THE SPATIAL AND TEMPORAL DISTRIBUTION OF PIPING PLOVERS IN NEW JERSEY: 1987-2007

by

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A Thesis submitted to the

Graduate School-New Brunswick

Rutgers, The State University of New Jersey

in partial fulfillment of the requirements

for the degree of

Master of Science

Graduate Program in Ecology and Evolution

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New Brunswick, New Jersey

May, 2009

ABSTRACT OF THE THESIS

The spatial and temporal distribution of Piping Plovers in New Jersey: 1987-2007

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The Piping Plover (*Charadrius melodus melodus*) is a small shorebird that nests along the Atlantic coast beaches of New Jersey. The combination of habitat degradation and human disturbance caused a precipitous population decline during the last century. It was listed as state endangered in 1984 and federally threatened in 1986. New Jersey biologists have taken protective measures, such as fencing nesting sites and restricting human activities in sensitive areas, in an attempt to increase the population. Despite these intense efforts, Piping Plover pair numbers are not recovering in New Jersey. The objective of this research was to create a spatial representation of all nesting areas, and pair use at those sites, utilized in New Jersey from 1987-2007 to better understand site selection of breeding Piping Plovers. Analysis of this information indicated that the plovers showed a strong preference for selecting nesting areas near inlets, particularly those that were not shored with jetties or other stabilization features. Beach replenishments, however, did not appear to significantly attract or deter nesting birds to or from sites. Nest fate and reproductive success were found to be fairly consistent throughout the state (for the factors tested) and the rates were lower than what was necessary to sustain and grow the population. Since there are a limited number of unshored inlet areas left in New Jersey, it is imperative that large-scale restoration efforts and more aggressive management techniques (i.e., widespread predator control) are implemented to initiate recovery of the Piping Plover in this state.

Acknowledgements

Thanks to my advisor Dr. Joanna Burger for all the support and guidance she provided throughout this process. Thanks to the rest of my committee for their thoughtful comments during the planning and executing of this project – Dr. Julie Lockwood, Dr. Rick Lathrop and C. David Jenkins, Jr. Thanks to Marsha Morin, without whom I would have been utterly lost in the complex world that is Rutgers bureaucracy. Thanks to my co-workers at the Endangered and Nongame Species Program, including Dave Golden, Patrick Woerner and Pete Winkler who kindly offered technical assistance in the GIS and statistical realms. Special thanks to Todd Pover, who not only supplied excellent feedback at all stages of the process but also emotional support when I really needed it.

Thanks to my friends and family for offering nothing but complete support and love over the past four years. Liz, Becky, Carrie, Bean, Christina – there is no substitute for the friendship women provide and I thank you for yours. Mike, thanks for the blueberries and muffins at key moments. Lauren, thanks for talking me off the ledge on more than one occasion and insisting that I could, and would, get through this. Mom and Dad, the only reason I even thought I could complete this task is that you raised me to believe I could do anything I put my mind to – so far, so good! Glen, thanks for shepherding me through the final push with your music and unwavering belief in my abilities. I could not have done this without the unique support that you each so selflessly offered to me.

Many thanks to all the biologists and field technicians who followed every known Piping Plover pair from their first scrape until their last fledge over the past 20 years. Your blood, sweat and tears stained the datasheets and I thank you for your heart.

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Spatial and Temporal Distribution of Piping Plovers in New Jersey

Chapter 2

Factors Influencing Nesting Site Selection of Piping Plovers in New Jersey

Chapter 1 Spatial and Temporal Distribution of Piping Plovers in New Jersey

Introduction

The Piping Plover (*Charadrius melodus melodus*) is a small shorebird that occurs throughout North America along lakes, rivers and the ocean. There are three distinct breeding geographical populations – the Atlantic coast population, the Great Lakes population, and the Great Plains population (Miller, Haig, Gratto-Trevor & Mullins, 2009). All three populations winter from coastal North Carolina to Mexico and on some Caribbean islands. New Jersey's Piping Plover population is part of the Atlantic coast population, which extends from Newfoundland in Canada to North Carolina in the United States (Elliott-Smith & Haig, 2004). In this region they are found primarily on ocean beaches where they nest between the toe of the dune and the high tide line. Adults arrive on the breeding grounds in late March and begin laying eggs in April. An egg is generally laid every other day until the determinate clutch is complete at four (occasionally three on a renest). Incubation commences after the last egg is laid, thus assuring synchronous hatching (Cairns, 1982). The adults split incubation duties evenly and the eggs hatch in approximately 28 days. The precocial chicks leave the nest bowl within a few hours and are responsible for feeding themselves. The adults play a strong role in defense and protection from the elements (the chicks cannot regulate their body temperature until approximately 2 weeks of age). After 25 days, the chicks are capable of short flights and are considered fledged. If a nest is destroyed, or chicks are lost before they fledge, the adults may renest (occasionally up to 3 more times but most often with just one additional attempt) (Elliott-Smith & Haig, 2004). Migration from the New Jersey breeding grounds peaks in August but begins as early as July (especially for the females, who sometimes leave before their chicks are fully fledged) and extends into October, with the rare recording of a late individual into November and December (T. Pover, personal communication, 3 December 2008, http://www.njaudubon.org/Tools.Net/Sightings/ SightingsArchive).

Piping Plover nesting season corresponds to the peak tourism season in coastal communities and this pressure on their habitat, coupled with its degradation as it has been (and continues to be) developed, led to the species being state listed as endangered in 1984 (E.N.S.C.A. 23:2A) and federally listed (Endangered Species Act of 1973) as endangered or threatened in 1986. The Great Lakes population is listed as endangered while the Atlantic coastal and Great Plains populations are listed as threatened. After the species was listed the New Jersey Division of Fish and Wildlife's Endangered and Nongame Species Program (ENSP) and its partners began closely monitoring the Piping Plover population, recording the location and outcome of each known nesting attempt. Therefore, a long-term dataset set, comprised of detailed population, reproductive and nest location information was available for analysis.

The US Fish and Wildlife Service's (USFWS) Atlantic Coast Piping Plover Recovery Plan, the guidance document used by species managers, has created population and reproductive goals for this species (USFWS, 1996). In the twenty-plus years since the Piping Plover was listed, New Jersey has never reached its reproductive goals (a five year average of 1.5 fledges/pair) (Pover, 2007). The state population, despite yearly fluctuations, is relatively flat with no long-term gains (see Fig. 1). Although a single variable is unlikely to explain all the limiting factors on the New Jersey Piping Plover population, a detailed understanding of each apparent contributing factor could be vital to recovery of the species. One variable that might help explain the Piping Plover reproductive success (and subsequent population gains and losses) in New Jersey is nest site selection.

The overall aim of this research is to describe the spatial distribution of breeding Piping Plovers in New Jersey through analysis of nesting patterns on a landscape scale. Site selection on a micro level has been fairly well covered in the literature (Burger, 1987, Whyte, 1985, Haig & Oring, 1988). However, site selection on a macro scale has been largely ignored in research projects. This may be due to the difficulty in obtaining enough data to consider it properly, or defining what constitutes "landscape scale".

Understanding macro site selection by Piping Plovers is important because management decisions are often made on a coarser scale. Decisions concerning the placement of beach replenishments, or where restoration projects will occur, help exemplify the need to understand the larger scale when it comes to Piping Plover nest site use. Beach replenishments are shore protection projects where sand is pumped from an offshore source to an eroding beach in order to create a wider profile. Beach replenishments generally endure for 2-5 years with sites often needing to be renourished on a semi-regular basis to ensure that the beach profile is maintained. Restoration projects, on the other hand, can take many forms but their general goal is to improve habitat conditions for one or more species of conservation concern. The US Army Corps of Engineers is generally responsible for both types of projects, with funding coming from local, state, and federal funds. An understanding of the implications of site selection over a long term period will best serve the species while accomplishing project objectives.

The first step in understanding the distribution of Piping Plovers in New Jersey is to describe the nesting patterns over the 20 years they have been closely monitored. ENSP possesses a database that details almost every nesting attempt of every known pair since 1987, including nest location, nest fate, and number of chicks fledged. It is rare to have this level of detail over a long period so this analysis represents a unique opportunity. Its worth is even greater because it focuses on an endangered species, and one that is still steeped in the very real possibility of extirpation/extinction statewide. Despite the best efforts of ENSP and its cooperators, the state population is not progressing towards recovery. Other states in the Atlantic coast region have seen population increases, in some cases dramatically (Hecht, 2007, Table1). Understanding the distribution of NJ's plovers might be the first step in understanding why we are unable to emulate other states' successes. Although ENSP compiles yearly reports and NJ information is folded into Atlantic coast reports, there has not been an effort to conduct a long-term examination of the spatial and temporal distribution of nesting Piping Plovers in this state. The ability to understand the factors that influence site selection may offer valuable insight into their habitat requirements as well as focus management efforts into the areas that are the most important in the state for nesting success. Past is prologue and understanding the distribution of the birds over the last 20 years may be the best way to determine future directions of New Jersey Piping Plover conservation efforts.

The specific objective of this research, therefore, was two-fold: first, to organize and digitize all known nesting attempts or nesting areas (where points were not available) to create a spatial tool accessible to species managers that illustrated where Piping Plovers have nested; second, to examine this distribution for patterns of preferred site use. Prior to this effort, digitized spatial information was only available on a state-wide basis from 2003, sporadic information was available from 1995-2002, and very little was available prior to 1995. Since digital images are so critical to most management efforts today, the completion of this task provided a visual tool depicting nesting sites over the past 20 years. This marks a vast improvement over the previous method of looking at tables, charts and paper datasheets with no corresponding visual component. Once that task was complete, the second goal was to understand the location of the birds throughout the time and space and draw conclusions based on those distributions. The overarching goal was to provide a greater understanding of Piping Plover site selection to assist species managers in making decisions that could lead to the recovery of this species.

Study Area

The study area was the Atlantic coast beaches of New Jersey from Sandy Hook to Cape May. The southern part of the Cape May peninsula, on the Delaware Bay side, north to the Cape May Ferry Terminal (or the western outlet of the Cape May Canal) was also included (Fig. 2). From 1987-2007 there was no documented nesting by Piping Plovers north of the Cape May Canal. It is likely that any pairs in this area would be detected because the Delaware Bay region is a stopover habitat for migratory shorebirds and there are many biologists working in that area who would be aware of nesting birds. No nesting was detected on the beaches of interior Sandy Hook Bay during the study period, so that area was also not part of this project. There is a high density of humans in that area, and if nesting occurred there it is likely it would have been observed and reported.

The study area was divided into delineated areas called “sites”. The sites were not designated by this researcher, but rather by species managers over time. Since Piping Plovers were managed by different agencies throughout the state and there were multiple people that worked at each agency throughout the 20 years, there was no one definition of what constituted a site. This was not unique to New Jersey as there is no range-wide standard protocol for defining a site. In almost all cases, a site had only one landowner (although sites were infrequently grouped when they were so biologically similar that the birds were interacting and crossing boundary lines and it thus, made more sense to identify them as one site). Unfortunately, the lack of standardization of what constituted a site could make analysis difficult. One result of this unsystematic classification is that the size of a site could vary considerably. For example, Holgate (at ~ 4 miles long) was considered one site by its landowner. One the other hand, Sandy Hook (at ~ 7 miles long) was divided into 8 sites by its landowner. This could be problematic for comparisons but their boundaries did remain relatively stable through the 20 years. Each year, the exact site boundary could contract and expand as pairs occupied the space differently, but none of the site boundaries ever overlapped, nor were pairs ever assigned to different sites when occupying the same area year to year. Additionally, in almost every case each site was treated by species managers (which included biologists from federal, state and non profit organizations) for 20 years as an independent unit that had its own management regulations. For example, although Holgate was considered one site and much larger than the smaller Sandy Hook contingents, the entirety of Holgate was managed the same way while each of Sandy Hook's sites were managed slightly differently.

In New Jersey, there were 52 separate sites, with approximately half being occupied in any given year (Fig. 3, Table 2). The sites were managed by various federal, state and non-profit agencies. The US Park Service managed Gateway National Recreation Area – Sandy Hook Unit sites (Coast Guard, North Beach, North Gunnison, South Gunnison, Critical Zone, Hidden Beach, Fee Beach and South Fee Beach). The US Fish and Wildlife Service managed the Forsythe and Cape May National Wildlife Refuges (Holgate, Little Beach , 2-Mile Beach and Cape May NWR). The US Coast Guard jointly managed the Training Center (TRACEN) site with ENSP. The Nature Conservancy jointly managed the Cape May Meadows site with the ENSP. ENSP monitored and managed all other sites (approximately half of the active sites each year) which were located on federal, state, county and municipal beaches. Since ENSP was not a landowner per se, they worked with each property owner to ensure the needs of the nesting birds were met. ENSP was also the lead partner among these agencies so they were responsible for collecting and collating all the data at the end of each field season and submitting it to the USFWS Atlantic Coast recovery team leader. They also took the lead in management and policy decisions made on a state-wide level and as a co-lead with USFWS for law enforcement actions.

Methods

The detailed data that existed for all the nesting areas in the state was previously only available in paper format for 1987-2007 in ENSP reports. The purpose of this portion of the research was to create a GIS tool so species managers would have a visual representation of all known nesting sites since 1987. Prior to this effort, the digital spatial information available was as follows: point data for every known nesting attempt was available from 2003-2007 for the entire state; point data for some sites (but not the same sites each year) existed from 1995-2002, but was not complete enough to be utilized on a state-wide level analysis. In addition to the spatial information there was an Access database that had a complete record of every known nesting attempt statewide from 1995-present and incomplete statewide data from 1990-1994 and an Excel database that detailed pair use and success by site from 1987-2007. Finally, there were paper datasheets since 1983 that represented the partial surveys that were undertaken until 1987. After the Piping Plover was listed as federally threatened in 1986, data collection was increased to a state-wide yearly basis beginning with the 1987 field season. Paper datasheets existed for every year from 1987 – present. Over the course of the last 20 years, the paper datasheets became increasingly detailed as managers recognized what information was most critical to record. However, all versions recorded the site of the nesting attempt, nest fate and reproductive success.

To generate a digital tool with the available data, I created polygons that represented each nesting site. There was not enough information to create points for each nesting attempt but the datasheets provided enough information to pinpoint the location of each nest to an accuracy that was acceptable for this polygon-based approach. In most years and for most sites, there was enough information to delineate the location of the nests to a degree that a polygon could be created to represent the active nesting area of that year. In the cases where detailed nesting attempt location data was not as available (which did not happen often and was most frequent during the early years of the dataset), I used the polygons of the previous year. Piping Plovers display site fidelity and point data from later years confirmed that birds often nest in the same areas of a site one year to the next (Elliot-Smith & Haig, 2004).

Polygons were hand digitized on aerial images with ArcMap 9.2 software. The beach is a dynamic environment that constantly changes over time. Although the New Jersey does have high resolution aerial images available for a variety of years they are not available for every year. Based on what was available, I divided the nesting seasons so that each was digitized on the aerial image that was taken closest to the year nesting took place. The 2007 aerial images were used for 2007 data, the 2006 aerial images for the 2005-06 data, the 2003 aerial images for the 2003-04 data, the 2002 aerial images for 1999-2002 data and the 1996 aerial images for 1987-1998 data. The completion of this step created a visual representation of all the nesting areas in the state that did not previously exist.

I then used Adobe Photoshop to create a .GIF image that represented all the nesting polygons in an animated time series. At this scale (state view), polygons were not clearly discernable so each site in this is animation each is represented as a point. The points are coded color and size to show the importance of the site based on number of nesting pairs (more pairs were represented with a larger point). I also created a similar time series showing fledge rate (higher reproductive success was denoted with a larger point). Again, this was a visual representation of the data that has not been available up to this point.

I next divided the sites into three categories based on the number of pairs a site supported and how long it was active. These three categories were core, secondary and satellite sites (additional detail about these categories can be found in the Results section). After the sites were divided into their respective categories I was able to compare hatch and fledge rates among core, secondary and satellite sites using ANOVA and Chi square tests. Since individuals were not banded on a long term or large scale basis during the study period, there was no way to account for multiple measurements on the same pairs. However, the majority of Piping Plovers probably live less than 5 years (maximum recorded was 11 yrs) and many do not nest in their first year post-fledge (Wilcox, 1959). Therefore, the twenty year survey period might have captured portions of or the entirety of at least 6 generations, assuaging some of the implications for multiple measurements on the same individuals since it is likely there was a high degree of turnover due to natural mortality from 1987-2007.

