HOW DO HUMAN DISTURBANCE, BEACH CHARACTERISTICS, AND COASTAL ENGINEERING AFFECT SNOWY PLOVER (*CHARADRIUS ALEXANDRINUS*) HABITAT SELECTION ON THE FLORIDA PANHANDLE?

By

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ABSTRACT

Snowy plovers (*Charadrius alexandrinus*) are listed as threatened by the State of Florida, and have been a species of growing concern among wildlife management agencies. The population of snowy plovers breeding along the Florida Panhandle has a patchy distribution, and large stretches of private and public land go virtually unused by plovers. Further, there is a strong negative correlation between coastal engineering projects and snowy plover nest site use. The relationship between coastal engineering and snowy plover nesting distribution is unclear, however, because most engineering projects have occurred on developed beaches with high human use. My objectives were to better understand the relationships among beach characteristics, human disturbance, and snowy plover habitat selection and to determine if coastal engineering, human disturbance, or a combination between these two factors were limiting plover distributions. I sampled beach characteristics, human traffic, and plover occupancy patterns on 304 sites from January-July in 2009 and 2010. In these months, plovers were in pre-breeding, nesting (egg-laying and incubation), and brood-rearing stages. I used multi-season occupancy models that allow for colonization and emigration from sites between breeding stages to examine effects of seasonal changes in human activity and to allow for changes in stage-specific resource requirements of snowy plovers. High human use and high vegetation density were the main factors that discouraged snowy plover site selection during all time periods. Other factors, such as the amount of debris on a beach and access to the bay side of barrier islands, positively affected the probability of occupancy, mainly during the nesting stage. Coastal engineering that stabilized primary dunes, such as dune restoration and vegetation planting, were associated with dense vegetation, a beach characteristic that discouraged snowy plover occupancy throughout the breeding season. Projects that added sand to beach fronts (beach nourishment and emergency berms) were less likely to influence beach characteristics that contribute to plover habitat selection. Management projects interested in increasing suitable snowy plover habitat should focus on minimizing human traffic and refining dune stabilization techniques to better meet plover resource needs.

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GENERAL INTRODUCTION

Background

The selection of suitable habitat is crucial to avian reproductive success (Matessi and Bogliani 1999, Doligez et al. 2002). Habitat use and selection behavior of ground-nesting species that nest on exposed beach fronts has likely been shaped by predation pressure and variable climatic and foraging conditions. For example, birds may select features in their breeding habitat that decrease nest predation or provides an ample supply of food for chicks because exposure to predators (Ricklefs 1969, Martin and Roper 1988, Powell et al. 2002, Nguyen et al. 2007) and lack of adequate nutrition (Preston and Rotenberry 2006) are common causes of breeding failure. Conservation concerns merit analysis of factors affecting breeding habitat selection because the cumulative effect of each individual's reproductive success contributes to overall population trends (Martin 1993, Boettcher et al. 2007).

Predators are the leading cause of failure for avian nests (Ricklefs 1969, Martin and Roper 1988, Powell et al. 2002, Nguyen et al. 2007). Adult birds may evade nest predators by placing nests in areas that are difficult to locate (Colwell et al. 2011) and by performing defensive or distraction displays (Page et al. 1995). Humans may disturb adult birds in a way similar to predators, causing incubating birds to flush from nests or make defensive displays (Flemming et al. 1988, Verhulst 2001, Beale and Monaghan 2004, Burger et al. 2007). Wolcott and Wolcott (1999) hypothesized that repeated defensive displays by adult birds may draw the attention of other predators. A nest in an area with high predator density (including perceived predators like humans) may be at greater overall risk of failure than in areas with few predators (Verhulst 2001, Beale and Monaghan 2004).

Anthropogenic activities also may significantly alter landscapes and promote habitat degradation or loss by converting potential or historic nesting areas into residential or commercial developments (Wilcove et al. 1998). Human development on rapidly changing beach ecosystems often requires coastal engineering to prevent beach erosion and wave action from reaching residences or other infrastructure. Traditional coastal engineering, such as groins and seawalls, may be counteractive to preserving sandy beaches (Hsu et al. 2007). “Soft” engineering techniques, like beach nourishment are widely employed to replenish the sediment budget of beaches (Trembanis et al. 1999). Soft engineering entails manipulating sand to either widen the beach or build up dunes. This technique has become popular because of the higher aesthetic value, as it retains a beach, compared to hard structures like seawalls. These techniques also have presumably lower impacts on coastal-dependent wildlife (National Resource Council 1995). Lott (2009) raised concerns of a strong negative correlation between these coastal engineering projects and occupancy of shorebirds along the Florida Panhandle. He stipulated, however, that more research was required to determine if the patchy distribution of species was related to the engineering or to associated factors, such as development or human traffic (Lott 2009).

Coastal engineering attempts to mitigate erosion while maintaining the natural landscape as best as possible. Some factors, however, will be unavoidably different before and after the engineering occurs. Sediment sorting, for example, will be different after engineering. Sand sorting is a measure of the grain size uniformity in each sample. A poorly sorted sample will have sediment grains of very large and very small sizes (Folk 1974). Nourished beaches, which obtain their sand from farther out in the ocean where wind and waves have not acted on the sediments, are generally poorly sorted.

Nourished beaches often have other types of engineering associated with them. Dune engineering attempts to create and stabilize dunes at the back of the beach. The planting of vegetation on formed dunes assists in stabilizing the sand and capturing additional sand in the vegetation. This allows the dune to grow over time and combats erosion (Yozzo et al. 2003).

My project evaluated the factors that contribute to snowy plover nesting distributions on the Florida Panhandle. Snowy plovers (*Charadrius alexandrinus*) are small shorebirds that winter and breed on the beaches of the Florida Panhandle (Gore and Chase 1989). My objective was to determine whether physical habitat characteristics, human disturbance, or a combination of factors influence the habitat selection of snowy plovers. I also addressed whether or not the factors that contributed to habitat selection were significantly altered by coastal engineering.

