Myrica pensylvanica)* and Eastern red cedar (*Juniperus virginiana*).

American Mink (Mustela vison)

Mink are generally aquatic when in beach systems. They will use wrack deposits to build their nests along marsh creek edges, so sites nearby extensive saltmarsh are more likely to hold mink populations (Gorga 2012). They may also den in banks or dunes, leaving a 4 inch diameter entrance (Murie and Elbroch 2005). They will eat eggs whole or in fragments, often leaving pieces behind. Mink are generalist, opportunistic predators, with avian samples making up just part of their diet (Murie and Elbroch 2005). Mink have a unique gait pattern as compared to felids and canids. When they move, their hind feet land in almost the same spot as their front feet. The result is a distinct double print. This gait is also similar to skunks, but can be differentiated by the difference in shape of the pads (Murie and Elbroch 2005).

Raccoon (Procyon lotor)

Like the American mink, raccoons have a paired track pattern (Murie and Elbroch 2005). These tracks look superficially like human hands, with five distinct toes for both the hind and front paws (Murie and Elbroch 2005). Raccoons are also extremely intelligent and human dependent, often following human footprints to see where they lead. As such, extreme caution should be used in approaching the nest when raccoons are thought to be present. Raccoon predation is less opportunistic than mink, however, and nests are often targeted. When a raccoon finds eggs, it will often sit at the nest to eat them, leaving behind a much disrupted nest bowl and fragments of eggshells, similar to how one would peel a hard-boiled egg.

One key characteristic in identifying raccoons at your site is scat patterns. Raccoon scat, which in beach environments consists largely of undigested parts, such as shell fragments and crustaceans, reflects their generalist diet (Murie and Elbroch 2005). Due to this composition, raccoon scat remains identifiable much longer in the environment than other forms of scat. Scat is often found near the base of trees. In a barrier beach system, raccoon scat can be found in adjacent saltmarshes under Eastern Red Cedar (*Juniperus virginiana*), Beach Plum (*Prunus maritima*), or Eastern Baccharis bushes (*Baccharis halimifolia*).

Striped Skunk (Mephitis mephitis)

Skunks have unique tracks amongst the other possible beach nesting bird predators. They have the heel pads which look similar to raccoons, but with the separated toe markings and exposed claws of mink (Murie and Elbroch 2005). Their gait is paired, like the raccoon and mink, but unlike those two species, the skunk's hind paw will often extend beyond the previous front paw (Murie and Elbroch 2005).

In sand, skunks will often root for crustaceans or worms under the surface, resulting in small pits throughout the sandy substrate. (Murie and Elbroch 2005). They are scent-based predators, possibly attracted to the smell of incubating Piping Plovers. They will often occupy old dens of other animals (Murie and Elbroch 2005).

Avian Predators

Gull Species (Larus species)

The three major threats to Piping Plovers in New Jersey in the gull family are Laughing Gulls (*Leucophaeus atricilla*), Herring Gulls (*Larus smithsonianus*), and Great Black-backed Gulls (*Larus marinus*). All three of these species nest on barrier islands or on nearby saltmarsh islands (Burger 1978). Gulls are opportunistic, sight-based predators. They can be cued in from visual signals to the nest. The most vulnerable time for nests or chicks is when the parents are distracted by another cause of disturbance. Gulls are also often associated with people, and are often more prevalent at beaches that share space with humans.

Gull tracks show webbing between the toes, as opposed to most other bird tracks that would be present on beaches. The webbing is usually faint as compared to the three toes, which are usually distinct. Claw marks are sometimes visible, with the first toe claw mark almost never present in laughing gulls (Elbroch and Marks 2001). To assess the species by track, use a ruler. Differences in size are obvious, with Laughing Gull tracks measuring just 2 inches and Great Black-backed Gulls measuring 4 inches. Herring Gulls lie within those two extremes (Elbroch and Marks 2001). Sometimes gulls will opportunistically fly in and take an entire egg with them, leaving few tracks as they leave the nest area to eat the egg elsewhere. Occasionally, gulls will take eggs on the wing without landing. This is especially true in Laughing Gulls. Sometimes, though, gulls will leave many tracks around the nest bowl, leisurely eating eggs on site. In these scenarios, some yolk and eggshell pieces are usually left behind.

Eggshell evidence is important when it comes to avian predators. Avian predators puncture holes in eggs and eat the contents. In early stages of development, eggs can be found largely intact with only a hole taken out. In later stages of development, some smaller pieces of eggshell may be found, but at least half of the eggshell will remain intact. This can be easily confused with hatching patterns, described in the previous section. Most notably, larger pieces of eggshell may be present in avian depredated eggs. When taking all possible evidence into consideration, it becomes easier to identify gull-predated nests.