Results

There were 52 total sites that were active during at least one field season over the past 20 years. These sites were divided into three categories – core, secondary, and satellite sites. A site's category designation was determined through a matrix of the number of years a site was active and how many pairs used it. Core sites had the highest number of pairs over the longest periods of time. Secondary sites had either high pair numbers for shorter periods or lower numbers over longer time periods. Satellite sites had low pair numbers for short periods of time. After assigning a designation it was possible to examine how each varied with respect to hatch and fledge rates.

There were approximately 137 miles of coastline available in New Jersey for potential Piping Plover nesting habitat. This number was derived from measuring the from the northernmost point at Sandy Hook, south all the way to Cape May Point and then north up the Cape May peninsula to southern side of the Cape May Canal. The areas west of Sandy Hook peninsula and north of the Cape May Canal were not considered habitat since they have never been used by the Piping Plovers over the timeframe that data was available. An occasional marsh island had enough of a sandy area to support Piping Plovers, but these areas were not considered reliable nesting habitat for this species. From a linear perspective, of the 137 miles available, 38 miles (28% of available habitat) was used as nesting habitat for at least one year and almost 100 miles has never been utilized.

Every nesting site differed each year by not only the number of pairs it supported, but by how consistently the site was used over the course of the survey period. It was these two factors together that determined how critical the site was to the larger picture of the New

Jersey population. Quantifying these factors together provided a systematic approach to creating a hierarchy of “importance” among sites. For example, a site may have been used for many years but by only one or two pairs. Alternately, a site may only be used for a few years but by many pairs for the short time it is active (active was defined as having at least one nesting pair with at least one confirmed nesting attempt). There were also sites that were used for many years by many pairs or few pairs for just a year or two. Using the available nesting history data, I created three categories based on the range of pairs at the site and the number of years the site was active. The three categories were termed core, secondary and satellite sites. At the boundaries of each category there were sites that could fit in more than one category. I used my judgment based on knowledge of the site to make determinations in these cases.

A core site was defined as having a high number of pairs (usually >5% the average number of pairs in the state) and was active for at least 75% of the years surveyed (15-21 years). Core sites formed the foundation of the New Jersey population. They were the sites that consistently attracted pairs throughout years and changes in the environment. Often times these sites were quite stable and the habitat remained suitable over many years. Many of theses sites occurred on federally or state protected land. They generally occurred on undeveloped barrier islands or the most natural habitat available in the area. There was not a lot of human disturbance at these sites and many times the mission of the site was for, or related to, the preservation of natural resources.

Secondary sites were defined as those that had either a large number of pairs (maximum of 17) for a short period or a small number of pairs (as few as one) consistently through the survey period (active between 9-14 years). Secondary sites hosted as many or more pairs than some core sites but might not have persisted for as long. These sites played a central role in the population of Piping Plovers in New Jersey for the years they were active, and then virtually no role in the non-active years. Their nature was dynamic - the number of pairs at these sites ebbed and flowed by year. Many of these changes were habitat related and many of the sites were on municipal properties where human disturbance might have played a larger role. Alternately, secondary sites also included those that were consistently occupied over a long period but never attracted (or had the space for) a large number of pairs. However, their persistence over time made them an important component to the state population.

Satellite sites typically had a range of pairs from 1-5 (<5% of pairs and often just a pair or two) and were active between 1-11 years but the majority of them were from 1-5 years. Satellite sites did not contribute to the overall state population in any significant way. Although the average reproductive success was not lower than other categories, there were very few young produced (which may help explain why they were not active for many years – there were not enough young to replace the parental generation). Satellite sites supported the smallest number of pairs and produced the fewest number of fledges.

In NJ there were 13 sites (25%) that were considered core, 14 sites (27%) that were considered secondary, and 25 (48%) sites that were considered satellite (Table 2). Therefore the greatest number of all known active sites was satellite in nature, although they accounted for the smallest number of the pairs. On average (by year), the number of pairs (at active sites, i.e. non-active years “zero” pair count not incorporated into the average) at core sites was 75, at secondary sites was 38, and at satellite sites was 10. There was an average of 25 active sites each year (Table 3). Obviously, there were more pairs at the core and secondary sites than at the satellite sites, since this is one of the ways the sites were categorized, and it also followed that these sites also had the potential for more fledges.

A chi square test showed that nest fate among the categories did differ significantly (P=0.035). Hatch rate (a pair that hatched at least one egg on at least one nesting attempt) was 62.8% at core sites, 62.5% at secondary site, and 67.3% at satellite sites. Failed (those that were flooded, predated or abandoned) nest rates were 33.2% at core sites, 30.8% at secondary sites, and 28.5% at satellite sites. Unknown nest rates were 3.9% at core sites, 6.6% at secondary sites, and 4.1% at satellite sites (Table 4). The fledge rate at the core sites over the survey period was 1.02 fledges/pair. The rate at the secondary and satellite sites were 0.82 and 1.02 fledges/pair, respectively. An ANOVA test coupled with a Dunn’s Method Pairwise test revealed no significant differences between fledge rates at core and satellite sites, or secondary and satellite sites but that there was a significant difference between core and secondary sites (P= <0.001 for ANOVA, P= <0.05 for Dunn’s, Tables 5 & 6).

Discussion

Over the past 20 years, Piping Plovers have occupied about a third of the habitat available to them in New Jersey. The 52 sites where active nesting occurred were divided into three categories – core, secondary, and satellite sites – based on the longevity of site use and the number of pairs located there. Core sites were the most critical to sustaining the population in New Jersey. Secondary and satellite sites played less important roles, yet were vital in their own ways. Management of these sites should be specific to the category they fall in, with the majority of effort being placed on core sites. The hatch and fledge rates did not differ significantly among categories. Increasing these rates, especially at core sites, is imperative to growing the plover population in New Jersey.

Available and suitable habitat

Only 28% of the linear habitat (in miles) that can be considered suitable habitat, to some degree, has ever been utilized by Piping Plovers since 1987. This is a relatively small percentage of the coast, and since it is an inclusive figure over 20 years, the figure in any given year would be smaller. This could be due to a number of reasons. One explanation is that there was never a large enough population at any time during the survey period to occupy all suitable habitat. Another explanation would be that the habitat that was considered suitable (loosely defined for these purposes as any sandy beach on the Atlantic coast and lower Delaware Bay) in this analysis was not considered as such by the nesting birds. If this was the case, there are serious implications for the recovery of the population because it implies there was either not enough habitat or management of existing habitat to support more plovers than currently nest in NJ.

Role of different habitat types

Despite their differences (or perhaps because of them) each category has an important role to play in the overall state landscape view of Piping Plover nesting. It is important to recognize these differences because they can help guide management practices to maintain and increase plover populations.

Core sites are the foundation, and are the most critical sites in the state, for maintaining plover populations. These sites are where the majority of the management monies should be placed. They are the sites that attract the greatest number of pairs. The data suggest that to improve population numbers these sites should be the focus of increased efforts since their high numbers of pairs have the potential to produce large numbers of fledges. Management should be focused on site specific issues at each site. Due to the close monitoring of each pair, and species managers generally know the issues that are of concern for their pairs. For example, excessive predation can be a problem towards achieving reproductive success. If this is the case at a core site, all efforts should be made to address the problem given the enormous importance and potential of a core site. Fledge rate at core sites is far below the level deemed necessary to grow the population thus increased management at these sites is vital to the recovery of this species. Since these are sites that the birds are showing a preference for, efforts at these locations are the most efficient way to achieve population goals.

Secondary sites are also important but should be managed in a slightly different manner. These sites are more ephemeral in nature and while they are active, can be some of the most important sites on a year by year basis (see Whale Beach circa 1990s or Stone Harbor Point circa early 2000s, Fig. 3). They may not have the longevity of the core sites but can support just as many pairs in the years they are active. Secondary sites often follow a pattern of starting out with a few pairs, building to a peak and then declining to less significant numbers or becoming inactive. During the active years, managers should take all measures possible to ensure their success. Unlike the long-term policies necessary to allow core sites to flourish, secondary site management can be shorter term. As stated previously, many of these sites occur on municipal beaches. It may be easier to implement certain restrictive measures at these sites if municipal administrators understand that they are not likely to be long-term changes. Of course, this needs to be balanced with habitat management that would still encourage birds to return to the sites (i.e., beach raking restrictions should remain in place). But on the whole, these sites can be managed at an elevated state when active and reduced to a lower state when pairs are absent.

The third type of site, satellite, can be handled much differently than the first two. Although they can account for a high percentage of the number of active sites in a given year, they comprise a small percentage of the population. They may represent "prospecting" sites where pairs (perhaps younger birds) experiment with new nesting locations. The reasons why some of these “prospecting” sites develop into core or secondary sites while others never attract additional pairs are not well understood. Since these sites have the potential to evolve into more critical areas for nesting, managers should remain cognizant of their presence. However, if management monies are limited or restrictions are deemed too difficult to successfully implement, then these may be the sites where compromise is a valid management alternative.

With respect to nest fate and fledge rate, the sites did differ statistically but these differences do not translate into numbers that significantly impact the plover population. Fledge rates did not, on average, reach the levels believed necessary for a sustainable population (1.24 fledges/pair), much less those necessary to grow the population (1.50 fledges/pair) (USFWS, 1996). It is clear from this data that all the sites, no matter their designation, are in need of improved reproductive success. This is especially true of core sites, where the majority of the breeding plover population resided.

Management Implications and Conclusions

Piping Plovers were listed as state endangered in 1984 (E.N.S.C.A. 23:2A). To the credit of the biologists that have worked on protecting this species in NJ over the past 20 years, the plover population has not declined further, despite ever increasing human-related pressures on their habitat (Pover, 2007). However, the state's population has not recovered. Nearly all barrier island habitats have been developed over the past 100 years and the human desire for living and vacationing in this environment has not waned, nor is it likely to (http://deathstar.rutgers.edu/projects/lc/download/reportsdata72_84_95/index.html). Fortunately, there are areas that remain undeveloped, some of which are protected under state and federal laws. Still the majority of the land has been developed and the remaining parcels are being developed at an alarming rate (such as the area known as Avalon-Dunes). While development of areas adjacent to nesting sites does not eliminate their ability to provide habitat to nesting pairs, the additional human presence and human-related impacts (increased populations of human subsidized predators such as cats and fox probably does reduce the suitability to some unknown extent.

The nesting areas in NJ were delineated into areas called “sites”. The definition of a site was a somewhat arbitrary (but consistent) designation by land managers, but served an important role in understanding the mechanics of where plovers nested in the state and for how long. The spatial polygon files created by this research by mapping the active sites (since 1987) provides a valuable tool for species managers in understanding where, how many, and for how long Piping Plovers have nested at various locations throughout the state. Obviously, plovers may nest in new areas in the future that have not yet been mapped, but this twenty year data set provides an accurate picture of where plovers have been and where the majority of them are expected to be located in the future. We can be more confident in the robustness of its predictive qualities because Piping Plovers are a relatively short-lived species and the dataset represents multiple generations. Additionally, the spatial dataset provides a framework upon which future year’s data can be built on.

Categorizing the sites as core, secondary and satellite further allows species managers to identify where their site fits along the usage continuum. For those who manage and make decisions at core sites, this is especially pertinent. This data provides confirmation that there are some sites in the state which are, by virtue of their long term usage by many pairs, the foundation of the population and deserve the strongest protective measures. Incidentally, these protective measures (e.g., restrictions on negative impact of human disturbance, vehicles, beach raking, and increased predator control) are likely to benefit other beach nesting bird species as well as other flora and fauna of the coastal beach system (T. Pover, personal communication, 3 December 2008.).

This analysis identified the areas that plovers used as nesting habitat over the past 20 years and highlighted the sites that the plovers have used most consistency over time with the highest number of pairs. There are management tools that can be utilized at these sites that should be fully taken advantage of, namely the implementation of integrated predator control plans. Rather than targeting removals at focused, small areas, predator control should be applied on a larger scale at the most important areas, much like the successful programs that have taken place in Virginia and Connecticut where reproductive success, and thus populations, have dramatically increased following these efforts (Wilke, 2007). These types of programs would be most successful at sites like Little Beach, which as an island ensures that removal programs would be effective over the long term since it would be more difficult for predators to access the island and repopulate the site). Tools like exclosures could also be utilized on a greater scale, especially when used in conjunction with predator removal. In addition to predator control, additional efforts should be made at core sites to restrict activities that are detrimental to the beach environment, such as vehicle use which can have a direct impact by running over birds or an indirect impact by compacting sand and degrading foraging habitat in the wrack line) and beach raking (which removes trash from a beach but also all the wrack that contains prey items for plovers). Increased management at all sites, and especially those designated as core, may lead to improved reproductive success and thus higher population rates for this species.

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Table 1. Atlantic coast Piping Plover population: 1986-2007.

Estimated abundance of breeding pairs of Atlantic Coast piping plovers, 1986 – 2007 **PARENTHESES DENOTE PRELIMINARY ESTIMATES**

State/RECOVERY UNIT	Pairs 1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Maine	15	12	20	16	17	18	24	32	35	40	60	47	60	56	50	55	65	61	55	49	40	35
New Hampshire												5	5	6	6	7	7	7	4	3	3	3
Massachusetts	139	126	134	137	140	160	213	289	352	441	454	483	495	501	496	495	538	511	(490)	(475)	482	(550)
Rhode Island	10	17	19	19	28	26	20	31	32	40	50	51	46	39	49	52	58	71	70	69	72	73
Connecticut	20	24	27	34	43	36	40	24	30	31	26	26	21	22	22	32	31	37	40	34	37	36
NEW ENGLAND	184	179	200	206	228	240	297	376	449	552	590	612	627	624	623	641	699	687	(659)	(630)	634	(697)
New York	106	135	172	191	197	191	187	193	209	249	256	256	245	243	289	309	369	386	384	374	422	(464)
New Jersey	102	93	105	128	126	126	134	127	124	132	127	115	93	107	112	122	138	144	135	111	116	129
NY-NJ	208	228	277	319	323	317	321	320	333	381	383	371	338	350	401	431	507	530	519	485	538	(593)
Delaware	8	7	3	3	6	5	2	2	4	5	6	4	6	4	3	6	6	6	7	8	9	9
Maryland	17	23	25	20	14	17	24	19	32	44	61	60	56	58	60	60	60	59	66	63	64	64
Virginia	100	100	103	121	125	131	97	106	96	118	87	88	95	89	96	119	120	114	152	192	202	199
North Carolina	30	30	40	55	55	40	49	53	54	50	35	52	46	31	24	23	23	24	20	37	46	61
South Carolina	3		0		1	1		1			0					0						0
SOUTHERN	158	160	171	199	201	194	172	181	186	217	189	204	203	182	183	208	209	203	245	300	321	333
U.S. TOTAL	550	567	648	724	752	751	790	877	968	1150	1162	1187	1168	1156	1207	1280	1415	1420	(1423)	(1415)	1493	(1623)
ATLANTIC CANADA*	240	223	238	233	230	252	223	223	194	200	202	199	211	236	230	250	274	256	237	217	256	(266)
ATLANTIC COAST TOTAL*	790	790	886	957	982	1003	1013	1100	1162	1350	1364	1386	1379	1392	1437	1530	1689	1676	(1660)	(1632)	1749	(1889)

*** Includes minor revisions to 1990-2002 Atlantic Canada estimates made by Canadian Wildlife Service in 2005.**

Table 2. New Jersey Piping Plover abundance and reproductive success at nesting sites: 1987-2007.