Research Questions and Objectives

In Chapter 1, I examine the habitat parameters that affected snowy plover occupancy, colonization, and emigration from sites on the Florida Panhandle. My first objective was to determine whether or not snowy plovers move within the breeding season or remain in the area where they initially settle. To do this, I surveyed for plover presence over 165 km of beach during three temporal periods that corresponded to different plover breeding stages: pre-breeding, nesting (egg-laying and incubation), and brood-rearing. I also sampled beach characteristics and human disturbance. I evaluated results from two types of occupancy models: a multi-season model, which allowed for movement among sites between specific sampling periods and a single-season model that assumes no immigration or emigration among sites during the study period (January-July). My second objective was to determine the factors that affected plover site occupancy. I hypothesized that human disturbance and beach characteristics would influence plover habitat selection. I evaluated the beach characteristics within two frameworks: beach topography as well as substrate and vegetation. I predicted topography would influence the probability of nest loss due to flooding and availability of foraging habitat. I predicted substrate and vegetation characteristics would influence the ability of birds to avoid both adult and nest predators.

Chapter 2 examines how coastal engineering projects impact the beach topography as well as substrate and vegetation characteristics that were strong predictors of plover site occupancy. Since there are several types of coastal engineering (beach nourishment, emergency berms, dune restoration, and vegetation planting), which often occur simultaneously in one area, I used canonical correlation analysis to determine what types of engineering are correlated with changes in which beach characteristics. Once I identified beach characteristics that affected the movement of snowy plovers (Chapter 1), I was able to correlate them to a specific type of engineering. These correlations shed light on how engineering is changing the coastal habitat. This research can be used as a tool in a decision-making framework when coastal engineering is being considered in snowy plover habitat.

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CHAPTER 1: INTRA-SEASONAL MOVEMENTS OF SNOWY PLOVERS REFLECT EFFECTS OF HUMAN DISTURBANCE AND STAGE-SPECIFIC HABITAT REQUIREMENTS

Abstract

Habitat selection during the breeding season has important consequences for reproductive success and, in seasonal and heterogeneous environments, most likely occurs on several temporal and spatial scales. I examined several possible topographical, substrate and vegetation, as well as anthropological effects on snowy plover (*Charadrius alexandrinus*) habitat selection across pre-breeding and breeding stages to better understand the factors that affect snowy plover habitat selection on the Florida Panhandle. To allow for intra-seasonal movements and stage-specific habitat selection, I used multi-season occupancy modeling. I hypothesized that seasonal changes in human disturbance and stage-specific resource requirements would drive occupancy, colonization, and emigration patterns of snowy plovers. I found that high human use and high vegetation density were the main factors tested that discourage snowy plover habitat selection during all time periods. Other factors, such as the amount of debris on a beach, dune sinuosity, and access to the bay, increased the probability of occupancy during the nesting period. These results indicate that human disturbance may be preventing plovers from using otherwise suitable habitat and that plovers select habitat based on beach characteristics that provide stage-specific resource needs.

Introduction

Habitat selection during the breeding season has important consequences for avian reproductive success (Matessi and Bogliani 1999, Doligez et al. 2002, Sergio et al. 2009). Birds should select nesting areas that maximize access to resources (Sergio and Newton 2003, Preston and Rotenberry 2006, Crampton et al. 2011) while minimizing predation risk to nests and adults (Ricklefs 1969, Martin and Roper 1988, Powell et al. 2002, Nguyen et al. 2003). In seasonal and heterogeneous environments, habitat selection most likely occurs on several temporal and spatial scales (Hutto 1985).

Ideal free distribution theory predicts that birds will occupy the highest quality habitats first and, as a result, population densities may be highest in areas that provide the best chance at reproductive success (Fretwell and Lucas 1970). High quality territories, then, may be identified by the consistent presence of individuals during the breeding season. Conservation concerns merit analysis of preferred breeding habitat because the cumulative effect of each individual's reproductive success results in the overall population of a species (Martin 1993, Boettcher et al. 2007). As species become increasingly conservation-dependent, management programs and restoration projects will need to manage or create landscapes that promote site selection and provide resources for successful reproduction.

Occupancy models that allow for within season movements may be useful for understanding habitat selection over time (Betts et al. 2008, Rota et al. 2009, Crampton et al. 2011). Instead of assuming a breeding season closed to movement, Betts et al. (2008) hypothesized that later-arriving young black-throated blue warblers (*Dendroica caerulescens*) would initially occupy random sites but move to more suitable territories once more information was available. Warbler occupancy patterns provided no support for the non-dynamic (no movement) model, but fit well with models that allowed for colonization to better habitat and emigration from poorer habitat. Rota et al. (2009) tested for closure (no movement between sampling periods) among two sets of breeding bird surveys – one approximately three weeks between visits (in Montana) and the other with 8 days between visits (in New Hampshire). In the three-week separation, the hypothesis of closure between visits was rejected in likelihood-ratio tests for 20 out of the 28 species. For the New Hampshire dataset with eight-day separation between visits, the closure hypothesis was rejected for all species. These results indicate that for many species habitat selection is not static, and instead occupancy is likely to change throughout the breeding season. What causes birds to move among sites is not always obvious. Betts et al. (2008) suggested that there is a lack of information available to birds early in the breeding season so birds adjust their location accordingly as information becomes available. Rota et al. (2009) showed that for a number of species, movement was possible (if not prevalent), although no hypotheses as to why birds moved were tested.

Instead of assuming that initial occupancy represents all current and future preferred habitat for the entire breeding period, using models that allow for colonization and emigration between surveys has the potential to pinpoint spatial and temporal variations in the landscape that reflect this movement. Covariates that are useful for modeling initial site occupancy may be less important later in the season, and stage-specific requirements may contribute to the complexity of habitat selection during the nesting season. For example, ground-nesting shorebirds may attempt to minimize predation risk during incubation by choosing cryptic sites with lower risk of predation (Winton et al. 2000, Colwell et al. 2005, Hood and Dinsmore 2007). Once precocial chicks hatch, adults may attempt to move them to foraging areas that will have high food availability during brood-rearing (Cohen et al. 2009, McIntyre and Heath 2011). In a species not bound to its nesting territory during the brood-rearing period, a multi-season occupancy model may provide more information about habitat selection in each reproductive stage.