Crow Species

Two crow species patrol the beaches in New Jersey for beach nesting bird eggs: Fish Crows (*Corvus ossifragus*), and to a lesser extent, the American Crow (*Corvus brachyrhynchos*). Crows have a prominent back toe, which is unique from gulls but can be confused with other potential beach nesting bird predators (Elbroch and Marks 2001). This is especially true in the size overlap of boat-tailed grackles and smaller fish crows. Crow tracks, however, have thicker lines. The back toe is usually of equal length to the three front toes. Claw marks are sometimes visible, especially in toes 1 and 2 (Elbroch and Marks 2001).

Crows will usually take eggs away from the nest site, while leaving the nest bowl largely undisturbed. If crows are suspected to be a culprit in nest loss, look at the wrack line or in back dunes for dropped eggs with a narrow, sharply edged hole in them. Occasionally, a punctured egg will be found in the nest bowl, the crow having been chased off by the adult nesting bird. Crows are very smart and can use visual cues to key into a nest, such as nest markers or exclosures.

Raptors

Peregrine Falcons (*Falco peregrinus*), Merlins (*Falco columbarius*), and Great Horned Owls (*Bubo virginianus*) are considered to be the most likely avian predators of adult birds and chicks during the summertime breeding season. Avian raptors can be hard to detect, as sightings are opportunistic, or nocturnal in the Case of Great Horned Owls, and track or eggshell evidence is limited or nonexistent. However, evidence in the form of piles of feathers, the feathers exhibiting breaks in the quill, or attached wings can be indicative of raptor predation. These predators often decapitate their prey, unlike any other likely Piping Plover predator (Elbroch and Marks 2001). They are unlikely to consume eggs or destroy the nest bowl.

Other Predators

Ghost Crab (Ocypode quadrata)

The ghost crab is a terrestrial crab that lives along the Atlantic and Gulf coasts. In New Jersey, they are only abundant in part of the beach nesting bird season, active on the beaches from late May through the end of the summer. Their burrows are apparent in the sand, and largely restricted to near the intertidal zone. Though witnessing a distinct predation event or proving it was due to ghost crab is a challenge, it does occur. A 1999 study by Wolcott and Wolcott states that adult and chick Piping Plovers change behavior in areas where there are abundant ghost crabs, avoiding foraging on the oceanfront intertidal zone.

Ghost crab tracks, though light, can usually be seen except in cases of high wind. They are about 2 inches in total width (Murie and Elbroch 2005), and reflect all of the claws that ghost crabs use for locomotion. Their burrows are composed of holes in the sand, about 1 inch in diameter, though this can be variable based on body size. The holes usually have sand splay patterns formed from the crab digging the burrow. This is not to be confused with fiddler crab burrows, which have neat piles of sand balls, and are usually found in wetter, muddier substrate on the backshore or adjacent saltmarsh.

Besides tracks up to and inside the nest bowl, the remaining eggs (if any) will be moved from their original position (Wolcott and Wolcott 1999). Look in the surrounding area for ghost crab burrows and the presence of yolk around these burrows. They often cannot carry off an egg completely intact, so yolk splattering in a trail will likely be present.

Humans

Full nest destruction by a human in New Jersey is certainly an infrequent occurrence, but does occur (n = 3 of 1,228 nest records). Humans were also observed altering a nest, destroying eggs, or causing nest abandonment in 11 distinct occurrences, of 590 total occurrences. Most human-caused destruction of nests has been documented with clear evidence- instances of lifting exclosures to take eggs, for example, is the most common cause. Tire tracks from off-road vehicles (ORVs), footprints, and indirect causes such as prolonged and sustained disturbance are also causes of nest loss for Piping Plovers. Sign from direct events is usually obvious, as humans intentionally or inadvertently destroying nests have little reason to cover their tracks. Indirect failure caused by sustained disturbance is much harder to disentangle, and many publications have explored these issues (Serrano and Lopez 2014, MacIvor et al. 1990, Ibanez-Alamo et al. 2012, Doherty and Heath 2011). Monitors should be aware of their impact on nesting birds, and understand the potential threat of beach visitors to active nests.

Conclusion

The importance of assessing predator fate cannot be understated. An understanding of the primary predators of Piping Plovers in New Jersey, as well as how they interact with each other and plovers themselves, will help to guide ecosystem- and site-level management decisions. These decisions could include when to manage for predators, how to manage for the predator posing the greatest risk to nesting plovers, and whether or not to use nest protection measures such as exclosures. Decisions could be guided by the use of tools or decision trees. One such example is present in Figure 7. Standardized definitions and enhanced training of field monitors will serve to add valuable and vigorous data, allowing for an evidence-based, structured assessment to the benefit of Piping Plovers.