	1987			1988			1989			1990			1991			1992		
Site	pairs	fldgs	rate	pairs	fldgs	rate	pairs	fldgs	rate	pairs	fldgs	rate	pairs	fldgs	rate	pairs	fldgs	rate
Sandy Hook Coast Guard	4	6	1.50	2	4	2.00	4	4	1.00	3	1	0.33	4	11	2.75	3	8	2.67
Sandy Hook North Beach	2	3	1.50	6	2	0.33	11	12	1.09	10	19	1.90	9	10	1.11	8	13	1.63
Sandy Hook North Gunnison																		
Sandy Hook South Gunnison	3	5	1.67	4	3	0.75	4	3	0.75	3	1	0.33	3	0	0.00	4	7	1.75
Sandy Hook Critical Zone	1	2	2.00							2	0	0.00	4	2	0.50	5	6	1.20
Barnegat Light	5	3	0.60	3	6	2.00	3	4	1.33	4	8	2.00	7	5	0.71	9	13	1.44
Holgate	11	9	0.82	11	9	0.82	12	18	1.50	16	18	1.13	16	29	1.81	22	21	0.95
Little Beach	2	2	1.00	3	7	2.33	13	20	1.54	11	5	0.45	13	11	0.85	15	26	1.73
North Brigantine N. A.	1	0	0.00	1	0	0.00	1	2	2.00									
Avalon - Dunes	2	1	0.50	3	3	1.00	5	5	1.00	7	4	0.57	7	0	0.00	5	2	0.40
Coast Guard - TRACEN	1	2	2.00	2	0	0.00	1	2	2.00	1	2	2.00	3	4	1.33	6	2	0.33
Cape May Meadows	5	1	0.20	4	2	0.50	2	2	1.00	2	3	1.50	1	0	0.00	2	5	2.50
Sandy Hook Hidden Beach																1	1	1.00
Sea Bright North																		
Mantoloking	7	8	1.14	8	11	1.38	8	20	2.50	8	16	2.00	7	12	1.71	6	16	2.67
Brigantine Beach	8	2	0.25	10	10	1.00	11	17	1.55	12	15	1.25	15	5	0.33	10	3	0.30
Ocean City - North	3	4	1.33	2	2	1.00	1	0	0.00									
Ocean City - Center																		
Corson's Inlet State Park	5	2	0.40	8	6	0.75	7	7	1.00	8	5	0.63	6	6	1.00	7	1	0.14
Strathmere	3	1	0.33	3	4	1.33	8	2	0.25	4	0	0.00	5	1	0.20	5	3	0.60
Whale Beach	13	14	1.08	13	12	0.92	14	9	0.64	9	4	0.44	9	9	1.00	6	1	0.17
Sea Isle City - North	2	5	2.50	6	8	1.33	5	7	1.40	8	4	0.50	6	5	0.83	4	3	0.75
Sea Isle City - South							3	1	0.33	4	0	0.00	3	3	1.00	4	3	0.75
Townsend's Inlet	3	4	1.33	3	2	0.67	5	5	1.00	4	5	1.25	1	1	1.00	3	2	0.67
Avalon - North	2	2	1.00	1	0	0.00				1	2	2.00	1	2	2.00	4	6	1.50
Stone Harbor Point																		
Coast Guard - LSU	3	1	0.33	3	1	0.33	1	0	0.00	3	1	0.33	2	0	0.00			
Sandy Hook Fee Beach																		
Sandy Hook South Fee Beach																		
Monmouth Beach North																		
Monmouth Beach South																		
Seven Presidents Park																		
Long Branch																		
Sea Girt - Wreck Pond																		
Sea Girt - NGTC																		
Island Beach SP - Oceanfront	1	0	0.00	1	0	0.00	1	0	0.00									
Island Beach SP - Dike																		
Highbar	1	0	0.00															
Loveladies				1	2	2.00	1	2	2.00	1	1	1.00	1	0	0.00			
Brigantine - Inlet (Cove)	4	2	0.50	3	4	1.33	2	0	0.00	1	2	2.00	2	6	3.00	2	1	0.50
Longport Sodbanks	2	3	1.50	1	0	0.00												
Seaview Harbor Marina																		
Corson's Sodbank	1	0	0.00															
Strathmere NA																		
Champagne Island							1	4	4.00				1	0	0.00			
N. Wildwood - Hereford Inlet																		
N. Wildwood - Oceanfront				3	2	0.67	4	3	0.75	4	1	0.25				3	0	0.00
Wildwood Crest																		
USFWS - Cape May NWR																		
Cape May																		
Higbee/Magnesite	1	0	0.00															
Cape May Ferry	1	0	0.00	1	0	0.00												

Table 2. continued

Site	1993 pairs	1993 fldgs	1993 rate	1994 pairs	1994 fldgs	1994 rate	1995 pairs	1995 fldgs	1995 rate	1996 pairs	1996 fldgs	1996 rate	1997 pairs	1997 fldgs	1997 rate	1998 pairs	1998 fldgs	1998 rate
Sandy Hook Coast Guard	6	12	2.00	10	23	2.30	10	15	1.50	10	23	2.30	11	0	0.00	7	7	1.00
Sandy Hook North Beach	9	20	2.22	10	19	1.90	12	26	2.17	14	16	1.14	13	1	0.08	10	11	1.10
Sandy Hook North Gunnison	1	0	0.00	3	6	2.00	4	4	1.00	7	7	1.00	8	2	0.25	4	7	1.75
Sandy Hook South Gunnison	4	10	2.50	8	15	1.88	11	9	0.82	7	9	1.29	4	0	0.00	3	1	0.33
Sandy Hook Critical Zone	5	3	0.60	5	8	1.60	6	3	0.50	2	0	0.00						
Barnegat Light	12	8	0.67	9	11	1.22	6	2	0.33	5	3	0.60	5	1	0.20	2	5	2.50
Holgate	14	6	0.43	15	6	0.40	10	7	0.70	11	14	1.27	11	9	0.82	17	13	0.76
Little Beach	19	21	1.11	10	3	0.30	15	5	0.33	13	8	0.62	8	0	0.00	8	13	1.63
North Brigantine N. A.							1	0	0.00	5	12	2.40	8	2	0.25	8	12	1.50
Avalon - Dunes	3	0	0.00	1	4	4.00	2	0	0.00	3	4	1.33	3	1	0.33	2	3	1.50
Coast Guard - TRACEN	6	4	0.67	7	9	1.29	6	6	1.00	7	6	0.86	3	1	0.33	3	5	1.67
Cape May Meadows	3	4	1.33	4	7	1.75	12	9	0.75	10	9	0.90	9	6	0.67	7	3	0.43
Sandy Hook Hidden Beach													6	12	2.00	4	3	0.75
Sea Bright North																2	4	2.00
Mantoloking	4	6	1.50	5	4	0.80	4	7	1.75	3	0	0.00	1	0	0.00			
Brigantine Beach	8	3	0.38	4	4	1.00	5	1	0.20	5	0	0.00	2	0	0.00			
Ocean City - North	1	0	0.00	2	3	1.50	3	2	0.67	4	3	0.75	4	0	0.00	3	3	1.00
Ocean City - Center				3	0	0.00	3	2	0.67	5	1	0.20	5	2	0.40	6	2	0.33
Corson's Inlet State Park	5	6	1.20	5	0	0.00	3	1	0.33	2	0	0.00	3	2	0.67			
Strathmere	6	2	0.33	3	2	0.67	2	1	0.50	1	0	0.00						
Whale Beach	4	4	1.00	4	6	1.50	5	0	0.00	2	3	1.50	2	0	0.00	1	0	0.00
Sea Isle City - North	3	4	1.33	2	4	2.00	2	3	1.50	3	4	1.33	2	2	1.00			
Sea Isle City - South	3	2	0.67	4	1	0.25	3	5	1.67	3	1	0.33	1	0	0.00			
Townsend's Inlet	1	1	1.00	1	0	0.00												
Avalon - North	5	2	0.40	4	5	1.25	3	6	2.00	3	4	1.33	3	3	1.00	1	1	1.00
Stone Harbor Point																		
Coast Guard - LSU				1	0	0.00												
Sandy Hook Fee Beach																1	0	0.00
Sandy Hook South Fee Beach																		
Monmouth Beach North													1	0	0.00	2	6	3.00
Monmouth Beach South																		
Seven Presidents Park																		
Long Branch																		
Sea Girt - Wreck Pond																		
Sea Girt - NGTC																		
Island Beach SP - Oceanfront																		
Island Beach SP - Dike																		
Highbar																		
Loveladies				1	3	3.00	1	3	3.00	1	0	0.00						
Brigantine - Inlet (Cove)				1	4	4.00	1	3	3.00									
Longport Sodbanks																		
Seaview Harbor Marina																		
Corson's Sodbank																		
Strathmere NA																		
Champagne Island																		
N. Wildwood - Hereford Inlet																		
N. Wildwood - Oceanfront	5	0	0.00	2	0	0.00	2	0	0.00	1	0	0.00						
Wildwood Crest																1	0	0.00
USFWS - Cape May NWR																		
Cape May													1	1	1.00	1	2	2.00
Higbee/Magnesite																		
Cape May Ferry																		

Table 2. continued

Site	1999 pairss	1999 fldgs	1999 rate	2000 pairss	2000 fldgs	2000 rate	2001 pairss	2001 fldgs	2001 rate	2002 pairss	2002 fldgs	2002 rate	2003 pairss	2003 fldgs	2003 rate	2004 pairss	2004 fldgs	2004 rate
Sandy Hook Coast Guard	9	14	1.56	5	7	1.40	6	11	1.83	7	8	1.14	8	13	1.63	7	4	0.57
Sandy Hook North Beach	11	24	2.18	12	23	1.92	11	20	1.82	9	17	1.89	9	11	1.22	10	5	0.50
Sandy Hook North Gunnison	3	4	1.33	3	4	1.33	3	3	1.00	4	11	2.75	5	0	0.00	3	0	0.00
Sandy Hook South Gunnison										1	0	0.00	1	0	0.00	1	0	0.00
Sandy Hook Critical Zone							1	1	1.00	2	3	1.50	4	2	0.50	3	2	0.67
Barnegat Light	4	4	1.00	3	4	1.33	2	4	2.00	3	6	2.00	3	4	1.33	3	2	0.67
Holgate	24	20	0.83	19	19	1.00	19	18	0.95	14	15	1.07	13	17	1.31	16	8	0.50
Little Beach	7	14	2.00	8	10	1.25	12	11	0.92	17	13	0.76	19	22	1.16	19	4	0.21
North Brigantine N. A.	6	19	3.17	11	27	2.45	12	26	2.17	15	17	1.13	17	6	0.35	8	7	0.88
Avalon - Dunes	4	6	1.50	3	1	0.33	4	8	2.00	7	9	1.29	8	6	0.75	8	6	0.75
Coast Guard - TRACEN	5	4	0.80	5	5	1.00	2	4	2.00	3	3	1.00	4	3	0.75	1	1	1.00
Cape May Meadows	4	1	0.25	4	1	0.25	3	1	0.33	2	2	1.00	3	4	1.33	4	7	1.75
Sandy Hook Hidden Beach	4	2	0.50	3	10	3.33	3	6	2.00	5	10	2.00	4	3	0.75	3	3	1.00
Sea Bright North	4	4	1.00	3	2	0.67	3	4	1.33	5	10	2.00	7	3	0.43	5	7	1.40
Mantoloking																		
Brigantine Beach																		
Ocean City - North	4	4	1.00	5	11	2.20	8	10	1.25	8	5	0.63	2	2	1.00	1	1	1.00
Ocean City - Center	7	4	0.57	8	9	1.13	9	7	0.78	8	1	0.13	8	8	1.00	8	0	0.00
Corson's Inlet State Park	1	3	3.00	1	2	2.00	1	3	3.00	1	3	3.00	2	1	0.50	3	5	1.67
Strathmere													1	1	1.00	1	0	0.00
Whale Beach										1	0	0.00						
Sea Isle City - North																		
Sea Isle City - South							1	0	0.00									
Townsend's Inlet							1	0	0.00	1	2	2.00	1	2	2.00	1	2	2.00
Avalon - North	1	1	1.00	1	1	1.00	1	1	1.00									
Stone Harbor Point	3	3	1.00	5	0	0.00	5	1	0.20	6	1	0.17	6	3	0.50	9	1	0.11
Coast Guard - LSU				1	0	0.00	1	2	2.00	2	3	1.50	2	1	0.50	1	0	0.00
Sandy Hook Fee Beach	2	4	2.00	6	7	1.17	7	8	1.14	7	11	1.57	6	5	0.83	4	5	1.25
Sandy Hook South Fee Beach													1	2	2.00	1	2	2.00
Monmouth Beach North	3	8	2.67	4	8	2.00	4	2	0.50	3	2	0.67	2	5	2.50	4	4	1.00
Monmouth Beach South				1	3	3.00	1	4	4.00	1	4	4.00						
Seven Presidents Park													1	2	2.00	1	0	0.00
Long Branch													1	1	1.00			
Sea Girt - Wreck Pond													1	1	1.00	1	2	2.00
Sea Girt - NGTC										1	0	0.00						
Island Beach SP - Oceanfront																		
Island Beach SP - Dike													2	0	0.00	3	2	0.67
Highbar																		
Loveladies																		
Brigantine - Inlet (Cove)										1	1	1.00						
Longport Sodbanks																		
Seaview Harbor Marina																		
Corson's Sodbank																		
Strathmere NA																		
Champagne Island																1	0	0.00
N. Wildwood - Hereford Inlet										3	4	1.33	3	4	1.33	4	2	0.50
N. Wildwood - Oceanfront																		
Wildwood Crest																		
USFWS - Cape May NWR																		
Cape May	1	0	0.00	1	3	3.00	2	2	1.00	1	0	0.00				1	0	0.00
Higbee/Magnesite																		
Cape May Ferry																		

Table 2. continued

Site	2005 pairs	2005 fldgs	2005 rate	2006 pairs	2006 fldgs	2006 rate	2007 pairs	2007 fldgs	2007 rate
Sandy Hook Coast Guard	2	6	3.00	4	9	2.25	4	10	2.50
Sandy Hook North Beach	6	5	0.83	4	9	2.25	8	2	0.25
Sandy Hook North Gunnison	2	0	0.00	3	1	0.33	4	0	0.00
Sandy Hook South Gunnison							1	3	3.00
Sandy Hook Critical Zone	3	3	1.00	3	2	0.67	4	1	0.25
Barnegat Light	4	1	0.25	3	4	1.33	4	7	1.75
Holgate	13	11	0.85	16	6	0.38	14	7	0.50
Little Beach	11	2	0.18	12	7	0.58	17	11	0.65
North Brigantine N. A.	8	10	1.25	8	11	1.38	8	4	0.50
Avalon - Dunes	5	0	0.00	4	3	0.75	5	3	0.60
Coast Guard - TRACEN	3	0	0.00				2	0	0.00
Cape May Meadows	5	8	1.60	6	9	1.50	7	15	2.14
Sandy Hook Hidden Beach	3	3	1.00	3	3	1.00	4	0	0.00
Sea Bright North	7	9	1.29	7	12	1.71	8	6	0.75
Mantoloking									
Brigantine Beach									
Ocean City - North									
Ocean City - Center	5	5	1.00	7	1	0.14	4	1	0.25
Corson's Inlet State Park	2	0	0.00	2	1	0.50	2	0	0.00
Strathmere	1	0	0.00						
Whale Beach									
Sea Isle City - North									
Sea Isle City - South									
Townsend's Inlet	1	0	0.00						
Avalon - North									
Stone Harbor Point	10	6	0.60	17	3	0.18	17	5	0.29
Coast Guard - LSU	1	0	0.00	1	1	1.00	1	0	0.00
Sandy Hook Fee Beach	4	4	1.00	4	5	1.25	4	1	0.25
Sandy Hook South Fee Beach	1	4	4.00	1	0	0.00	1	4	4.00
Monmouth Beach North	3	5	1.67	3	6	2.00	1	1	1.00
Monmouth Beach South									
Seven Presidents Park	1	3	3.00	2	4	2.00	3	6	2.00
Long Branch									
Sea Girt - Wreck Pond	1	0	0.00				1	0	0.00
Sea Girt - NGTC							1	0	0.00
Island Beach SP - Oceanfront									
Island Beach SP - Dike	2	0	0.00						
Highbar									
Loveladies									
Brigantine - Inlet (Cove)									
Longport Sodbanks									
Seaview Harbor Marina	1	1	1.00						
Corson's Sodbank									
Strathmere NA	1	0	0.00	1	0	0.00			
Champagne Island	1	0	0.00	2	0	0.00	1	0	0.00
N. Wildwood - Hereford Inlet	3	0	0.00	3	0	0.00	2	0	0.00
N. Wildwood - Oceanfront									
Wildwood Crest									
USFWS - Cape May NWR							1	0	0.00
Cape May									
Higbee/Magnesite									
Cape May Ferry									

Table 3. Categorization of nesting sites as core, secondary and satellite: 1987-2007.