Snowy plovers (*Charadrius alexandrinus*) are territorial, ground-nesting, precocial shorebirds that nest on beaches along the Pacific and Gulf coasts and the interior flats of North America (Page et al. 1995). Snowy plovers are listed as threatened by the state of Florida (Wood 1989) and Pacific coast populations are federally listed (Federal Register 1993). Population declines and subsequent listings have been attributed to increased human development and recreational activities in the snowy plovers' breeding and wintering grounds (Gore and Chase 1989, Federal Register 1993). Snowy plovers are year-round residents on the beaches along the Florida Panhandle. Along the Florida Panhandle, the snowy plovers' annual cycle consist of wintering, pre-breeding (territory establishment), nesting (egg-laying and incubation), and brood-rearing.

In February, birds begin to disperse from their wintering groups and establish territories for the breeding season and in mid-March plover pairs will establish nests in the sand. Snowy plovers dig out a shallow scrape for nesting, frequently positioning it in proximity to an object such as a shell or a piece of driftwood (Page et al. 1985, Gore and Chase 1989, Winton et al. 2000, Powell 2001, Hood and Dinsmore 2007, Colwell et al. 2011) and far from dense vegetation (Muir and Colwell 2010). Nesting among objects on the beach may assist with keeping the nest cryptic as eggs placed among shells or clumps of vegetation would be less obvious than those placed in an area comprised only of sand. In areas where plovers nested on beaches with a heterogeneous, varied landscape, nest predation decreased (Winton et al. 2000, Colwell et al. 2005, Hood and Dinsmore 2007). Many nesting attempts on the Panhandle fail because of predation and flooding. After approximately 25-27 days of incubation, plover eggs will hatch. The earliest chicks along the Florida Panhandle are observed in April, but the majority of chicks appear in May (Lamonte et al. 2002, Himes et al. 2006).

Snowy plover chicks are precocial and leave the nest within a few hours of hatching. The highest mortality of chicks is during the first few days after hatching (Hood and Dinsmore 2007). Adults will lead chicks to areas of high food availability like ephemeral pools or the bay side of barrier islands (Loegering and Fraser 1995, Elias et al. 2000) to increase the chances of foraging success (Kosztolányi et al. 2007, Kuwae 2007). Chicks fledge and are independent after approximately 30 days post-hatching (Page et al. 1995).

Nesting snowy plovers have a patchy distribution along the Florida Panhandle (Lott 2009). Further, human activities on Panhandle beaches increase over the course of the plover nesting season, from relatively few visitors in the winter to thousands of beach-goers during the spring and summer. Some physical beach characteristics also change over time (e.g., beach slope, width), whereas others, which are not as dynamic, may have greater benefits during one reproductive stage over another (e.g., surface debris during the nesting stage). This chapter addresses the question: do snowy plovers initially select habitat that accommodates them throughout the breeding season, or do they move to new areas over the course of the season as more information about the landscape becomes available? I hypothesized that snowy plover habitat use would change over the course of the breeding season due to stage-specific requirements. I also hypothesized that plover habitat selection would be affected by beach characteristics including: human disturbance, topography, as well as substrate and vegetation. I predicted that snowy plovers would respond to habitats quality similarly to other Charadriiformes. Specifically, plovers would attempt to minimize predation risk during incubation by nesting in areas with high levels of debris (*C. alexandrinus:* Powell 2001, *C. semipalmatus*: Nguyen et al. 2003), and low vegetation density (*C. semipalmatus*: Nguyen et al. 2003, *C. melodus*: Cohen et al. 2009, *C. alexandrinus nivosis:* Muir and Colwell 2010). Plovers would avoid high human traffic (Lafferty 2001) and attempt to maximize food availability during brood-rearing by moving to areas with access to the bayside of barrier islands (*C. alexandrinus:* Loegering and Fraser 1995, Elias et al. 2000, *C. melodus*: Cohen et al. 2009). I used multi-season occupancy models to determine which environmental covariates promoted occupancy and movement to and from sites during stage-specific reproductive periods. I then used AICc model selection theory to determine which hypothesis or combination of the three hypotheses is best supported by the data, and therefore has the greatest descriptive power on snowy plover habitat selection.

Study Site

This study was conducted along the coast of Florida's Panhandle. Study sites included Escambia (Perdido Key State Park and National Seashore, Ft. Pickens National Seashore), Santa Rosa (Santa Rosa Island), Okaloosa (Eglin Air Force Base, Ft. Walton

Beach, Destin, Henderson Beach State Park), Walton (Topsail Hill State Park, Grayton Beach State Park, Deer Lake State Park), Bay (Camp Helen State Park, St. Andrews State Park, Tyndall Air Force Base), Gulf (St. Joseph Peninsula State Park), and Franklin (St. George Island State Park) counties. Most of the research was conducted on barrier islands. These islands are long, relatively thin (commonly less than 1 km across) and stretch parallel to the mainland. During storms, wave action can drastically change beach width, slope, and dune structure.

The Florida Panhandle's barrier islands have been highly developed for human use except for protected areas such as Florida State Parks, Department of Defense land, and National Seashores. Adjacent to these preservation areas, condominiums, vacation houses, and hotels line the beaches just behind the primary dunes. Roads run along the center of most islands and numerous parking areas allow pedestrian access to the beaches.

Methods

A field assistant and I collected information on plover distributions, human activity and beach characteristics from January thru July, 2009 and 2010. In 2009, we used a stratified random approach to select 101 sites, which consisted of a 200 m stretch of coastline that extended to the bay side of the island (or major obstruction like a building or forest). In 2010, we systematically selected 243 sites, 40 of which were the same site as the previous year. These sites represented a total of 165 km of the approximately 330 km of sandy beach shoreline of the Florida Panhandle. We sampled sites with relatively natural beaches (Florida State Parks, National Seashore, and Department of Defense land) and developed beaches adjacent to these areas.