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Table 1. Terminology used to record predator evidence in statewide datasheets from 2005-2013.

Terminology	Occurrences	Terminology	Occurrences
Predator observation without distance listed	248	South of area	1
In area	51	Along shoreline	1
X number of feet	46	Range of feet	1
Digging at exclosure	43	West of nest	1
Nearby	42	Not within vicinity	1
Around exclosure	40	18 paces	1
Nest bowl	29	Nearly outside fence	1
Near nest	24	Fenceline	1
On top of exclosure	19	Along back of site	1
Around nest	15	Present	1
Around	11	Relatively close to nest	1
Inside exclosure	9	walked by	1
In dunes	8	In general area	1
In vicinity	7	next to pathway	1
Not right by nest	6	On other side of dune	1
X number of yards	5	On berm	1
Near exclosure	4	Disturbed	1
Up to nest	4	In traffic	1
By nearby nest	3	On distance marker	1
X number of meters	3	In fence	1
Approached exclosure	3	On north end	1
Hole in netting	3	A ways away	1
Not within 10m	2	Immediately next to nest	1
On beach	2	In close proximity	1
In tidal pool N of nest	2	Alongside nest	1
flying overhead	2	Outside exclosure	1
Activity	2	All around	1
Zapped by fence	2	In front of exclosure	1
Very close to nest	2	Very nearby	1
Close to nest	2	Nearby exclosure	1
Circling exclosure	2	Next to exclosure	1
Outside nest	2	Exclosure raised	1
At exclosure	2	Within nest area	1
Near flag	2	Very close to brood	1
At nest	1	By nest bowl	1
inches	1		

Figure 1. Proposed alteration to the Nest Fate New Jersey Piping Plover datasheet.

Date Determined ___/___/___ Last observed incubating ___/___/___
___**Hatched** ___**Failed** ___**Unknown**
___#Chicks Seen (max) ___Flooded (unknown if hatched or failed)
___#Eggs remain unhatched ___Abandoned
___Predated ___Mammal ___Avian ___Undetermined predator
___Undetermined
___Other(describe)_______________________________________

Regardless of nest outcome, did any evidence (eggshell, yolk, tracks, overwash, etc) occur:
Within 3 meters: ____
Within 10 meters: ____
Outside 10 meters or other notes: ____
____

Photo numbers: ____________________
Clutch reduction (eggs lost before hatching) ? ___Yes ___No
Date(s) and # lost _________________________________
Predator occurrence (provide tally from log):
Cat:_____ Coyote:_____ Fox:_____ Raccoon:_____ Skunk:______ Crow:______ Gull:_______ Raptor:______Ghost crab: ______ Human: ______ Other: ____________

Figure 2. Proposed Predator Track Index datasheet.

Predator Track Index

Entered _______
Proofed _______

Date:________________ Monitor: ____________________ Nest #: ______
GPS Waypoint: _______ Lat:___________________Long:___________________
Temp: ______ Wind: _____ Sky (circle): Sunny Partial Clouds Overcast
Tide (circle): Low Rising High Falling
Notes: ____

Trail Number	**Distance from Nest**	**Species**	**Photo Number**

Figure 3. Piping Plover hatch/fledge calendar

HATCHING AND FLEDGING DATES

Hatching dates are obtained by adding 27 days to the date the clutch was completed. If the clutch was discovered after the laying cycle, add 27 days to date found; this is the *latest* possible date the nest will hatch. If the clutch was discovered during the laying cycle, estimate 1 egg laid every other day to obtain date of clutch completion.

Fledging dates are obtained by adding 25 days to the hatch date.