Site	**Range of Pairs**	**Number of Years Active**	**Category**
Holgate	10-24	21	Core
Little Beach	2-19	21	Core
Sandy Hook North Beach	2-14	21	Core
Barnegat Light	2-12	21	Core
Sandy Hook Coast Guard	2-11	21	Core
North Brigantine N. A.	1-17	16	Core
Cape May Meadows	1-12	21	Core
Sandy Hook South Gunnison	1-11	16	Core
Avalon - Dunes	1-8	21	Core
Corson's Inlet State Park	1-8	20	Core
Sandy Hook North Gunnison	1-8	15	Core
Coast Guard - TRACEN	1-7	20	Core
Sandy Hook Critical Zone	1-6	15	Core
Stone Harbor Point	3-17	9	Secondary
Ocean City - Center	3-9	14	Secondary
Brigantine Beach	2-15	11	Secondary
Sea Isle City - North	2-8	11	Secondary
Sea Bright North	2-8	10	Secondary
Whale Beach	1-14	12	Secondary
Ocean City - North	1-8	16	Secondary
Strathmere	1-8	12	Secondary
Mantoloking	1-8	11	Secondary
Sandy Hook Hidden Beach	1-6	12	Secondary
Avalon - North	1-5	14	Secondary
Townsend's Inlet	1-5	13	Secondary
Sea Isle City - South	1-4	9	Secondary
Coast Guard - LSU	1-3	14	Secondary
N. Wildwood - Hereford Inlet	2-4	6	Satellite
Island Beach SP - Dike	2-3	3	Satellite
Sandy Hook Fee Beach	1-7	10	Satellite
N. Wildwood - Oceanfront	1-5	8	Satellite
Monmouth Beach North	1-4	11	Satellite
Brigantine - Inlet (Cove)	1-4	9	Satellite
Seven Presidents Park	1-3	5	Satellite
Cape May	1-2	7	Satellite
Champagne Island	1-2	6	Satellite
Longport Sodbanks	1-2	2	Satellite
Loveladies	1-1	7	Satellite
Strathmere NA	1-1	5	Satellite
Sandy Hook South Fee Beach	1-1	5	Satellite
Sea Girt - Wreck Pond	1-1	4	Satellite
Monmouth Beach South	1-1	3	Satellite
Island Beach SP - Oceanfront	1-1	3	Satellite
Sea Girt - NGTC	1-1	2	Satellite
Cape May Ferry	1-1	2	Satellite
Long Branch	1-1	1	Satellite
Highbar	1-1	1	Satellite
Seaview Harbor Marina	1-1	1	Satellite
Corson's Sodbank	1-1	1	Satellite
USFWS - Cape May NWR	1-1	1	Satellite
Wildwood Crest	1-1	1	Satellite
Higbee/Magnesite	1-1	1	Satellite

Table 4. Results of chi square test of nest fate by site category.

	Site Category							
	Core		*Secondary*		*Satellite*			
	n	**%**	**n**	**%**	**n**	**%**	x^2	**P**
Nest Fate								
Hatched	999	63	464	63	132	67	10.367	0.035
Failed	528	33	229	31	56	29		
Unknown	62	4	49	7	8	4		

Table 5. Results of ANOVA test of fledge rate by site category.

	n	**Avg Fledge Rate**	**H**	**P**
Category				
Core	**1589**	**1.02**	**25.79**	**<.001**
Secondary	**742**	**0.82**		
Satellite	**196**	**1.02**		

Table 6. Results of Dunn's method mulitple pairwise comparison of fledge rate among site categories.

Comparison	**Q**	**P<0.05**
Core vs Secondary	4.63	Yes
Core vs. Satellite	0.42	No
Satellite vs. Secondary	2.167	No

Figure 1. Piping Plover abundance and reproductive success in New Jersey: 1987-2007.

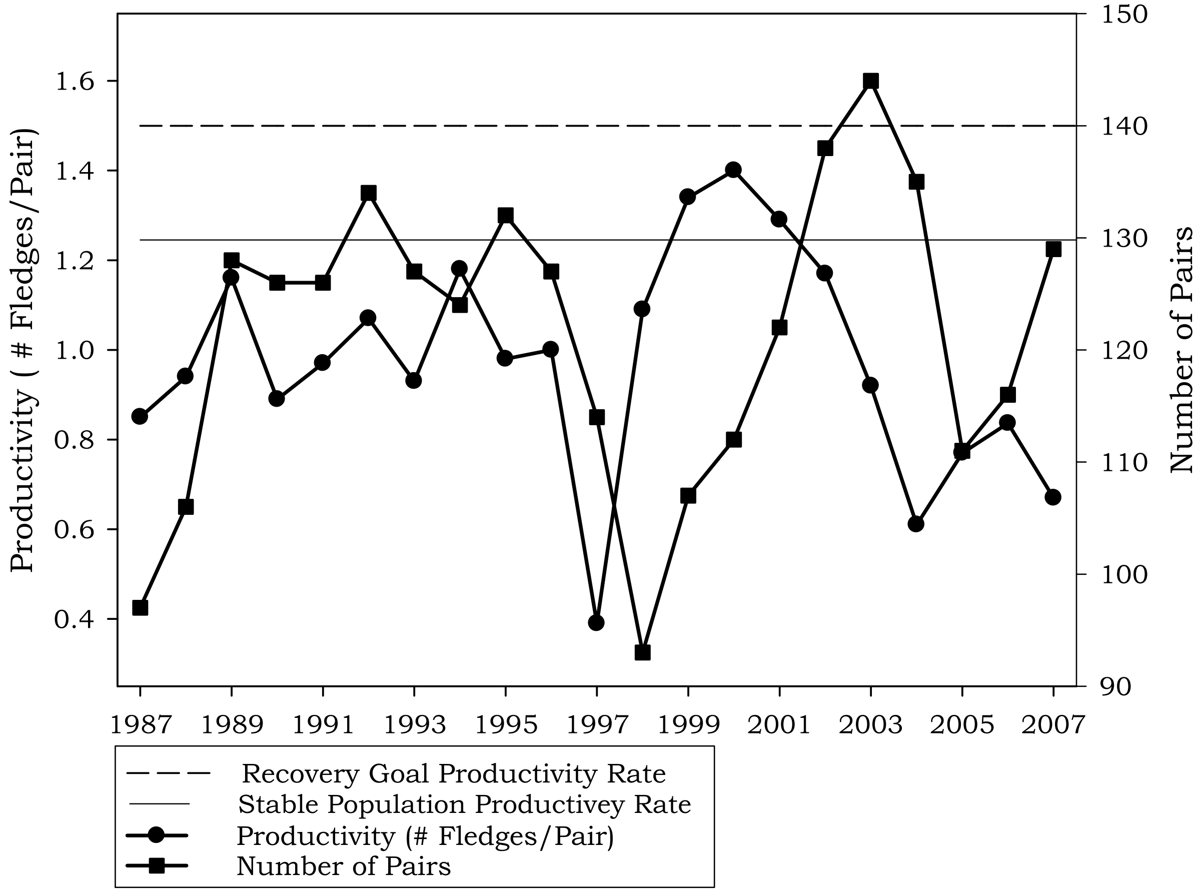
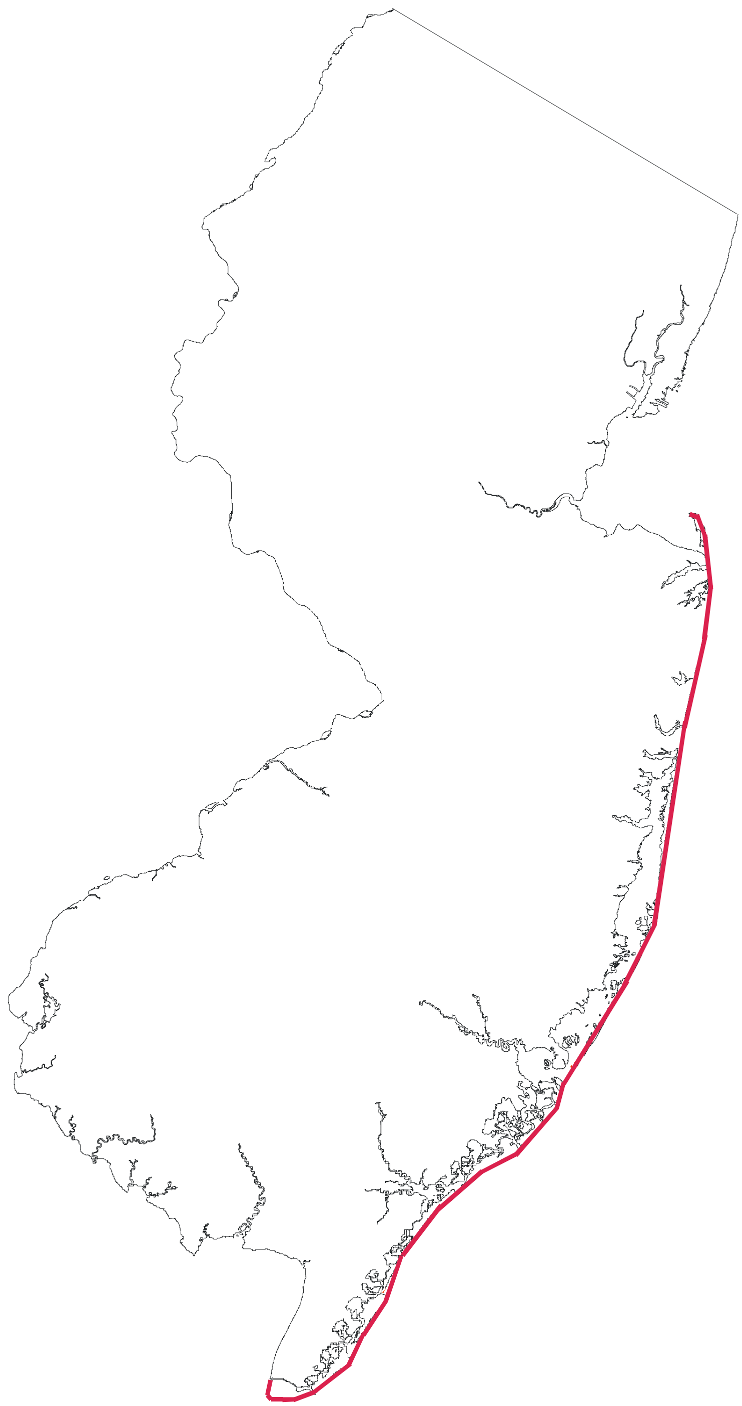


Figure 2. Study area (highlighted in red).



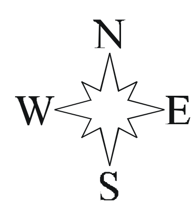
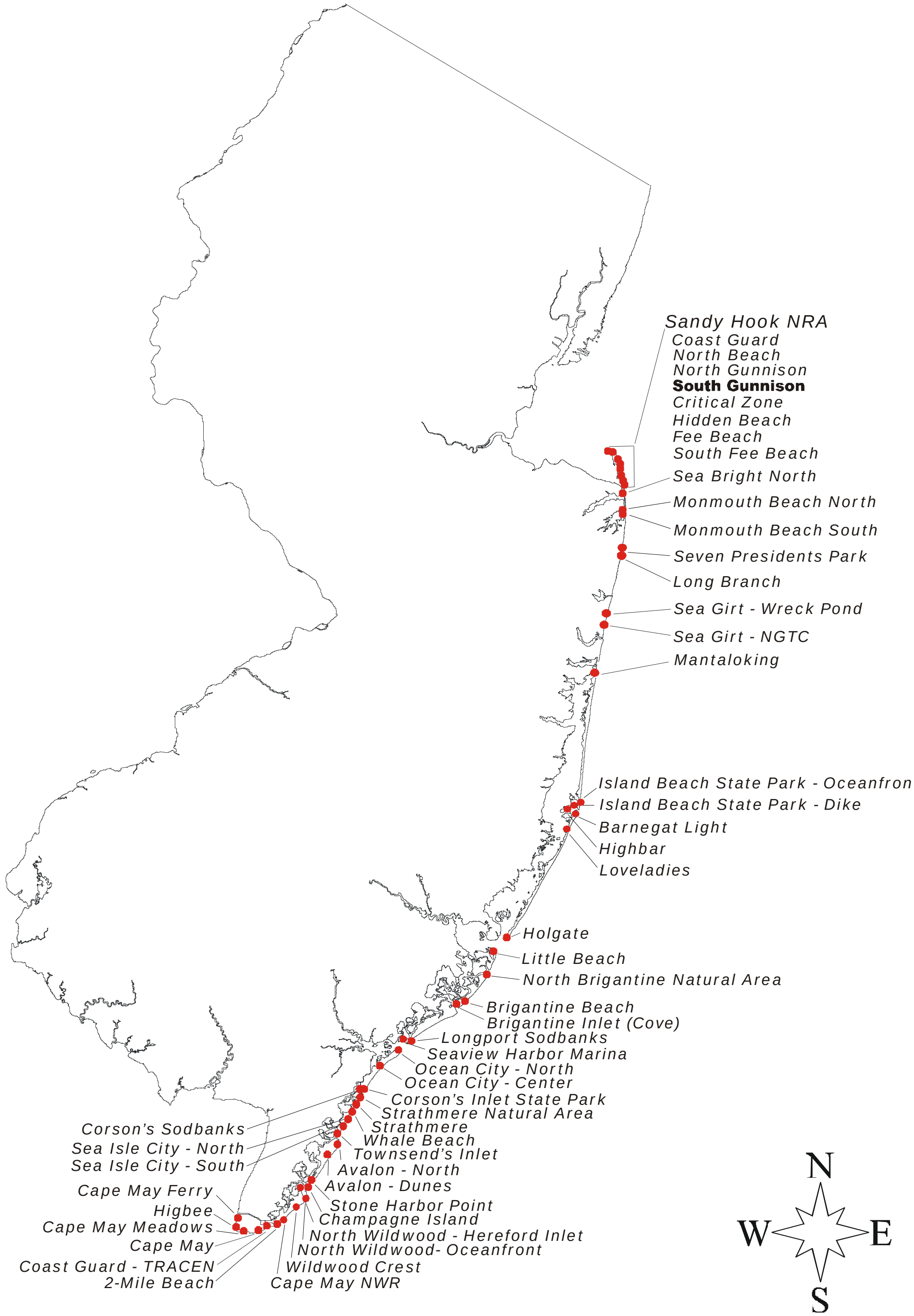


Figure 3. Active Piping Plover nesting sites in New Jersey: 1987-2007.



Chapter 2 Factors Influencing Nesting Site Selection of Piping Plovers in New Jersey

Introduction

The Piping Plover (*Charadrius melodus melodus*) is a small shorebird that occurs throughout North America along lakes, rivers and the ocean. There are three distinct breeding geographical populations – the Atlantic coast population, the Great Lakes population, and the Great Plains population (Miller, Haig, Gratto-Trevor & Mullins, 2009). New Jersey's Piping Plover population is part of the Atlantic Coast population, which extends from Newfoundland in Canada to North Carolina in the United States. In New Jersey they are found primarily on ocean beaches where they nest between the toe of the dune and the high tide line (Elliott-Smith & Haig, 2004).

Most research on Piping Plover site selection has generally concentrated on micro-habitat selection. Burger (1987) found that Piping Plover nests were "closer to dunes and vegetation, farther from water, closer to tern nests, farther from other Piping Plover nests and in spots with more shell cover" as compared to random points. In the Great Plains, research showed they favored wide, sparsely vegetated sand or gravel and beaches adjacent to vast alkali lakes (Whyte, 1985, Haig & Oring, 1988). Others haves shown that they prefer nesting in areas with less than 20% vegetation cover (Haig, 1986, Schwalbach, 1988). They have been reported to nest in or near least tern colonies and adjacent to sand dunes (Elliot-Smith & Haig, 2004).

Few studies, however, have considered site selection on a landscape level which would consider variables on a much larger scale than the studies reported above. Although micro-level factors are critical to our understanding of nesting site selection, understanding the macro factors is equally important to building a comprehensive knowledge of this species' breeding preferences, particularly as they relate to management decisions. For example, recognizing that plovers prefer to nest in areas of low vegetation cover or within least tern colonies could be important for site specific management decisions. On the other hand, understanding how they respond to beach replenishments will help guide decisions on a larger, state-wide scale.