We visited each site a total of nine times during each year, three consecutive day visits per each of three primary sampling periods. We established the primary sampling periods as: mid-January through mid-March (pre-breeding), mid-March through mid-May (nesting), and mid-May through mid-July (brood-rearing). We assumed that plovers did not immigrate or emigrate from a site within the three consecutive day visits (i.e., closure), but not between the primary sampling periods.

In 2009, we remained at a site for 1 hr per day to take measurements of beach characteristics. If at any time in that 1 hour period we observed a snowy plover within the site, the site was considered occupied. In 2010, in an effort to visit more sites, we remained in a site anywhere from 5 min to 1 hr. Because of this difference in protocol, we included year as a detection (p) covariate in occupancy models. For both years, the entire site and surrounding areas were searched for nesting during the nesting and brood-rearing periods so to not miss incubating birds, or unknowingly disrupt incubation during sampling.

We measured beach width (distance between high tide and dune toe), the percent slope of beach 1.5 m above high tide (Emery 1961), and human disturbance during each consecutive site visit. We measured human disturbance by counting human footprints on a raked surface of the beach (Engemen and Allen 2000). We raked a 1 m wide section of beach from the water to the dune toe on day one of the three consecutive visits. On day two, we counted the number of tracks and re-raked the line. On day three, we counted tracks again. High wind or rain events occasionally destroyed the information and beach width varied greatly. Therefore, we calculated the track data as an average over the primary sampling period as humans/m/hr. We validated this measure with direct observations of human traffic during 60 min samplings.

We took other measurements each sampling period that we averaged over the entire season for analysis. We estimated a measurement of dune sinuosity as the percentage of dunes in the site that rose above half the height of the dunes. A long, bench-like dune had a sinuosity score close to 100%. Evenly undulating dunes had sinuosity scores close to 50% and sparse dunes had low scores (< 20%).

Access to the bayside of the island, a lake or permanent pool was represented as a binomial presence or absence of the bay. Bay access was recorded to account for the availability of prime brood-rearing and foraging habitat in the area.

We recorded information on substrate and vegetation characteristics such as vegetation density, sand color, sand size, sand sorting, and the amount of debris. Vegetation density was a categorical estimation of the presence or absence of high vegetation density. High vegetation density was recorded in sites where sea oats (*Uniola paniculata*) or shrubby vegetation was evenly and densely distributed behind the dunes. Many sites had dense patches of vegetation on dunes, but had large unvegetated areas between the dunes. These were not considered to have high vegetation density. The amount of debris (shells, asphalt fragments, dead vegetation) on the beachfront was measured using a tape 25 m long and 1 cm wide. We stretched the tape along the beach surface and tallied and shell, dead vegetation or other detritus 1 cm or larger that touched the tape. Each sample consisted of four debris transects centered on one spot, each leg radiating at a 90º angle to form a "+". Occasionally, on a narrow beach, one or more legs were shorter than 25 m, so the sum of shells counted for all four legs were divided by the sum of meters measured (max 100). This gave an average measurement of debris per m.

At the center of the "+", we also measured sand color. This was done in the shadow of the observer, with sunglasses off, and in dry sand to account for changes in lighting, sunglass color, and precipitation. The Munsell color palettes 2.5Y and 5Y were too dark for the beaches, so we used nine color swatches from Ace Hardware (Light: China Beach, Artist's Canvas, and Cottonwood Fluff; Medium: Lonesome Dove, Los Lunas, and Oatmeal Bath; Dark: Sedona Sand, Penny Hill, and Cocoa Beach), and the overall sand color matched to the closest paint swatch. Sand color was ultimately recorded as a categorical variable. The nine shades were divided into three categories, the three lightest shades were considered "light sand," the three darkest shades were recorded as "dark sand," and the remaining three were "medium sand."

We measured sand size (m) and sorting (d) from samples (at least 20 ml) collected at the toe of the primary dune. We washed samples with distilled water and let them dry for at least 72 hours. We weighed samples then shook the sand with a sieve shaker (Gilson Company, model SS-15) for 15 minutes through 6 (-2ф, -1ф, 1ф, 2ф, 2ф and 4ф) sieves (Folk 1974). The individual size classes were re-weighed to 0.01g. We included samples that were between 98% and 102% of their original weight in the analyses.

Statistical Analysis

Out of the 304 sites surveyed, one site was missing ample human track data due to windy weather and was subsequently removed from analysis. Forty of the sites were sampled in each year (2009 and 2010). To avoid pseudo-replication, I removed information from one of the years (2009 or 2010) for each of these 40 sites. I randomly selected which year was to be included in the dataset. Of the final dataset included in the analyses, 77 sites were sampled in 2009 and 226 were sampled in 2010. Human disturbance rates were different in 2009 than in 2010. I ran an ANCOVA analysis (SAS 9.2) with an interaction between the independent variables human traffic and years and snowy plover nesting as the dependent variable to examine whether the significant decrease in human traffic affected plover response.

Pollock's robust design (multi-season) (Pollock 1982) takes into account a system that may not be closed between sampling periods. To estimate the initial occupancy for each site as well as the subsequent colonization and emigration rates, I used multi-season occupancy analysis (MacKenzie et al. 2003) in the program PRESENCE (Hines 2006). These models not only allow for movement among sampling periods but also accounts for imperfect detection during site visits. The presence or absence of a plover was recorded as detection histories (e.g., "011 010 111"). If a plover is detected during at least one site visit within a sampling period, a site is considered occupied for that sampling period. Models based on maximum likelihoods estimate occupancy (ψ), colonization (γ), emigration (ε), and detection probability (p) for each site. Initial occupancy (during the pre-breeding season) was calculated and occupancy estimates for nesting and brood-rearing stages were inferred based on subsequent γ and ε. Since I had three sampling periods, there are estimates for colonization and emigration between pre-breeding and nesting (γ_1 and ε_1) and between nesting and brood-rearing (γ_2 and ε_2). I compared models by using Akaike's information criterion adjusted for small sample size (AICc).