Date Clutch Complete	*Est. Hatch Date*	*Fledge Date*	*Date Clutch complete*	*Est. Hatch Date*	*Fledge Date*	*Date Clutch Complete*	*Est. Hatch Date*	*Fledge Date*
4/15	5/12	6/6	5/18	6/14	7/9	6/20	7/17	8/11
4/16	5/13	6/7	5/19	6/15	7/10	6/21	7/18	8/12
4/17	5/14	6/8	5/20	6/16	7/11	6/22	7/19	8/13
4/18	5/15	6/9	5/21	6/17	7/12	6/23	7/20	8/14
4/19	5/16	6/10	5/22	6/18	7/13	6/24	7/21	8/15
4/20	5/17	6/11	5/23	6/19	7/14	6/25	7/22	8/16
4/21	5/18	6/12	5/24	6/20	7/15	6/26	7/23	8/17
4/22	5/19	6/13	5/25	6/21	7/16	6/27	7/24	8/18
4/23	5/20	6/14	5/26	6/22	7/17	6/28	7/25	8/19
4/24	5/21	6/15	5/27	6/23	7/18	6/29	7/26	8/20
4/25	5/22	6/16	5/28	6/24	7/19	6/30	7/27	8/21
4/26	5/23	6/17	5/29	6/25	7/20	7/1	7/28	8/22
4/27	5/24	6/18	5/30	6/26	7/21	7/2	7/29	8/23
4/28	5/25	6/19	5/31	6/27	7/22	7/3	7/30	8/24
4/29	5/26	6/20	6/1	6/28	7/23	7/4	7/31	8/25
4/30	5/27	6/21	6/2	6/29	7/24	7/5	8/1	8/26
5/1	5/28	6/22	6/3	6/30	7/25	7/6	8/2	8/27
5/2	5/29	6/23	6/4	7/1	7/26	7/7	8/3	8/28
5/3	5/30	6/24	6/5	7/2	7/27	7/8	8/4	8/29
5/4	5/31	6/25	6/6	7/3	7/28	7/9	8/5	8/30
5/5	6/1	6/26	6/7	7/4	7/29	7/10	8/6	8/31
5/6	6/2	6/27	6/8	7/5	7/30	7/11	8/7	9/1
5/7	6/3	6/28	6/9	7/6	7/31	7/12	8/8	9/2
5/8	6/4	6/29	6/10	7/7	8/1	7/13	8/9	9/3
5/9	6/5	6/30	6/11	7/8	8/2	7/14	8/10	9/4
5/10	6/6	7/1	6/12	7/9	8/3	7/15	8/11	9/5
5/11	6/7	7/2	6/13	7/10	8/4	7/16	8/12	9/6
5/12	6/8	7/3	6/14	7/11	8/5	7/17	8/13	9/7
5/13	6/9	7/4	6/15	7/12	8/6			
5/14	6/10	7/5	6/16	7/13	8/7			
5/15	6/11	7/6	6/17	7/14	8/8			
5/16	6/12	7/7	6/18	7/15	8/9			
5/17	6/13	7/8	6/19	7/16	8/10			

Figure 4. A standardized method to record nest fate evidence around a nest.

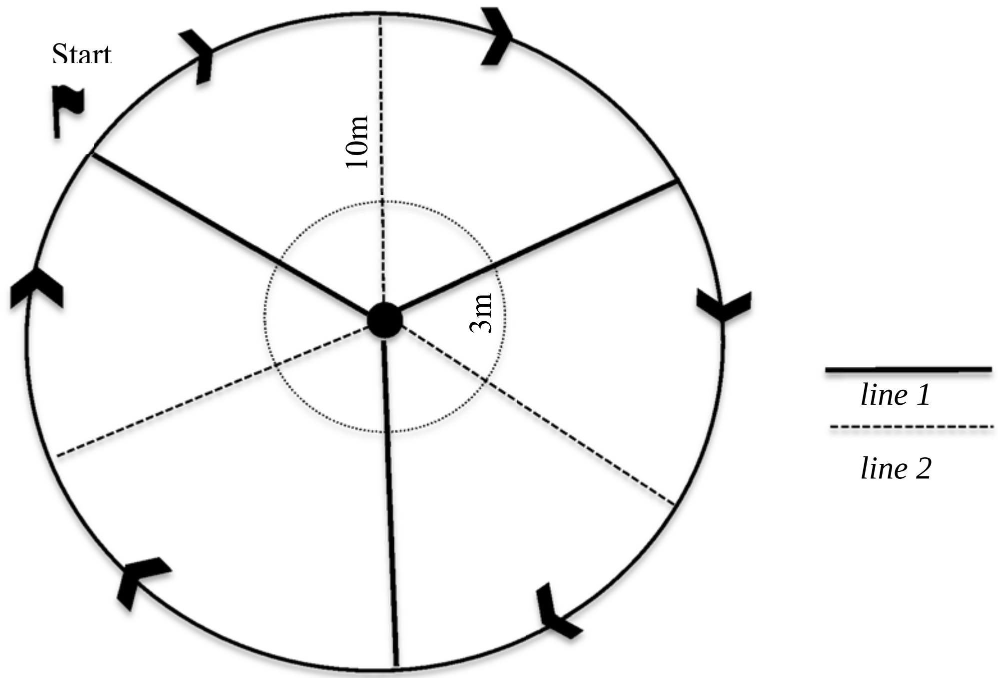

Figure 5. A guide to the tracks of common predators of Piping Plover nests in New Jersey.