Piping Plovers were state listed as endangered (E.N.S.C.A. 23:2A) and federally listed (Endangered Species Act of 1973) as threatened in 1984 and 1986, respectively. Since listing there have been large gains in regional populations portions of the range (see Table 1), especially in states such as Massachusetts and New York. Although New Jersey has experienced some increases they are often followed by declines, leaving the overall population growth decidedly flat (Fig. 1). The New Jersey population has not declined precipitously, which is remarkable considering the increasing human presence and pressure in coastal regions, but it certainly is not the degree of recovery that is the goal of management efforts.

The objective of this chapter is to examine the distribution to determine if there are discernable patterns related to environmental variables. Although there are dozens of potential variables to consider, this analysis will investigate just two: distance of nesting pairs to inlets, and the effect of beach replenishments on nesting pairs. The goal of this research was to provide information that can inform management decisions that will lead to increases in the New Jersey plover population. This information is also likely to be applicable to understanding nest site selection in other states of along the Atlantic coast range since their sites are similar in nature to the ones in this study.

Study Area

The study area was the Atlantic Coast beaches of New Jersey from Sandy Hook to Cape May. The southern part of the Cape May peninsula on the Delaware Bay side north to the Cape May Ferry Terminal (or the western outlet of the Cape May Canal) was also included (Fig. 2). From 1987-2007 there was no documented nesting by Piping Plovers north of the Cape May Canal. It is likely that any pairs in this area would be detected because the Delaware Bay region is a stopover habitat for migratory shorebirds and there are many biologists working in that area who would be aware of nesting birds. No nesting was detected on the beaches of interior Sandy Hook Bay during the study period, so that area was also not part of this project. There is a high density of humans in that area, and if there was nesting there it is likely it would have been observed and reported.

The study area was divided into delineated areas called “sites”. The sites were not designated by this researcher, but rather by species managers over time. Since Piping Plovers were managed by different agencies throughout the state and there were multiple people that worked at each agency throughout the 20 years, there was no one definition of what constituted a site. In almost all cases, a site had only one landowner (although sites are infrequently grouped when they are so biologically similar that the birds are interacting and crossing boundary lines and that it makes more sense to identify them as one site). Unfortunately, the lack of standardization of what constitutes a site can make analysis difficult. One result of this unsystematic method is that the size of a site can vary considerably. For example, Holgate (at ~ 4 miles long) was considered one site by its landowner. One the other hand, Sandy Hook (at ~ 7 miles long) was divided into 8 sites by its landowner. This could be problematic for comparisons but their boundaries did remain relatively stable through the 20 years. Each year, the exact site boundary could contract and expand as pairs occupied the space differently, but none of the site boundaries ever overlapped, nor were pairs ever assigned to different sites when occupying the same area year to year. Additionally, in almost every case each site was treated by species managers (which included biologists from federal, state and non profit organizations) for 20 years as an independent unit that had its own management regulations. For example, although Holgate was considered one site and much larger than the smaller Sandy Hook contingents, the entirety of Holgate was managed the same way while each of Sandy Hook's sites were managed slightly differently.

In New Jersey, there were 52 separate sites, with roughly half occupied in any given year (Fig. 3). The sites were managed by various federal, state and non-profit agencies. The US Park Service managed Gateway National Recreation Area – Sandy Hook Unit sites (Coast Guard, North Beach, North Gunnison, South Gunnison, Critical Zone, Hidden Beach, Fee Beach and South Fee Beach). The US Fish and Wildlife Service managed the

Forsythe and Cape May National Wildlife Refuges (Holgate, Little Beach and 2-Mile Beach). The US Coast Guard jointly managed the TRACEN site with ENSP. The Nature Conservancy jointly managed the Cape May Meadows site with the ENSP. ENSP monitored and managed all other sites (roughly half of the active sites each year) which were located on federal, state, county and municipal beaches. Since ENSP was not a landowner per se, they worked with each property owner to ensure the needs of the nesting birds were met. ENSP was also the lead partner among these agencies which meant they were responsible for collecting and collating all the data at the end of the season and submitting it to the Atlantic Coast recovery team leader. They also took the lead in major decisions made on a state-wide level and as a co-lead with USFWS in law enforcement actions.

Methods

This analysis was conducted with data that was collected from 20 years of field work by many people representing different agencies. All the data collected by the cooperating agencies (US Park Service – Gateway National Recreation Area, Sandy Hook Unit, US Fish and Wildlife Service- Forsythe and Cape May National Wildlife Refuges and The Nature Conservancy) was combined with data collected by the NJ Division of Fish and Wildlife Endangered and Nongame Species Program (ENSP), who, in addition to field duties are responsible for the organization and quality control of the data on a state-wide level. This data took four main forms – an Access database of nest fates from 1990-2007, paper datasheets from 1987-2007, polygon shapefiles that graphically represented the all nesting sites, by year, from 1987-2007 (this file was created as part of this thesis work), a point shapefile that represented all known nesting attempts from 2003-2007 and limited nesting attempts from 1995-2002. The nesting polygon files had the advantage of being comprehensive of all the years from 1987-2007. The nesting point shapefiles, while not representing as many years, had the advantage of specific spatial information for each nest and not just the nesting site as a whole. The combinations of these files were used to examine the variables investigated in this chapter.

The variables selected for analysis were partially selected by a process of elimination. Variables that were not easily measured or delineated in any discrete fashion were not considered. For example, comparing nesting on "natural" versus "unnatural" sites would appear to be a useful test. But many of the beaches in NJ have received nourishments at some point and all the sites are managed so differently that it would be an impossible task to realistically assign each to one category. Another variable that has been tested, with varying levels of success, is human disturbance (Flemming, Chiasson, Smith, Austin-Smith & Bancroft, 1988, Ortiz, 2001). Quantifying human disturbance, in terms of direct impact on nesting birds, is an incredibly difficult task and one that is not well suited to this type of analysis. However, human related impacts must be considered since their presence in coastal habitats is omnipresent. With that mind, I selected distance of nesting pair to nearest inlet and pair use pre and post beach replenishment. Their common thread of being directly related to human activities (the stabilization of inlets and the placing of sand on beaches) but easy to define and test made them ideal for accomplishing the goals of this analysis. Each is described below.

Distance to Inlet

A cursory examination of the nesting polygons that I created revealed an apparent clustering around this landscape feature. There are 13 inlets in the state (including the bays at either end, which function as inlets for all intents and purposes). The inlets that existed during this study were, from north to south, Sandy Hook Bay, Shark River Inlet, Manasquan Inlet, Barnegat Inlet, Little Egg Inlet, Brigantine Inlet, Absecon Inlet, Great Egg Inlet, Corson's Inlet, Townsend's Inlet, Hereford Inlet, Cape May Inlet and Delaware Bay.

The inlet systems were divided into two categories - shored and unshored. Shored inlets were those that had jetties (to stabilize the inlet and prevent any natural movement, as well as for boater safety/shipping ease) while unshored inlets had no jetties or other stabilizing features (such as sea walls) and the sand was free to move and shift naturally. Some of the inlets in New Jersey were stabilized on just one side and since the two sides functioned differently I split each inlet into north and south units and independently analyzed pair use on each side. Terminal jetties at a site did not make it eligible for inclusion as a shored inlet – the stabilization had to include shoring on the perimeter of the inlet, not on the beach that the inlet was adjacent to. Table 2 summarizes the status of each inlet in the state.

I created two shapefiles which represented every known nesting pair in New Jersey from 1987-2007. The first shapefile contained a record for every nesting attempt (note that this is slightly different than nesting pair since pairs can have multiple nests) from 2003-2007 and nesting attempts when data was available from 1995-2002. This was a point file where each point represented a nesting attempt that was recorded on a GPS unit. The second shapefile contained a record for all nesting pairs from 1987-1994 and the remainder of the pairs from 1995-2002. Specific nesting attempt point data was not available for these pairs since biologists were not collecting data with GPS units during those time periods. Instead, each of these pairs was represented by a polygon from the nesting site shapefile that was created in Chapter One. Between these two shapefiles, every known nesting pair was represented by either a point or polygon. Using ArcMap 9.2 I then created poly lines that represented the north and south boundaries of each inlet. I used the near distance tool in Arc Map 9.2 to measure the distance from the nesting attempt or pair (represented by the point or the centroid of the polygon) to the closest inlet (represented by the poly line), which provided a distance, in miles, for each record.

The next step was to convert each nesting attempt in the point file into a representation of each nesting pair. This was to equalize the data, since some pairs had one nesting attempt per season and others had up to four and I did not want some pairs to carry more weight than others. Each nesting attempt was assigned a nest fate of either hatch (at least one egg hatched), failed (through flooding, predation, abandonment or undetermined cause) or unknown (nest disappeared close enough to the hatch date that it may have hatched or been failed). If the pair had only hatched, failed or unknown fates, the assignment of fate was straightforward. When a pair had mixed nest fates, I assigned a hierarchy to the data – if at least one nesting attempt hatched, the pair’s overall nest fate was hatch (even if other attempts were failed or had an unknown fate). If the nesting attempts included only failed and unknown fates, I assigned it as failed since that designation was less nebulous. This step was also completed for the polygon file, although it was done during the creation of each record, since the polygon file represented pairs from its conception. Since each pair in the point file often had multiple nesting attempts, there were also multiple distances to the nearest inlet generated. At the same time that I condensed nest fates into one fate, I also condensed the multiple distances into one figure by averaging the distances.

I next created an Excel spreadsheet that combined all the data for all the years and added the number of fledges each pair produced as well number of pairs, fledges and fledge rate for each site. Some data was discarded at this point. There were some pairs, especially in the early years that were not monitored regularly enough to determine the nest fate of attempts of a pair. This was true of all nesting attempts at Little Beach in 1987- 1990 and at a few locations (Longport Sodbanks, Strathmere, North Wildwood - Oceanfront and Cape May) in 1988. There was enough data for a site pair and fledge count, but not enough to assign which pairs were responsible for which attempts and fledges so this data was eliminated. These eliminations consisted of less than 2% of the total data used for this analysis and therefore would not have significantly changed the outcome if they had been included.

Since these data were intended for use by managers, miles were the measurement most easily transferable to their needs and the way the information was originally calculated. These numbers were then converted to kilometers for purposes of reporting this research.

I took the distance to nearest inlet data from this table and created 1.6 kilometer increment categories (0-1.6 km, 1.7-3.2 km… 9 -16 km). Since so many pairs were located within one kilometer of an inlet, I also broke the 0.0-1.6 kilometer increments into tenth of kilometer categories (0-.16 km , .17-.32 …. ..1.45-1.6 km). I then split the data into shored and unshored inlets and looked at the number of pairs near each and also split each into the distance categories.

Finally, I looked at nest fate and fledge rate at shored versus unshored inlets and tested whether there were differences between the two categories. Since individuals were not banded on a long term or large scale basis during the study period, there was no way to account for multiple measurements on the same pairs. However, the majority of Piping Plovers probably do not live longer than 5 years (maximum recorded was 11 yrs) and many do not nest in their first year post fledge (Wilcox, 1959). Therefore, the twenty year survey period might have captured portions of or the entirety of at least 6 generations, assuaging some of the implications for multiple measurements on the same individuals since it is likely there was a lot of turnover from 1987-2007.

Beach Replenishment

The second variable in this analysis was beach replenishment (hereafter called fill where necessary in this paper). This seemed an obvious choice for a few reasons. The first was that fills have taken place in New Jersey for many decades and have become an established method of stabilizing and managing areas for shore protection and recreation to the point that they have become a defining factor of physical conditions of many beaches in the state. Beach replenishments have discrete boundaries of where they start and end. This allowed me to compare the use of the site by plovers before and after a fill to see what, if any, impact the replenishment had. For the purpose of this analysis, I looked at beach replenishments that have taken place in New Jersey from 1984-present. Since many replenished sites are on a 2-5 year cycle (due to erosion and shifting sand that generally makes a fill's impact negligible after this time), I looked at plover site use up to 3 years post-fill, thus making 1984 the first year information was required.

Since the ENSP does not maintain records on the specifics of beach replenishments, information was used from the US Army Corps of Engineers (USACE), the NJ Bureau of Coastal Engineering and municipal contacts to create a list of all the known fills from 1984 to the present, which proved difficult because the fills are sponsored by different agencies. In addition, New Jersey is split between two USACE districts (New York and Philadelphia), which complicated matters further. The many agencies involved in the fills meant that there was no central agency in charge of the fills or one database that tracked all such information.

Of the 100 fills that took place during the aforementioned years, I was able to procure enough information on 68 of them to make valuable determinations of site use pre and post fill. For each fill, I determined if the site was active before the fill took place, which generated two groups. From there, I looked at whether the site stayed the same (active or not active), changed status (from active to not active or not active to active) and at the site use by the Piping Plovers (quantified by the number of pairs at the site pre- and post-fill).

I next compared sites that were filled with control sites (where there was no fill in the time period 1983-2007) and looked at site use by nesting pairs three years prior to the fill and three years after to test whether fills were affecting pair numbers at those sites any more than would be expected by chance. To accomplish this, I took the mean of the three years post-fill and subtracted the mean of the three years pre-fill for each of the filled and control sites. I then ran a Mann-Whitney Rank Sum Test to compare these values. Using the same method described above, I also compared the change in fledge rate pre and post fills at control and filled sites, which I tested with a t-test. I also used a chi square test to determine if there was a significant difference in the frequency of increases, decreases or pair numbers remaining the same between fill and control sites.

Results

Distance to Inlet

The majority (62%) of all Piping Plover pairs were located within 1.6 km of an inlet (Fig. 4). The difference between <1.6 km and all other categories was so great that this category was further subdivided into one tenth divisions to determine if the pattern of a higher number of pairs nesting closer to inlets continued, and to a less dramatic degree, it did (Fig. 5). I next divided the data into those pairs that were closer to shored versus unshored inlets. Again, the pattern of being < 1.6 km from an inlet held for both categories (Fig. 6). Splitting the data into these two categories also showed that the majority of the pairs were located closer to unshored inlets. 70.6% of all known pairs were located closer to an unshored inlet, while 29.4% were located closer to a shored inlet. A similar trend was observed for the number of fledges, with 74.16% of fledges produced from 1987-2007 located on sites closer to unshored inlets versus 25.84% located at sites closer to shored inlets. A Mann-Whitney Rank Sum t-test revealed no significant difference (P = 0.121) between the distance to inlets between pairs who nested near shored inlets versus those who nested near unshored inlets (Table 3). Therefore more pairs were located near unshored inlets but the preference for nesting as close as possible to inlets held for both categories.

Nest fate and reproductive success did not differ whether pairs nested near a shored or unshored inlet. In fact, it was remarkable how similar the rates were for each category. Since Piping Plovers are a short lived species, the population trends are tightly correlated with reproductive success. Reproductive success can be observed through both hatch rate and fledge rate. Despite a higher number of pairs being attracted to unshored inlets (and therefore a higher number of young fledged from theses areas), these birds did not have higher hatch or fledge rates. The hatch rate for pairs located closer to unshored inlets was 62.86% and 63.99% at shored inlets. The failed and unknown rates for pairs near unshored and shored inlets were 33.20% and 28.67% and 3.94% and 7.34%, respectively. A chi square test confirmed that the only significant difference was between the unknown categories, but when those were grouped with the failed category (it is highly suspected that many of these are failed nests but without enough evidence to confirm this fate they are classified unknown) that difference disappeared (P=.001 and P=.660, Tables 4 & 5). The fledge rate was 0.95 fledges/pair at unshored areas and 0.90 fledges/pair at shored areas, which a Mann Whitney Rank Sum test confirmed was also not a significant difference (P=0.505, Table 6).

Since so many of the pairs were located closer to inlets than further, I also tested whether the nest fate and fledge rate were different at those nests located within 1.6 km from an inlet versus those located greater than 1.6 km from an inlet. The hatch rate for nests located within 1.6 km was 62.9% and 63.4% for those located greater than 1.6 km. The failed and unknown rates at less than and greater than 1.6 km from an inlet were 32.1% and 32.1%, and 4.8% and 4.4% respectively. A chi square test showed no significant difference (P=.849, Table 7). The fledge rate for pairs located within 1.6 km of an inlet was 0.93 fledges/pair and 0.95 fledges/pair for those further than 1.6 km. A Mann Whitney Rank Sum test showed no significant difference (P=0.915) and both of these figures were well below the indicators of a stable (1.245 fledges/pair) or increasing (1.5 fledges/pair) population (Table 8).