Movement within Breeding Season

To test the hypothesis that birds moved among sampling periods, I compared the AICc values of two models with no habitat parameters. The first model was the single-season occupancy model (no movement) and the second model was a multi-season occupancy model that accounted for colonization and emigration among the three sampling periods. I also ran a single-season model with all habitat parameters and a multi-season model with all habitat parameters in initial occupancy only. I compared the AICc values between the single-season and multi-season models to determine which models fit the plover occupancy data best.

I ran a Spearman correlation analysis for all beach characteristic and human disturbance parameters in SAS (SAS 9.2). For any pair of parameters that were correlated higher than 0.70, the parameter with less biological relevance was removed.

Habitat Selection

I evaluated the explanatory ability of each model based on AICc using normalized parameters for each occupancy event (initial occupancy [ψ], colonization between pre-breeding and nesting [$\gamma 1$], colonization between nesting and brood-rearing [$\gamma 2$], local extinction between pre-breeding and nesting [$\varepsilon 1$], and local extinction between nesting and brood-rearing [$\varepsilon 2$]). First, I evaluated model fit for each occupancy event starting with a global set of parameters that represented the hypotheses of disturbance (human tracks/h/m), beach topography (beach width, access to bay, dune sinuoisty), and substrate and vegetation characteristics (high vegetation density, debris, sand color, sand size and sorting), respectively (Table 1.1). I included a squared-value for dune sinuosity to allow a non-linear relationship between plover presence and dune shape. Variables that changed over time (human disturbance, beach width) were included only in the time step they applied to (e.g., humans traffic in the pre-breeding sampling period was used to explain initial occupancy, beach width sampled during the brood-rearing sampling period was used to explain $\gamma 2$ and $\varepsilon 2$). For each occupancy event, I removed the variable with the lowest explanatory power in a backwards-stepwise fashion to determine which variables best represented each hypothesis. The parameter that had the lowest absolute value of its parameter estimate divided by its standard error ($|\beta/SE|$) was removed (Zar 1999) and I repeated this process until the AICc increased with the removal of the parameter with the lowest explanatory power (Pagano and Arnold 2009). I considered the final models to be the best model for each combination of hypothesis and occupancy event.

Hypothesis Model Selection

Each of these models contained parameters from the three habitat selection hypotheses: human disturbance, substrate and vegetation, and topography. To test which hypothesis most influences snowy plover habitat selection, I built multi-season (pre-breeding, nesting, and brood-rearing) models that included all occupancy events based on these three hypotheses. The models contained only the parameters specific to the hypothesis being examined. This resulted in an AICc comparison of seven models to determine what overall characteristics most affected snowy plover habitat use.

I used model averaging to create new beta estimates (Anderson 2008) for each of the parameters based on the models that made 100% of the weight in the hypothesis model comparison. I reported 85% confidence intervals for these estimates to allow their significance to be AIC compatible (Arnold 2010).

Data were collected in a way that did not allow for any spatial autocorrelation component in the models (Betts et al. 2008), and may have some deficiencies as a result of this. My research also does not take into account any conspecific attraction that may have occurred.

Results

Movement within Breeding Season

Naïve occupancy rates (not corrected for imperfect detection) within 303 sites changed over the course of the study period: 75 sites had plovers in the pre-breeding period, 118 sites had plovers in the nesting period, and 147 sites had plovers in the brood-rearing period (Figure 1.1). Overall occupancy increased throughout the season but some sites (10%) were vacated after previously being occupied. Colonization rates were greater between pre-breeding and nesting (24%) than between nesting and brood-rearing (19%) (Figure 1.1). Emigration rates from previously occupied sites remained constant.

Models that included colonization and emigration fit the data better than models that assumed static occupancy (Table 1.2), which indicates that birds were moving between pre-breeding, nesting, and brood-rearing sampling periods.

Human Disturbance

Forty-eight sites had some human development, which was comprised of residences or other structures. Human traffic was lower in 2010 compared to 2009

(Wilcoxon Rank Sum z = 3.12, p = 0.0018), most likely because of the Deepwater Horizon oil spill, which occurred on April 20, 2010. The threat of beach closures and swimming restrictions drastically reduced beach recreation. However, snowy plover nesting response to humans did not depend on year (p = 0.09). During the pre-breeding sampling period, human traffic was 0.018 (±0.04) humans/m/hr. Human traffic increased to 0.052 (± 0.19) humans/m/hr during the nesting sampling period and 0.055 (± 0.20) humans/m/hr during the brood-rearing sampling period.

Beach Characteristics

During the pre-breeding sampling period, beaches were 43.9 m (± 26.9 m) wide from the high tide line to the dune toe and beach slope above the high tide mark was 3.4% (± 3.4%). Average beach width remained relatively constant throughout the study period, fluctuating from 40.9 m (±26.1 m) in the nesting period to 44.1 m (± 24.9 m) during the brood-rearing period. The slope above high tide decreased over the study, with a slope of 2.47 % (±3.22 %) during the nesting sampling period and a slope of 0.9% (± 3.2%) during the brood-rearing sampling period.

High vegetation density was recorded in 112 (37%) sites and bay access was available within 102 (33.6%) of the sites. Dark sand was predominant in 71 (23.4%) and light sand was in 52 (17.2%) of the sites. The average sinuosity measurement was 65.1 (± 24.3) % of dune above half height. Debris averaged 0.82 (± 0.84) debris/m, sand size was 1.61 (± 0.30) or “fine sand to medium sand” and sorting averaged 0.31 (± 0.13) or “well sorted to very well sorted” over the course of the study (Folk and Ward 1957).