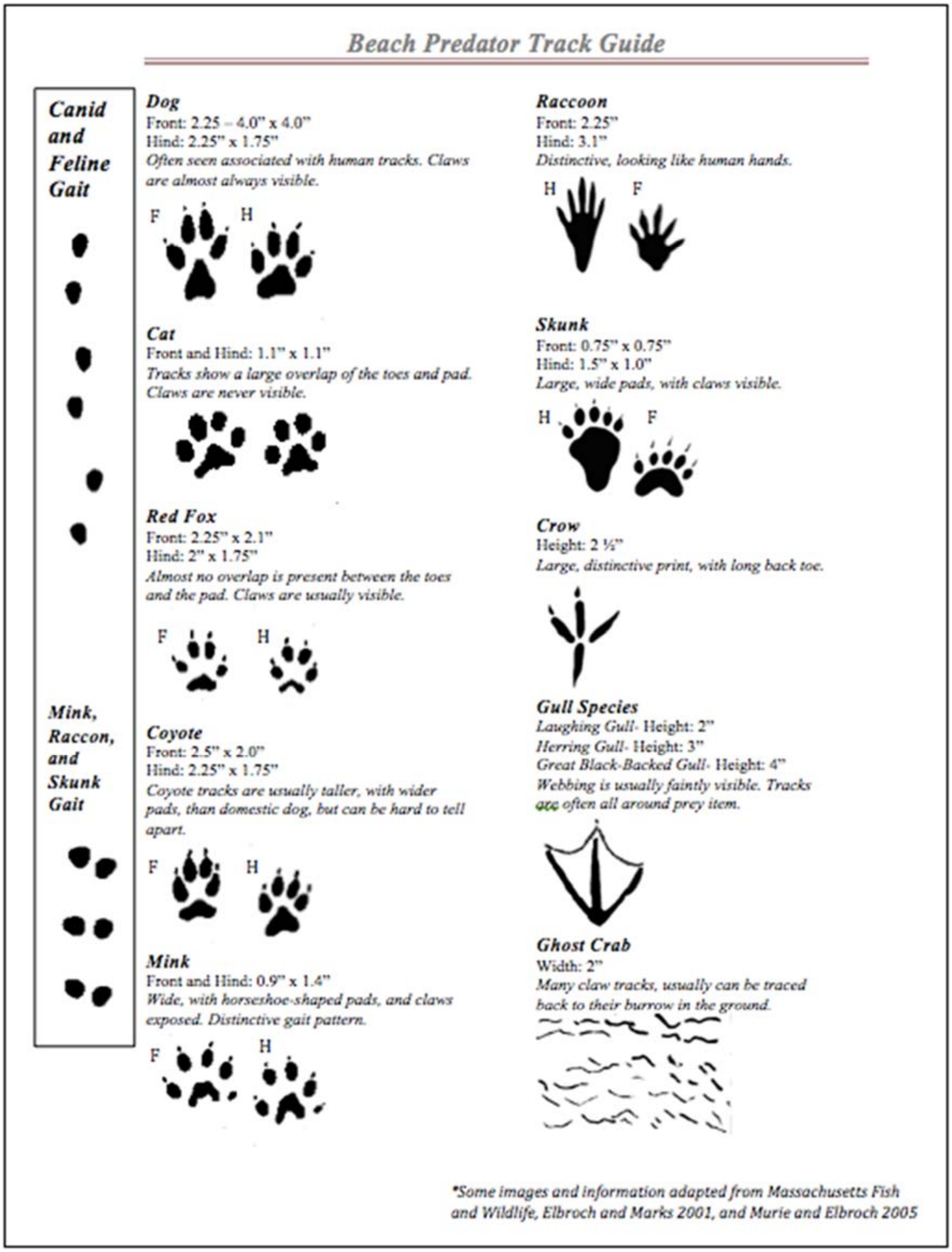

Figure 6. Photo guide to common tracks of Piping Plover predators in New Jersey.

Beach Predator Track Guide

Eggshell Evidence

Avian predated egg

Avian predated egg

Raccoon predated egg

Ghost crab predated eggs

Gait Patterns

Paired gait pattern of a mink

Gait pattern of a skunk

Gait pattern of a cat

Ghost crab tracks

Figure 7. An evidence-based decision model of assessing nest fate, specific to New Jersey's most common Piping Plover predators.