Beach Replenishment

The analysis of beach replenishment data provided interesting results (Fig. 7). Of the 68 beach replenishments that took place in New Jersey from 1984 -2007 (that had specific enough location information to be included), 37 had no prior nesting activity while 31 were at sites with at least some Piping Plover nesting history. Of the previously non-active sites, 34 (92%) remained inactive post fill while 3 (8%) sites became active nesting sites. Of the previously active sites, 29 (94%) remained active post-fill, while 2 (6%)

became inactive post-fill. Of the sites that remained active post fill, 15 (52%) posted increases in pair numbers post fill.

In the 3 sites that were not active that became active (Table 9), beach replenishment operations probably played a role in attracting birds by providing new habitat. In 1993, there was a fill in Ocean City from 15th to 36th Streets. Prior to this fill, there was no known nesting (at least back to 1987) at this site. The fill appeared to "jumpstart" nesting at this site the following year and it peaked with a pair total of 9 in 2001 and remained active all the way through 2007. In 1995 and 1996 Monmouth Beach and Sea Bright were filled, respectively. There had been no nesting at either site prior to the fill (since 1987), but in both cases nesting occurred shortly after the fills and both sites continued to be active through 2007.

There were only 2 fills where the site was active prior to the fill, but inactive after. Both fills took place at Avalon – North. This site was experiencing extreme erosion so severe that the fills did not last long enough to maintain the nesting habitat. The site likely would have become inactive whether or not the fills took place.

Of the sites that were active pre and post fill, just over half gained pairs post fill. Although some of the sites showed modest increases (such as Ocean City – North which gained a pair after the 1995 fill or Strathmere, which gained 1 pair after the 2001 fill) many of the other examples were striking. Examples include Avalon – North which had 1 pair in 1991 pre-fill and increased to 5 by 1993 or Cape May Meadows which had 2 pairs in 1992 and increased to 12 pairs by 1995. Although these appear to be results of the beach replenishments, the only way of statistically testing the impact was to compare the filled sites with control sites over the same time period. A t-test and chi square showed that there was not a significant difference between these two categories, suggesting that beach replenishments do not statistically attract Piping Plovers to or deter them from filled sites (t-test P=0.782, chi square P=0.561, Tables 10 & 11). Furthermore, a t-test comparing fledge rates pre and post fill at control and fill sites also revealed no statistical difference (P=0.528, Table 12).

Finally, it should be noted that occasionally a fill can have an effect on a site that was not the one where the sand was placed. This situation is obviously much harder to quantify, but in some cases it was apparent that sand shifted to another site and that it created habitat. For example, there was a fill that took place in Stone Harbor in 2003 between 80^{th} and 123^{rd} streets. There was never any recorded nesting in this location (at least since 1987) and the fill did not change that. However, as it eroded, the sand was deposited southward at Stone Harbor Point, which is the area directly adjacent to 123^{rd} Street. From 1987-1998 there had been no nesting, but historical records indicated that beach nesting birds, including Piping Plovers, were present through the last century, which incidentally is also located on an unshored inlet (Stone, 1965, Sutton, 2003) . In 1999, 3 pairs of Piping Plovers began nesting in the marginal habitat. As additional fills from Avalon and Stone Harbor was deposited at the Point, the site and its plover population grew dramatically, which increased to 17 pairs by 2007. Although there was no actual fill at this site, it is clear that the increase in available habitat that came from fills north of this site contributed to the increase in population, especially in light of how dire the reproductive success was (average of 0.29 chicks/pair 1999-2007).

Discussion

This research clearly indicates that Piping Plovers are nesting in specific patterns in New Jersey. They selected nesting sites located close to inlets, particularly those inlets that were not stabilized. Beach replenishments did not generally create or eliminate sites, but could lead to an increase in pairs at previously active sites. These findings have management implications (which are discussed below) to the recovery of Piping Plovers in New Jersey.

Distance to Inlet

Inlets played a crucial role in Piping Plovers nesting site selection and this was especially true for those that were unshored. This was a critical finding to understanding nesting site selection and ultimately the ability of Piping Plovers to recover in New Jersey. It suggests that Piping Plovers searching for optimal habitat in New Jersey may be limited by the number of unstabilized inlet areas available for nesting, which are available only at a small number of locations.

There are several possible reasons why Piping Plovers prefer to nest near inlets. The first hypothesis is that inlets provide the kind of dynamic environment that Piping Plovers naturally prefer. The only other habitat type in a coastal system that probably exceeds inlets in dynamism is an overwash, which occurs when a dune is breached. Overwashes however, are even less common along the NJ coast than unshored inlets and even more ephemeral in nature (they provide short-term habitat that is only available after a storm creates it and fill in with vegetation quickly). Since inlet beaches are subject to the effects of weather and the sea on more than one side (as opposed to the single orientation of the oceanfront beach) they are more likely to be shaped and reshaped as flooding events, storms, wind and waves hammer the multiple sides of the inlet beach. This rejuvenation of the beach is probably very attractive to the birds since it can reduce vegetation density and provide a fresh quality to the habitat. The "newness" factor of habitat is appealing to Piping Plovers. An example of this attraction to novel habitat can be seen in the work that is being done on the Missouri River in Nebraska by the US Army Corps of Engineers (USACE) and which is being studied by researchers from Virginia Polytechnic Institute and State University. The USACE has created sandbars in the middle of the river, which provide new habitat to the plovers. The sandbars are not vegetated and compete with the older, natural sandbars that plovers have previously utilized as nesting areas. The work there has shown that the plovers prefer the engineered sandbars at a higher rate than would be expected by chance and perhaps even to their detriment (the higher than average densities that the birds are nesting in are exacerbating predation issues and may also be leading to infanticide) (D. Catlin, personal communication, 8 November 2008). Other examples have been observed in New Jersey. As mentioned previously, Stone Harbor Point saw enormous growth, despite dismal reproductive success, over a period of time when the habitat was increasing. When the overwash was created at North

Brigantine Natural Area in the mid-1990's, birds nested at a higher density and with great reproductive output than is often the norm in NJ.

A second hypothesis is that inlets provide more surface area available for foraging than an oceanfront beach. For a precocial species like a Piping Plover one can imagine that proximity to quality foraging habitat (also known as MoSH, or moist substrate habitat/moist sparse habitat) is a central component to nesting site selection (Cohen, 2005). Since the adults do not feed the young, they must locate the areas where MoSH opportunities are highest. Inlet beaches provide a greater chance that the young will encounter foraging opportunities than oceanfront beaches do. It might also be hypothesized that since the adults share incubation and defense duties, adults might want to situate their nests close to MoSH habitat so that the non-attending adult is never too far from the nest if there is a need to return and defend the nest. In fact, previous research confirms some of this hypothesis. One study showed that the fledge rate for chicks foraging on an inlet beach was 69% versus 19% on oceanfront beaches (Patterson, Fraser & Roggenbuck, 1991). Another showed that chicks with access to salt-pond mudflats experienced higher fledge success (Regosin, 1998). A third study showed that all segments within 1 km of ephemeral pools or tidal bay flats were used for nesting, while <50% of beach segments without these features were used (Elias, Fraser & Buckley, 2000). Finally, Fraser, Keane & Buckley showed that plovers nest near MoSH, even if they cannot access it easily (2005). With washover events a fairly common occurrence in inlet systems, it is not hard to imagine the foraging habitat being invigorated by these regular overwash events and the plovers being attracted to that feature.

In New Jersey, there were 13 inlets systems that were within the area that was suitable, usable habitat for Piping Plovers, but only 5 remained unshored and natural on both sides (and that number is likely to decline very soon). The remainder have a jetty (or some other stabilizing element) on one or both sides. Inlets by nature are somewhat ephemeral in that they open and close as sand shifts and moves along the coast. This characteristic is not compatible with the human wants and needs of a stable environment on which to live and operate. Humans prefer inlets to be stable for boater safety, to keep channels open and to stop or slow down the shifting of the barrier islands that people live and work on. The first jetties were installed in New Jersey early last century in an effort to stabilize inlets (Salvini, 1995). Over time, efforts became more sophisticated and permanent so that jetties now consist of large granite stones packed together to prevent movement (http://intraweb.stockton.edu/eyos/page.cfm?siteID=149&pageID=4).

Unfortunately, jetties also prevent the natural washovers of a site and reduce the amount of MoSH available to plovers for foraging. There are fewer mud flat areas and overwash areas at these shored inlet beaches than in unshored inlet beaches. It is unlikely that these sites will ever return to their unshored versions since that would involve the removal of the jetties, a highly improbable scenario. The focus from here forward should be to reduce the chance that any additional shoring will occur at unshored inlet areas and to increase restoration efforts that mimic the conditions of these areas to compensate for the loss of habitat. Due to their large size, Sandy Hook and Delaware Bay are not likely to be candidates, nor are the inlets associated with the federal refuges and some state natural areas (where there are no nearby human structures). One or both sides of Great Egg Inlet, Corson's Inlet, Townsend's Inlet and Hereford Inlet are the ones that are susceptible to additional shoring.

Of special concern is Corson's Inlet, which was unshored on both sides. Over the last few years, and especially in 2008, the beginning of an effort to shore up the southern side of this inlet has begun. Severe erosion has eliminated most of the beach at that site (estimated to be approximately 90 acres), so it is an uncomfortable situation for the homeowner's in the area. The beach itself is a state natural area, but the houses bordering it are in danger of being compromised. Setting aside the question of whether is makes economical sense to try and stabilize one of the most unstable configurations found in nature, this research has shown that stabilizing an inlet will greatly reduce the probability that Piping Plovers (and most likely other beach nesting birds) will select this habitat for future use. Inlet systems accrete and erode over time and although this area is presently greatly reduced it is likely that it would accrete over time and a new beach would be formed. The current efforts (piling large rocks and steel walls around the homes) appear to be beginning of an endeavor to permanently shore this side of the inlet. If this is the case, and it likely is, it should be done with the realization that it will permanently alter the ability of the site to function in a natural state and that there will be consequences for Piping Plovers and other species that utilize this habitat.

There were no differences in nest fate between shored and unshored inlet systems. There was a slight difference in fledge rate among the categories, but not to the degree that it was affecting recovery – in all categories, reproductive success was far below target levels. This suggests that although unshored systems attracted a larger population of Piping Plovers to their sites, they were not better at hatching or fledging birds, which are ultimately the metrics used to measure success in this population. These data suggested the need to concentrate management efforts at increasing reproductive success at sites adjacent to unshored systems since this is where this is where the majority of the birds were located within the state.

Beach Replenishments

Although the dataset was not complete due to a lack of location data for some of the fills, the majority of the beach replenishments that have taken place between 1984-2007 revealed strong patterns. In general, beach replenishments did not affect nesting site use by Piping Plovers in a negative or positive way. If the site was not active prior to the fill, it was most likely to continue in that vein post fill and vice versa. Beach replenishments also did not statistically differ in the pattern of increasing or decreasing pair use or fledge rates among filled sites when compared with control sites. For the small number of examples where beach replenishments occurred between years of a site being active and then becoming inactive, it would be difficult to identify the fill as the reason for this change. A more likely explanation was that severe erosion right after the fill resulted in no suitable habitat for plovers to use.

The most interesting findings were the sites that were inactive prior to the fill that became active afterwards. Due to the lack of habitat prior to the fill and then the fresh habitat created (with little vegetation cover) post-fill, it is a safe assumption that the creation of suitable habitat played a role in attracting birds to the site. However, that alone does not explain the sites becoming active, since there were sites that were not active pre- and post- fill that also might have had an increase in suitable habitat post-fill. I postulate that a site changes from inactive to active post fill in two circumstances: 1) if the site had some previous history of nesting prior to the fill (for example, Sea Isle City - South) or 2) if it was adjacent to an area that could serve as a source population (for example the fills at Sea Bright and Monmouth Beaches possibly being populated by Sandy Hook birds). Since it can easily be determined whether either of these scenarios is in play before a fill takes place, they should be taken into consideration when contemplating potential impacts of a beach fill on site selection by Piping Plovers. If an area is likely to attract birds after a fill, then managers should take steps to be adequately prepared for their arrival – including the completion of a beach management plan prior to the fill.

Since beach replenishments are currently the primary measure taken to reduce the impact of coastal erosion (though this may not continue indefinitely due to the temporary nature and high cost of each fill), it is valuable to know that they do not generally change the status of a site in terms of its status as active or inactive. This should assuage some fears that beach replenishments are attracting birds to sites that may become population sinks (because fills often take place in highly developed, recreational areas where Piping Plovers have not historically fared well). In some cases, they can create suitable habitat that the plovers will exploit and in those situations actions should be taken to promote the success of the birds at a site.

Management Implications and Conclusions

Piping Plovers may have become victims of their own adaptiveness. For thousands of years they have survived as a species by capitalizing on their unique ability to not only endure, but thrive, in an environment that is constantly changing. The coastal beach ecosystem is a harsh setting whose inhabitants must be able to cope with salt, sand, water and much less cover (in terms of vegetation and other protective features) than their inland counterparts. Due to these conditions, biodiversity on a beach is much lower than can be found in more forgiving environments elsewhere. However, the species who endure in coastal systems are exquisitely adapted to the conditions they encounter on a daily basis.

For these species, they have not only adapted to a naturally changing environment but have come to rely on that change to successfully navigate their way through the landscape. Unfortunately, the advent of human development in coastal regions brought a revolution the likes of which had never occurred in this system. Stabilization was thrust upon it and its effect has had far reaching consequences for the species that had spent so much time honing their abilities to take advantage of, and eventually depend on, the dynamism that is so intrinsic to the system.

In their natural state, beaches are constantly shifting and being reshaped over time. Entire islands migrate westward, inlets open and close, dunes develop and are later blown out. The massive power source that is the ocean, coupled with the force of winds and tides, ensure that no area in a coastal system is likely to remain static for very long (Kaufman & Pilkey, 1983). The impact of global climate change and the subsequent increased sea-level rise will only intensify its dynamic quality. But for humans, there is no greater threat to their environment than change. Despite the positive impacts that (what humans define as) catastrophic events can have (hurricanes revitalize habitat, wildfires allow a forest to grow and remain healthy) humans stubbornly refuse to accept that these events are a part of the natural cycle and work tirelessly to prevent systems from functioning in healthy, natural ways. In systems across the globe, humans have sought prophylactic solutions to avoid the change that they perceive as a danger to their way of life.

One of the greatest examples of this is found within coastal systems, which are more prone to change than many other ecosystems. Once humans began to live and work in coastal environments (rather than just use them seasonally), stability became a central goal. There have been many attempts to reach this goal and those attempts have taken many forms. People have filled low lying areas, built jetties and groins, placed sand in eroding areas and built miles of dune fence. But every storm demonstrates that our attempts will never be permanent. However, these storms have a peculiar effect - instead of proving that our attempts are futile, they instead harden our resolve that we will eventually be successful in our endeavors.

This propensity for stability has serious implications for Piping Plovers. This research has shown that nesting site selection by Piping Plovers is primarily driven by access to natural, changing beach environments. These are quite often adjacent to inlet systems, which are unfortunately one of the most highly targeted areas for stabilization. Many of the inlet systems in New Jersey have already been stabilized. The result of these efforts (in this case, through the construction of jetties on the north and/or south sides of an inlet) appears to have had negative consequences for the inlet's ability to attract Piping Plovers to the beaches near it. Although the stabilized inlets still attracted Piping Plovers to their beaches, it was at a rate of almost 1:3 when compared to unshored inlet systems. The jetties no longer allow the water and sand to interact as they once did – no washovers, no severe erosion or accretion, no opening or closing of the inlet itself – which is precisely what they were meant to accomplish. The irony is that they will never be successful in the long term –in fact, jetties exacerbate erosion- and yet in the short term they are incredibly efficient in disturbing the natural patterns of the system – often to the detriment of its inhabitants (Pilkey, 1998, Brown, 2002).

The analysis of nest fate and fledge rate around different types of inlets reinforced the conclusions found in the first chapter of this thesis. In short, the location of a nest made no significant difference to its nest fate or fledge rate. In other words, a preference for one type of site over another did not translate into higher reproductive success. This supposition reinforces the conclusion that as many measures as are realistically possible should be taken to improve fecundity in this species.