Habitat Selection

Human traffic was a strong predictor of ψ, γ1, ε1, γ2, and ε2. High human disturbance was negatively associated with initial occupancy and both colonization events, and positively correlated with snowy plover emigration (Table 1.3). In other words, human disturbance is negatively associated with snowy plover habitat use during all stages. This effect is illustrated by an increasing amount of human traffic (that reflects seasonal changes) at unoccupied sites and consistently low human traffic at occupied sites over the course of the breeding season (Figure 1.2)

Beach width best represented the effects of topography at predicting initial colonization and had a positive effect on plover presence. Beach width, access to bay, and dune sinuosity all had a negative effect on emigration between pre-breeding and nesting (ε1) (Table 1.3). Snowy plovers selected habitat with wider beaches earlier in the season (ψ), and bay access and higher dune sinuosity is negatively associated with snowy plovers leaving pre-breeding sites (ε1).

Substrate and vegetation characteristics (dense vegetation and debris) were good predictors of plover occupancy (Table 1.3). High vegetation density was present in all occupancy event models but ε1. High vegetation density was negatively associated with plover presence in initial occupancy and both colonization events, and positively associated with birds emigrating after nesting. Therefore, high vegetation density is negatively associated with snowy plover habitat selection in all breeding stages. The amount of debris had a positive effect on the colonization of an area before nesting and a negative effect on emigration after nesting (ε2). A greater amount of debris was positively associated with snowy plover habitat selection in the breeding stages (nesting and brood-rearing) but had no strong associations during the pre-breeding period.

Hypothesis Model Selection

The habitat characteristics within the hypotheses of disturbance and substrate and vegetation performed the best at explaining habitat selection by snowy plovers (Table 1.4). These hypotheses were present in both models that made 100% of the model weight. Beach topography played a part in the explanatory values (included in the top model). However, the top model, which included topography, did not perform much better (Δ AICc = -0.4) than the next best model, which did not include topography. Consistent with poor support, parameter estimates for beach width were variable and 85% confidence intervals overlapped zero (Table 1.5). Human disturbance and high vegetation density had greater effects on snowy plover habitat use during both breeding periods (nesting and brood-rearing) than during the pre-breeding period.

Discussion

The use of multi-season occupancy analysis can be a useful tool for identifying habitat parameters that are influential in habitat selection only during certain reproductive stages. Stage-specific resource requirements could be an overlooked aspect of information in developing management plans for protected species. In particular, species not bound to nesting areas, like shorebirds with precocial young, may be able to move easily to habitats that meet these stage-specific requirements.

Snowy plovers moved during the course of the breeding season, most likely to adjust to changing levels of human disturbance and accommodate the changing needs from pre-breeding to nesting to brood-rearing.

Human disturbance played a strong role in predicting snowy plover habitat selection throughout the study period. Humans can be perceived as predators to adults, eggs, or chicks (Flemming et al. 1988, Verhulst et al. 2001, Beale and Monaghan 2004, Burger et al. 2007). High levels of human traffic may increase the chances that eggs are trampled. On some of the developed beaches, where human traffic is the highest, so many people crossed the line raked in the sand that it would be obliterated within 24 hours. Human traffic also may disturb plover foraging (Burger 1994), as plovers frequently feed on terrestrial insects that cluster around the wrack line where people prefer to walk. Foraging plover's interrupted by human traffic will stop foraging, move away from the wrack, and stand until the disturbance has passed. If the bird spends too much time avoiding disturbance, it may not be able to dedicate the time necessary to hunt invertebrates, regardless of the amount of food available.

Disturbance had a strong effect on plover occupancy during the nesting and brood-rearing periods. This result could indicate that plovers perceived humans as nest and egg predators, and not as a threat to adults. Disturbance also had a stronger effect on emigration than colonization. Snowy plovers are more likely to leave an area with high disturbance than they are to colonize an area with low disturbance. This may indicate that human disturbance levels may be difficult for the birds to predict, as there is no evolutionary basis for cues to indicate that an area will have high levels of disturbance until the disturbance occurs. Human traffic may elicit a response similar to stochastic events, which occur randomly.

An effective tool for reducing the impact of human disturbance is the use of symbolic fencing. This technique uses signage to section off a part of the beach for shorebird nesting. It has been successful in the past in reducing the impacts of disturbance on snowy plovers in California (Lafferty 2001, Wilson and Colwell 2010) and piping plovers in New York (Doherty and Heath 2011). One site in this study (Deer Lake State Park) had a large area of symbolic fencing that restricted pedestrians to areas near the high tide line. These sites had pre-breeding disturbance levels twice as high as the average snowy plover occupied sites, and the brood-rearing disturbance levels were higher than the average beach without snowy plovers. Nonetheless several pairs of plovers nested at this site in 2009 and 2010, at least one of which successfully hatched chicks each year. While the symbolic fencing did not decrease human traffic, it may have restricted its effects to a localized area that the birds could choose to avoid.

High vegetation density was negatively associated with plover habitat use. This could be due to the tactics employed by incubating adults to reduce nest predation. Snowy plovers distract predators from nest locations by leaving the nest and performing a “broken-wing” display. The display attracts potential predators to the adult who will feign injury and lead the predator away from the nest. For this ploy to be effective, a nesting adult may need to identify a threat early (by line of sight). Muir and Colwell (2010) found that western snowy plovers selected nesting habitat that was free of dense vegetation in a radius that was similar to their flushing distance when a human approached. In dense vegetation, predators may be more difficult to spot, and the adults may have more difficulty maneuvering through dense vegetation to a point where the predator can easily notice the display.

While dense vegetation is negatively associated with snowy plover habitat selection at all periods, the estimate for emigration between nesting and brood-rearing was especially high. Since many important brood-foraging areas have wet sand (Fraser et al. 1995, Loegering and Fraser 1995, Elias et al. 2000) and wet sand is not conducive for vegetation growth, snowy plover broods may coincidentally avoid dense vegetation. However, for management purposes, having open areas may be important for brood-rearing. It must be pointed out, however, that these results are based on the presence of high vegetation density. My methods described high vegetation density as areas that had little to no open areas between dunes. It should not be interpreted that an area should have no vegetation at all. In fact, many broods that I observed would hide in clumps of vegetation at the adults' alarms. It is possible that vegetation that is too dense prevents quick movements away from predators, but some vegetation is advantageous for cover.