In addition to jetties, beach replenishments have become one of the most widely utilized tools in the stabilization tool box. The results of this research are encouraging in that, at least for the cases studied here, they generally do not change affect the status of a nesting site in a negative way. In the cases where status changed from active to not active, it did not appear that it was beach replenishments that made the difference. Promisingly, in the cases that the status went from inactive to active, the habitat that beach replenishments provided apparently resulted in an attraction of birds to the site. Since beach replenishments are likely to continue until a new solution to erosion is developed, it is useful to know that they are not affecting Piping Plover nest selection in either a highly positive or negative way.

It appears that Piping Plovers are maladapted to the human-disturbed coastal environment commonly found in New Jersey. The amount of habitat that they find attractive is dwindling on a yearly basis. Although much of the development that could occur already has, there are still vulnerable areas (such as Corson's Inlet) that must be protected to the highest degree possible. It may already be too late for Piping Plovers in New Jersey. We may never reach our population goals or see long-term population growth simply because there is not enough suitable habitat available for this species. It is virtually impossible to imagine a scenario where inlet stabilization efforts will be reversed, or that future stabilization efforts will be eliminated. So where does that leave the future of Piping Plovers in New Jersey?

For one, projects whose goal is to restore or improve existing habitat conditions should be aggressively pursued. An excellent example of this is the Cape May Meadows restoration project that was completed in conjunction with a beach replenishment in 2005. This was a near perfect execution of the type of projects that should be pursued.

The site is located near an inlet and is a core site, with a long history of site use by plovers. The restoration project sought not only to attract birds to the site but to increase reproductive success among them, clearly the Achilles heel for New Jersey plovers, and both goals have been met. The foraging ponds have been an undisputed success, and the commitment to maintaining this habitat has been paramount to its triumphant execution. This is a shining example of the type of restoration project that must be undertaken if we are to have any chance at recovery in this state. Other sites that would be excellent candidates for large scale restoration efforts are Barnegat Light and Cape May NWR. They both have a history of birds nesting at their sites and could see an increase in pair numbers with the right conditions.

However, that is only part of the solution. Nest fate does not vary throughout the state and fledge rates are low in virtually all locations over time. Low hatch and fledge rates may have been sustainable if there was an abundance of suitable habitat available. But in its absence, the rates are alarming and do not bode well for the long term viability and growth of this population. In addition to creating more habitat opportunities, we must ensure that the birds that are attracted to these sites are not being drawn into population sinks. Therefore, we must enact stronger measures in terms of predator control, reduction of ORV and beach rake use to ensure that all efforts are made to improve reproductive success for this population.

Finally, information must be disseminated to other regions of the Piping Plover range, especially in coastal areas that are comparable to New Jersey’s habitat. New Jersey is unique on the east coast in that it was one of the first states whose barrier islands were developed for recreational purposes. Cape May holds the distinction of being the nation's "oldest seaside resort" and many of our barrier islands were developed before the federal government could purchase the land, which was the case in other regions of the Atlantic coast. Since this state's coast was developed early, its lessons can serve as a harbinger to the rest of the coast about what can happen to the suitability of habitat for Piping Plovers when inlet areas are stabilized or otherwise artificially maintained.

Piping Plovers may never recover in New Jersey and we may only ever maintain a stable population. However, by proceeding in a thoughtful and careful manner, we may be able to mitigate some of the damage that has been done to their habitat and create new opportunities for nesting and high reproductive rates in this state.

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Table 1. Atlantic Coast Piping Plover population: 1986-2007.

Estimated abundance of breeding pairs of Atlantic Coast piping plovers, 1986 – 2007

PARENTHESES DENOTE PRELIMINARY ESTIMATES

State/RECOVERY UNIT	Pairs																					
	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Maine	15	12	20	16	17	18	24	32	35	40	60	47	60	56	50	55	65	61	55	49	40	35
New Hampshire												5	5	6	6	7	7	7	4	3	3	3
Massachusetts	139	126	134	137	140	160	213	289	352	441	454	483	495	501	496	495	538	511	(490)	(475)	482	(550)
Rhode Island	10	17	19	19	28	26	20	31	32	40	50	51	46	39	49	52	58	71	70	69	72	73
Connecticut	20	24	27	34	43	36	40	24	30	31	26	26	21	22	22	32	31	37	40	34	37	36
NEW ENGLAND	184	179	200	206	228	240	297	376	449	552	590	612	627	624	623	641	699	687	(659)	(630)	634	(697)
New York	106	135	172	191	197	191	187	193	209	249	256	256	245	243	289	309	369	386	384	374	422	(464)
New Jersey	102	93	105	128	126	126	134	127	124	132	127	115	93	107	112	122	138	144	135	111	116	129
NY-NJ	208	228	277	319	323	317	321	320	333	381	383	371	338	350	401	431	507	530	519	485	538	(593)
Delaware	8	7	3	3	6	5	2	2	4	5	6	4	6	4	3	6	6	6	7	8	9	9
Maryland	17	23	25	20	14	17	24	19	32	44	61	60	56	58	60	60	60	59	66	63	64	64
Virginia	100	100	103	121	125	131	97	106	96	118	87	88	95	89	96	119	120	114	152	192	202	199
North Carolina	30	30	40	55	55	40	49	53	54	50	35	52	46	31	24	23	23	24	20	37	46	61
South Carolina	3		0		1	1		1			0					0						0
SOUTHERN	158	160	171	199	201	194	172	181	186	217	189	204	203	182	183	208	209	203	245	300	321	333
U.S. TOTAL	550	567	648	724	752	751	790	877	968	1150	1162	1187	1168	1156	1207	1280	1415	1420	(1423)	(1415)	1493	(1623)
ATLANTIC CANADA*	240	223	238	233	230	252	223	223	194	200	202	199	211	236	230	250	274	256	237	217	256	(266)
ATLANTIC COAST TOTAL*	790	790	886	957	982	1003	1013	1100	1162	1350	1364	1386	1379	1392	1437	1530	1689	1676	(1660)	(1632)	1749	(1889)

* Includes minor revisions to 1990-2002 Atlantic Canada estimates made by Canadian Wildlife Service in 2005.

Table 2. Stabilization status of northern and southern boundaries of New Jersey inlets.

Inlet	Unshored	Shored
Sandy Hook	South	
Shark River		North, South
Manasquan		North, South
Barnegat		North, South
Little Egg	North, South	
Brigantine	North, South	
Absecon		North, South
Great Egg	South	North
Corson's	North, South	
Townsend's	North	South
Hereford	North	South
Cape May		North, South
Delaware Bay	North	
Total	11	13

Table 3. Results of Mann-Whitney Rank Sum Test comparing average distance of nesting pairs to nearest inlet.

	n	T	P
Inlet Type			
Shored	572	746819.5	0.121
Unshored	1955		

Table 4. Results of chi square comparing nest fate at shored and unshored inlet areas.

	Inlet Category					
	Shored		**Unshored**			
	n	%	n	%	x^2	P
Nest Fate						
Hatched	366	64	1229	63	13.794	0.001
Failed	164	29	649	33		
Unknown	42	7	77	4		

Table 5. Results of chi square comparing nest fate at shored and unshored inlet areas.

	Inlet Category					
	Shored		**Unshored**			
	n	%	n	%	x^2	P
Nest Fate						
Hatched	366	64	1229	63	0	0.660
Dest/Unkn	206	36	726	37		

Table 6. Results of t-test comparing fledge rates at shored and unshored areas.

	n	Average Fledge Rate	T	P
Inlet Type				
Shored	572	0.90	712776	0.505
Unshored	1955	0.95		

Table 7. Results of chi square comparing nest fate of pairs located within 1.6km versus those located greater than 1.6 km from nearest inlet.

	Distance of Pair to Inlet					
	within 1.6 km		**greater than 1.6 km**			
	n	**%**	**n**	**%**	x^2	**P**
Nest Fate						
Hatched	999	63	605	64	0.328	0.849
Failed	506	32	307	32		
Unknown	77	5	42	4		

Table 8. Results of Mann-Whitney Rank Sum test comparing fledge rate of pairs nesting within 1.6km to those nesting greater than 1.6km from nearest inlet.

	n	Average Fledge Rate	T	P
Distance				
Within 1.6 km	1573	0.93	120779	0.915
Greater than 1.6 km	954	0.95		

Table 9. Beach replenishments in New Jersey with specific location information: 1984-2007.

Site	Fill Year	Site active pre-fill?	Year last active	Site active post-fill?	Year active post fill	If active, pair increase?
Asbury to Manasquan (South Reach)	1999	No	n/a	No	n/a	n/a
Atlantic City	1986	No	n/a	No	n/a	n/a
Atlantic City	1995	No	n/a	No	n/a	n/a
Atlantic City -- Illinois Ave. to Boston Ave.	1997	No	n/a	No	n/a	n/a
Belmar/Spring Lake	1994	No	n/a	No	n/a	n/a
Brigantine	2005	No	n/a	No	n/a	n/a
Cape May Point	2004	No	n/a	No	n/a	n/a
Harvey Cedars	1990	No	n/a	No	n/a	n/a
Harvey Cedars	1992	No	n/a	No	n/a	n/a
Harvey Cedars	1995	No	n/a	No	n/a	n/a
Keansburg	1985	No	n/a	No	n/a	n/a
Keansburg	1988	No	n/a	No	n/a	n/a
Keansburg	1995	No	n/a	No	n/a	n/a
Keansburg	1997	No	n/a	No	n/a	n/a
Keansburg	2000	No	n/a	No	n/a	n/a
Laurence Harbor	1993	No	n/a	No	n/a	n/a
Longport	1990	No	n/a	No	n/a	n/a
Middletown-Atlantic Highlands	1994	No	n/a	No	n/a	n/a
Middletown-Atlantic Highlands	1999	No	n/a	No	n/a	n/a
Middletown-Atlantic Highlands	2002	No	n/a	No	n/a	n/a
Ocean City	1995	No	n/a	No	n/a	n/a
Ocean City	1997	No	n/a	No	n/a	n/a
Ocean City	2000	No	n/a	No	n/a	n/a
Sandy Hook to Barnegat Inlet: Bradley Beach	2001	No	n/a	No	n/a	n/a
Sandy Hook to Barnegat Inlet: Bradley Beach	2001	No	n/a	No	n/a	n/a
Sandy Hook: Long Branch	1999	No	n/a	No	n/a	n/a
Shark River Inlet	2000	No	n/a	No	n/a	n/a
Spring Lake	2002	No	n/a	No	n/a	n/a
Spring Lake/Belmar	1994	No	n/a	No	n/a	n/a
Stone Harbor	2003	No	n/a	No	n/a	No
Cape May Point	2001	No	n/a	No	n/a	n/a
Monmouth	1995	No	n/a	Yes	1997	Y
Ocean City	1993	No	n/a	Yes	1994	Y
Sea Bright	1996	No	n/a	Yes	1998	Y
Avalon	2003	Yes	2001	No	n/a	n/a
Avalon	2005	Yes	1996	No	n/a	n/a
Ocean City	2004	Yes	2003	Yes	2004	N
Avalon	1987	Yes	1987	Yes	1988	N
Avalon	1993	Yes	1992/1993	Yes	1993/1994	N
Cape May Inlet to Lower Twp	1993	Yes	1992	Yes	1993	N
Cape May Inlet to Lower Twp	1993	Yes	1993	Yes	1994	N
Cape May Inlet to Lower Twp	1995	Yes	1994	Yes	1995	N
Cape May Inlet to Lower Twp	1999	Yes	1999	Yes	2000	N
Cape May Inlet to Lower Twp	2003	Yes	2002	Yes	2003	N
Cape May Inlet to Lower Twp	2004	Yes	2004	Yes	2005	N
Cape May Inlet to Lower Twp	2006	Yes	2005	Yes	2007	N
Cape May Point	1999	Yes	1998/99	Yes	1999/00	N
Wildwood	1991	Yes	1990	Yes	1992	N
Ocean City	2004	Yes	2004	Yes	2005	N
Wildwood	1991	Yes	1990	Yes	1992	N
Avalon	1992	Yes	1991/1992	Yes	1992/1993	Y
Avalon	1990	Yes	1988	Yes	1991	Y
Cape May Inlet to Lower Twp	1989	Yes	1989	Yes	1990	Y
Cape May Inlet to Lower Twp	1997	Yes	1996	Yes	1997	Y
Cape May Point	1992	Yes	1991	Yes	1992	Y
Cape May Point	1992	Yes	1991	Yes	1992	Y
Lower Cape May Meadows/CM Point	2004	Yes	2004	Yes	2005	Y
Ocean City	1992	Yes	1989	Yes	1993	Y
Ocean City	1994	Yes	1993	Yes	1995	Y
Ocean City	1995	Yes	1995	Yes	1996	Y
Ocean City	2000	Yes	2000	Yes	2001	Y
Sandy Hook	1998	Yes	1996	Yes	2001	Y
Sandy Hook: Monmouth - Sea Bright	2002	Yes	2001/02	Yes	2002/03	Y
Strathmere	2001	Yes	1996	Yes	2003	Y
Cape May Point	1986	Yes	1985	Yes	1987	Y

Table 10. Results of t- test comparing change in pairs at filled and control sites.

	n	t	P
Site Type			
Filled	30	-0.277	0.782
Control	30		

Table 11. Results of chi square test comparing changes in status of pairs at control and filled sites.

	Fill Type					
	Control		**Filled**			
	n	**%**	**n**	**%**	x^2	**P**
Mean Pair Status						
Same	1	3	0	0	1	0.561
Increase	17	57	19	63		
Decrease	12	40	11	37		

Table 12. Results of t-test comparing change in fledge rate at filled and control sites.

	n	t	P
Site Type			
Filled	30	0.635	0.5528
Control	30		

Figure 1. Piping Plover abundance and reproductive success in New Jersey: 1987-2007.

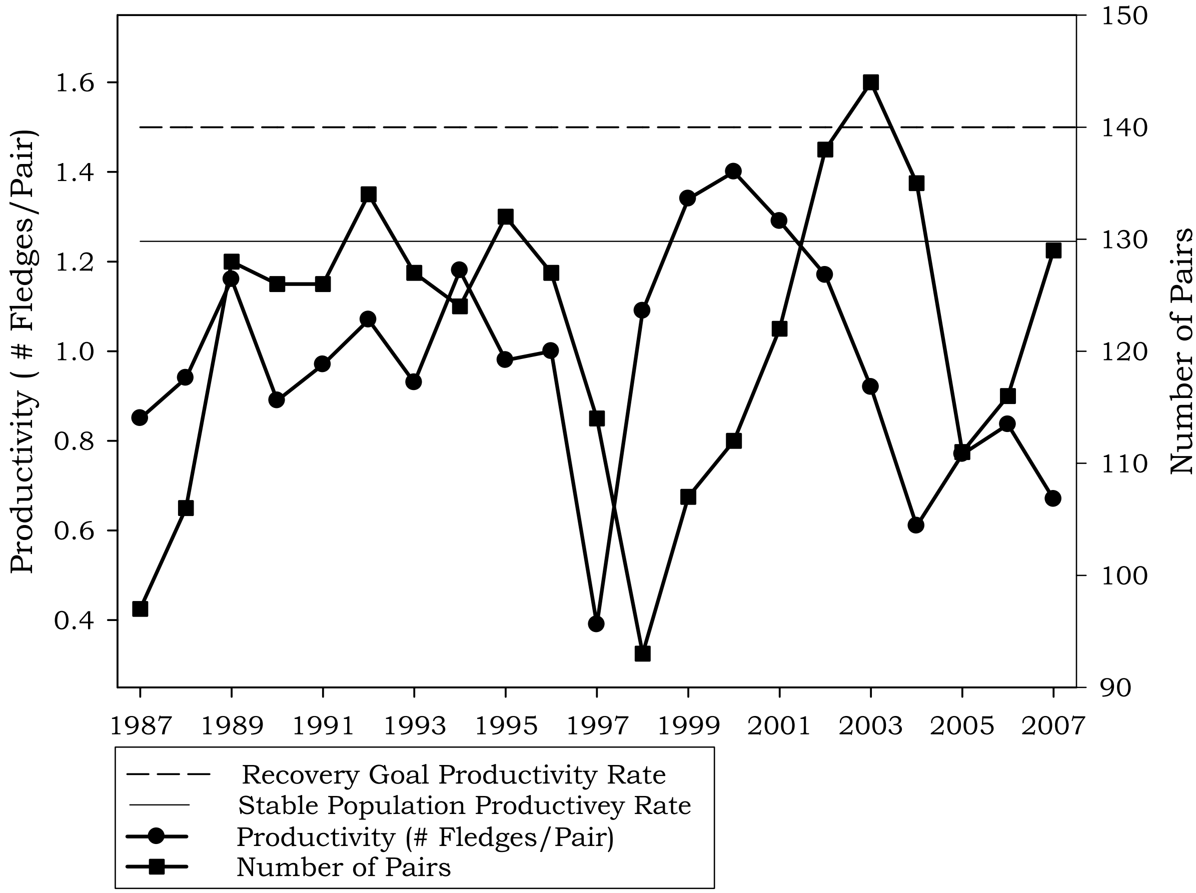

Figure 2. Study area (highlighted in red).

Figure 3. Active Piping Plover nesting sites in New Jersey: 1987-2007.

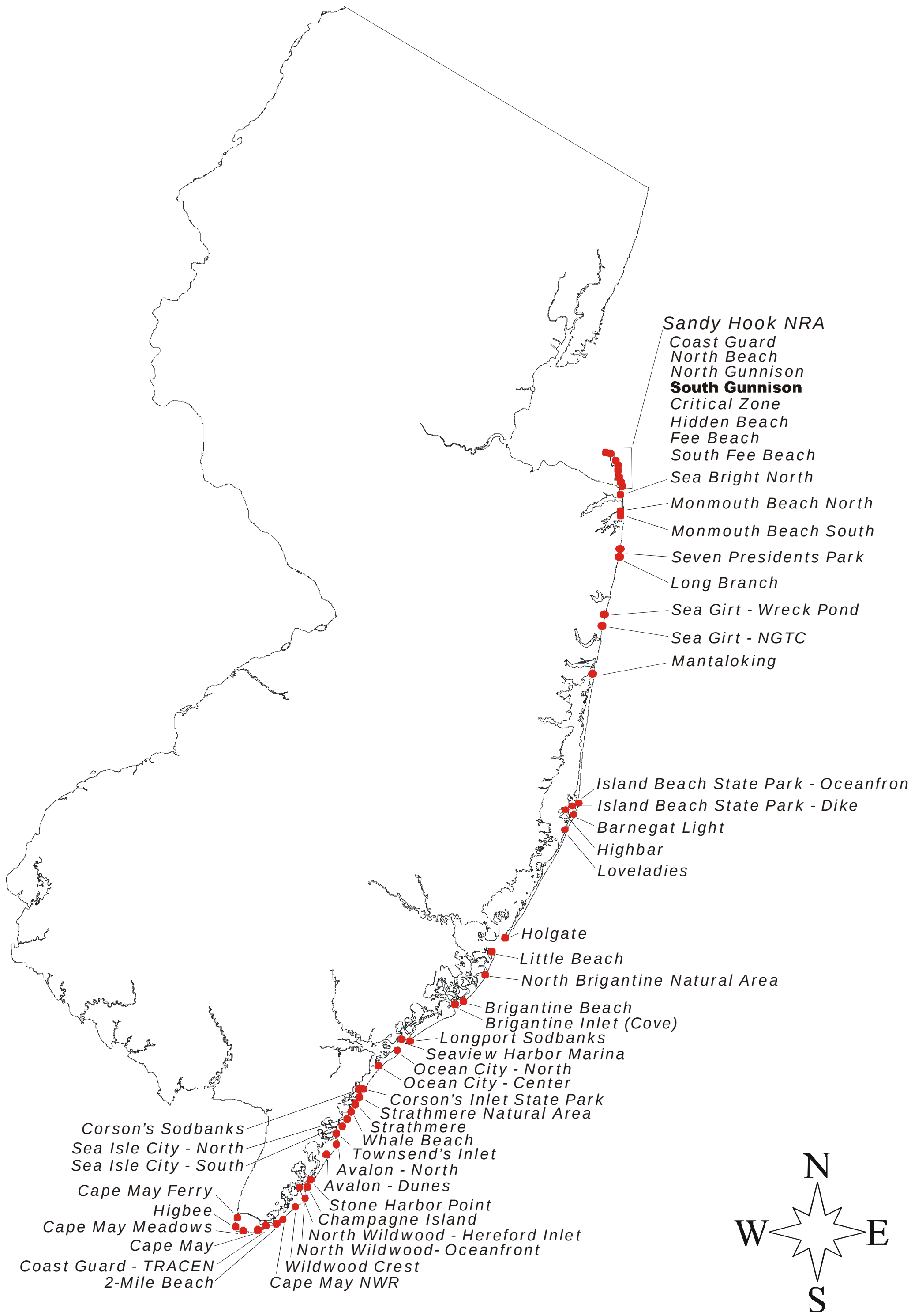

Figure 4. Distance of Piping Plover nesting pairs to nearest inlet: 1987-2007.

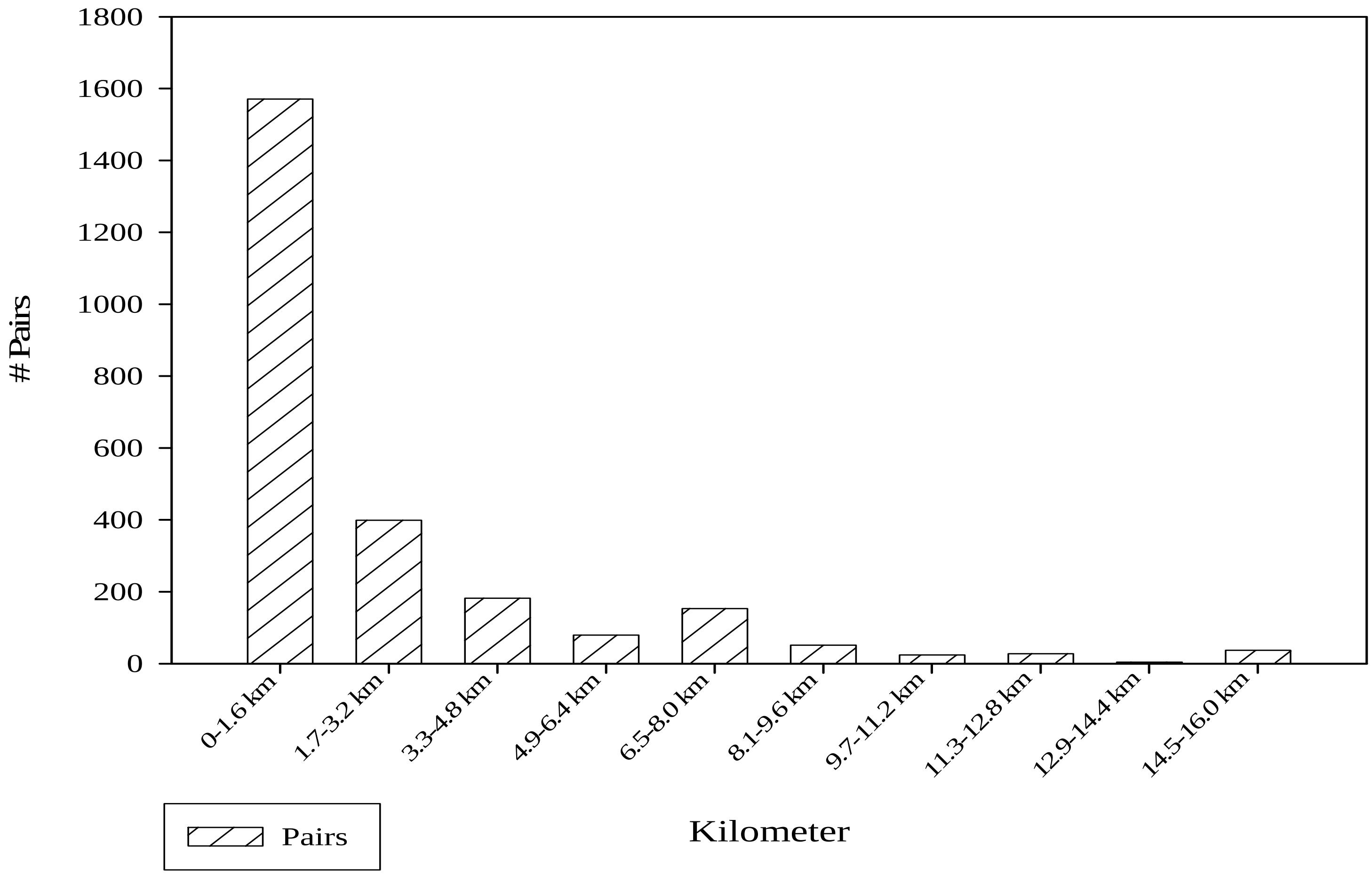

Figure 5. Distance of Piping Plover nesting pairs to nearest inlet within 1.6 km: 1987-2007.

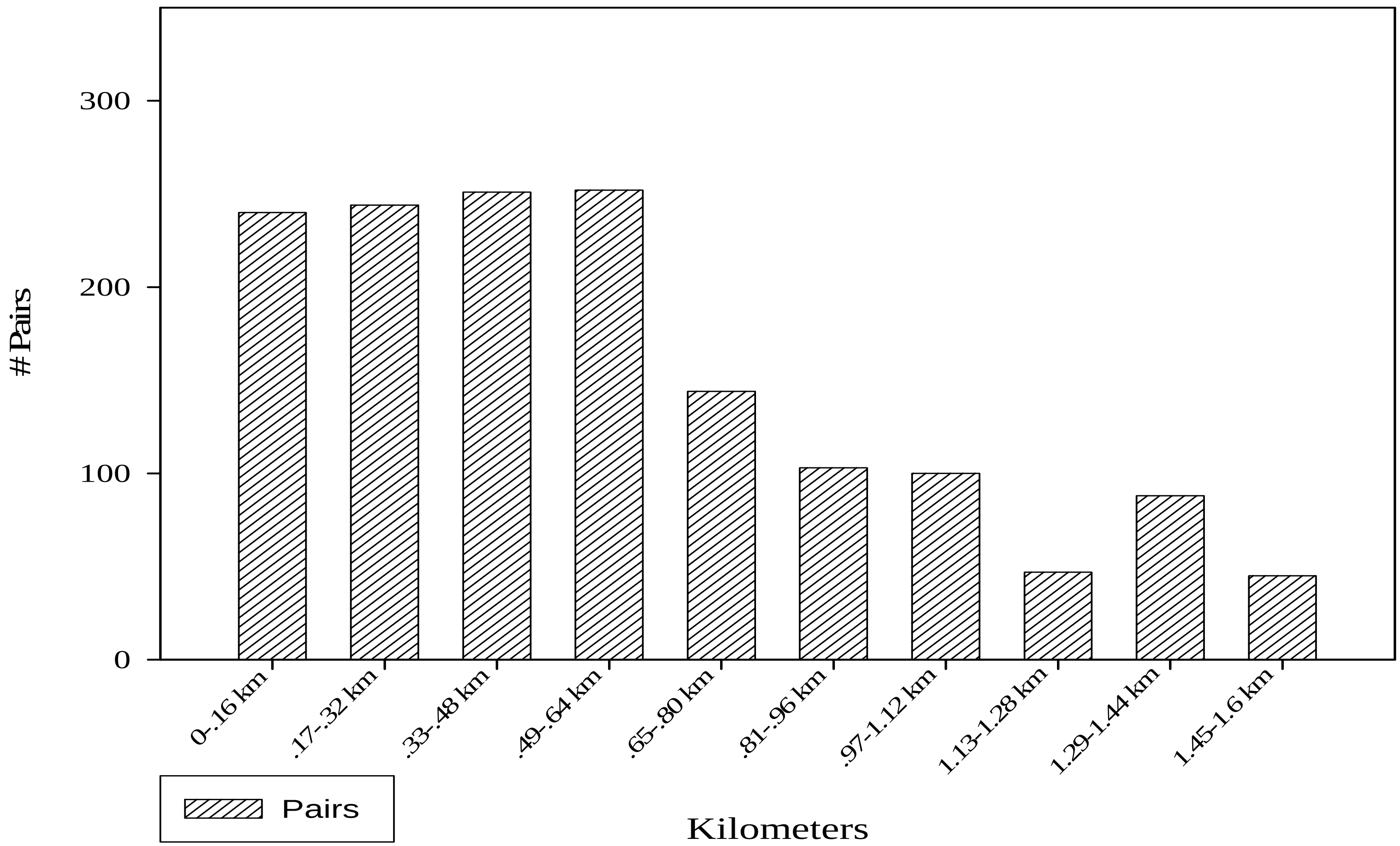

Figure 6. Distance of Piping Plover nesting pairs to nearest shored or unshored inlet: 1987-2007.

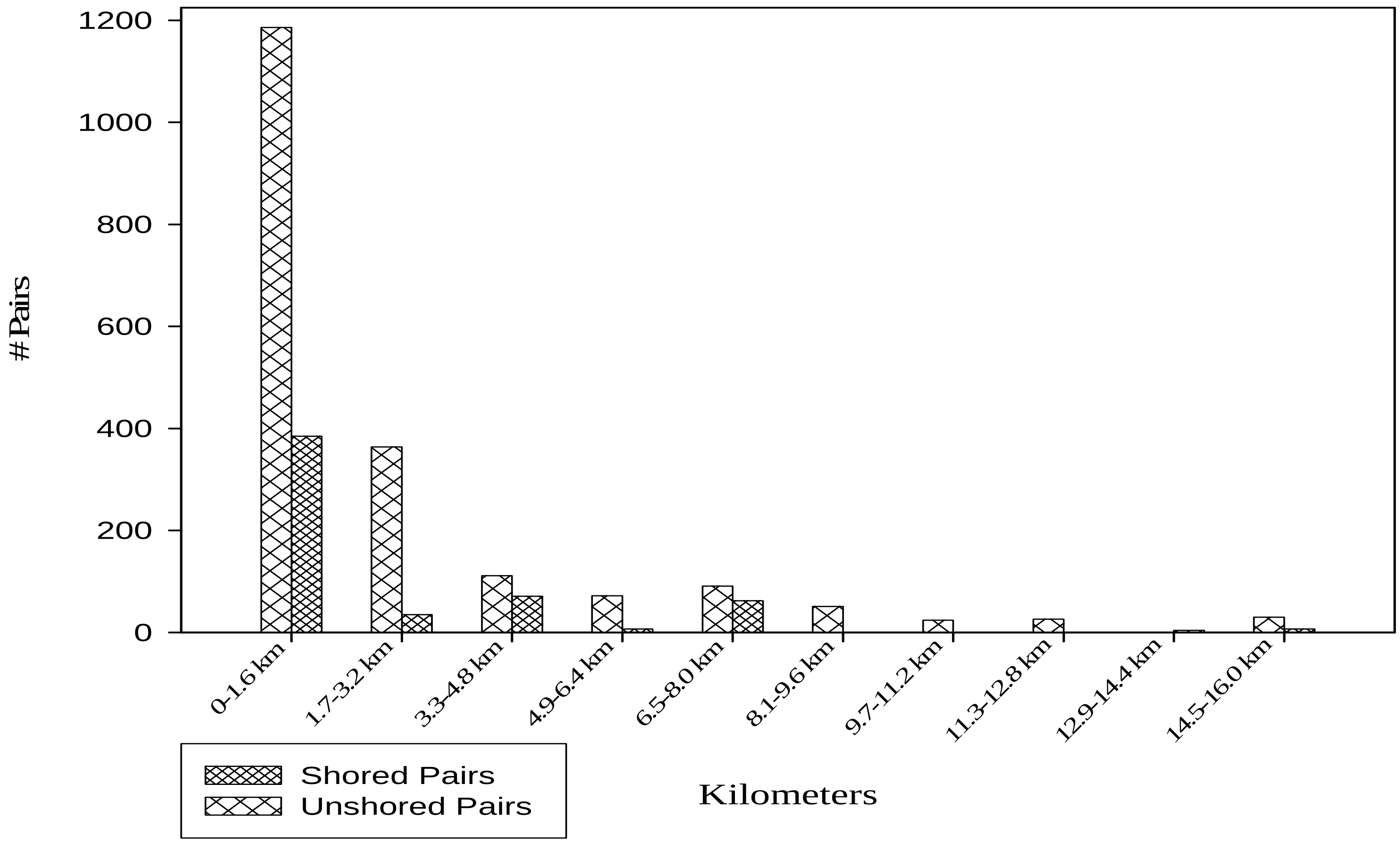

Figure 7. Flow chart of beach replenishments 1983-2007.