The amount of debris on the beachfront was positively associated with snowy plover presence during the nesting and brood-rearing periods. Other studies have found that a higher percentage of shell of pebble cover is positively associated with other Charadriiformes habitat selection (Winton et al. 2000, Colwell et al. 2005, Hood and Dinsmore 2007, Nguyen et al. 2003). Debris had a slightly positive effect on the colonization between pre-breeding and nesting ($\gamma 1$), and a much larger negative effect on the emigration from an area between nesting and brood-rearing ($\varepsilon 2$). A nest placed among debris on the beach may be less likely to be depredated, as shells and vegetation act as camouflage for the nest itself. Once nesting is done, however, it seems that the more shell on the beach, the less likely the birds are to move away from the area. Perhaps the debris can act as camouflage for chicks as well as the nests.

Beach topography, in general, did not predict plover occupancy. Dune sinuosity and access to bay each had a negative effect on the emigration between pre-breeding and nesting. Long dunes and access to bay areas decreased the likelihood that birds will leave before nesting. Dune sinuosity and beach width relate to the possibility of a nest being washed away by flooding. Many nests are flooded and washed away by storms (Himes et al. 2006), and a wide beach and dune with few breaks can create a buffer from these effects. Other topography characteristics were related to the availability of food. Beach slope is related to the formation of tide pools (an area where invertebrates congregate), and bay access is another area of high invertebrate density. By topography not predicting plover occupancy, this could imply that there are ample food resources and areas protected from storms for snowy plovers at their current densities on the Florida Panhandle. Selecting habitats with better food resources may not improve chances of reproductive success at this time.

Overall, snowy plover habitat needs may be more specific during the nesting and brood-rearing than it is in the wintering or pre-breeding stages. While during all stages they select habitat with lower human traffic and vegetation densities, they tend to colonize areas for breeding that have higher amounts of debris, wider beaches, longer dunes, and access to bay habitat. Increasing coastal development counteracts most of these habitat characteristics by providing more access areas for beach goers, increasing beach raking which decreases debris, and increasing structures or busy roads, which may restrict access to the bay side of a barrier island.

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Figures

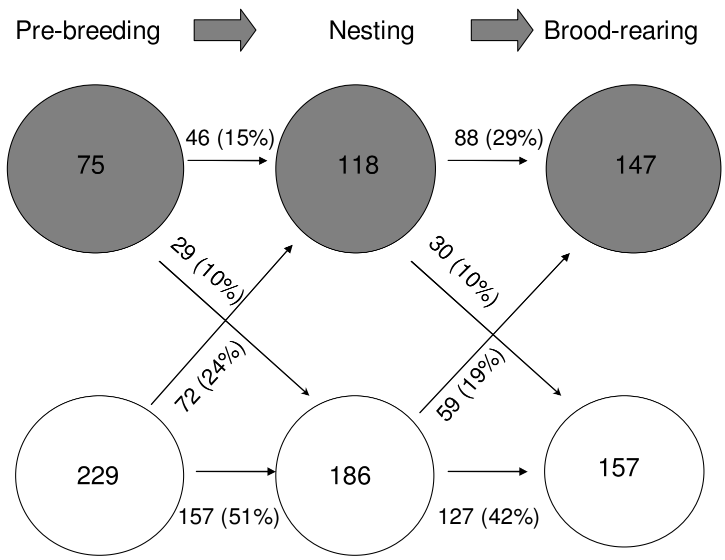

Figure 1.1. Naïve occupancy rates (assuming perfect detection) between primary sampling periods. Overall occupancy increased (circles) while number of sites without birds decreased (squares). Between each period, approximately 10% of the sites were vacated. The colonization rate was greater between pre-breeding and nesting (24%) and was slower between nesting and brood-rearing (19%).

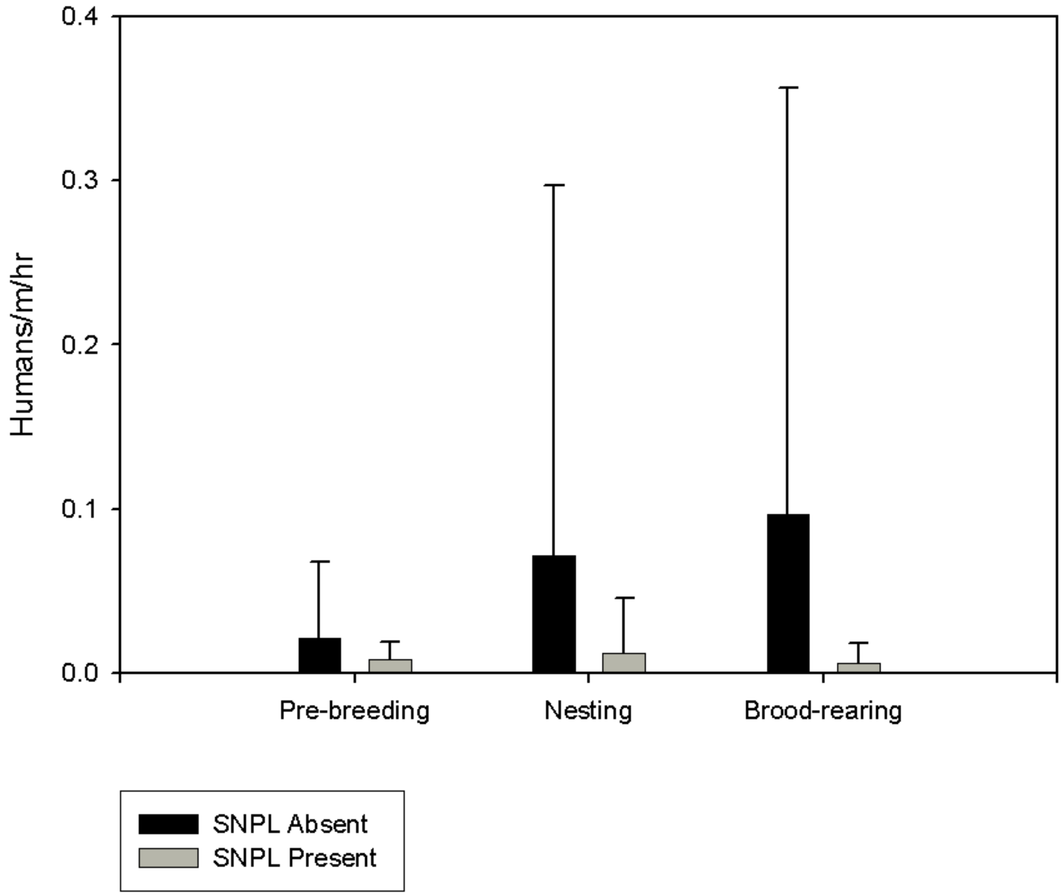

Figure 1.2: The mean (± standard deviation) number of humans /m/hr recorded at sites with and without (naïve measurement) snowy plovers present on FL Panhandle beaches in 2009 and 2010. Snowy plovers occupied areas with relatively constant disturbance rates, while non-occupied areas saw an increase in disturbance over the course of the nesting and brood-rearing stages.

Tables

Table 1.1: The beach parameters that were measured are divided into three hypotheses of humans, beach topography and substrate and vegetation characteristics. Humans = number of humans/m/hr, bay = presence of bay or pool access, AHH = % Dune above half height, Above slope = % slope five feet above high tide, Dense Veg = presence of high vegetative density, Debris = # of shells/debris per meter, m = average sand size, d = sand sorting, DarkSand = sand color recorded in the darkest 3 color palettes, LightSand = sand recorded in the lightest three palettes.

Disturbance	Topography	Substrate and Vegetation
Humans	Beach width	Dense Veg
	Bay	Debris
	Dune Sinuosity	Dark Sand
	Beach Slope	Light Sand
		m
		d

Table 1.2: Model comparisons of open and closed models Model comparisons to check for closure within the breeding period show that any model which contains colonization and emigration parameters performs better than it's analogous single-state occupancy model. Ψ is initial occupancy, γ is colonization, ε is emigration and p is detection probability. H1 is human traffic in humans/m/hr during pre-breeding period, W1 is beach width during the pre-breeding period and AbSp1 is above tide slope during the pre-breeding period. DenseVeg is a categorical measurement of high vegetation density, Bay is categorical availability of access to permanent pool or bay, Debris is the measurement of debris/m, and $sinu^2$ is a squared measurement of percent above half height of dunes or dune sinuosity. 2010 is a categorical variable that accounts for year and (.) indicates no habitat parameters were included in this part of the model.

Model	K	AICc
ψ (H1 + W1 + AbSp1 + DenseVeg + Bay + Debris + $sinu^2$) γ(.) ε(.) p(2010)	12	2297.3
ψ (.) γ(.) ε(.) p(.)	4	2310.5
ψ (H1 + W1 + AbSp1 + DenseVeg + Bay + Debris + $sinu^2$) p(2010)	10	2418.5
ψ (.) p(.)	2	2499.3

Table 1.3: The top models for ψ, γ1, γ2, ε1 and ε2. Each is broken down to its individual parameters and placed in a column which represents one of the three hypotheses. Parameters with numbers following (e.g. Humans 1) varied throughout the study period. (*1*) corresponds to pre-breeding, (*2*) to nesting and (*3*) to the brood-rearing period.

	Disturbance	**Topography**	**Substrate and Vegetation**
ψ	Humans 1 (-)	Width 1 (+)	Dense Veg (-)
γ 1	Humans 2 (-)		Dense Veg (-) Debris (+)
γ 2	Humans 3 (-)		Dense Veg (-)
ε1	Humans 2 (+)	Width 2 (-) Bay (-) Dune sinuosity (-)	
ε 2	Humans 3 (+)		Dense Veg (+) Debris (+)

Table 1.4: Model comparison between habitat hypotheses: human disturbance, beach topography, and substrate and vegetation. Where ΔAICc is the difference from the top model, ***w*** is the model weight and K is the number of parameters included within the model. The model which contains components for all three hypotheses performs the best (lowest AICc) and the model which contains human disturbance and predation avoidance categories fits the data almost as well. These two top models make 100% of the weight.

Model	**AICc**	**Δ AICc**	***w***	**Model Likelihood**	**K**
Disturbance[a] + Substrate and vegetation [b] + Topography[c]	2211.77	0	0.55	1	22
Disturbance[a] + Substrate and vegetation [b]	2212.17	0.4	0.45	0.8187	18
Disturbance[a] + Topography[c]	2233.49	21.72	0	0	16
Disturbance[a]	2236.05	24.28	0	0	12
Topography[c] + Substrate and vegetation [b]	2255.08	43.31	0	0	17
Substrate and vegetation [b]	2256.02	44.25	0	0	13
Topography[c]	2299.12	87.35	0	0	11
Null[d]	2310.5	98.73	0	0	4

a. Disturbance model: ψ(Humans1), γ1 (Humans2), ε1(Humans2), γ2(Humans3), ε2(Humans3), p(2010).
b. Substrate and vegetation: ψ(DenseVeg), γ1(DenseVeg + Debris), ε1, γ2(DenseVeg), p(2010).
c. Topography model: ψ(Width1), γ1(.), ε1(Width2 + Bay + Sinuosity), γ2(.), ε2(.), p(2010).
d. Null model ψ(.), γ1(.), ε1(.), γ2(.), ε2(.), p(.)

Table 1.5: Model averaged parameter estimates and 85% confidence limits for each of the parameters within each occupancy event. These estimates were calculated using the beta estimates and weights of the top two hypothesis models. These are estimates on the normalized, not the raw data.

Occupancy event	**β**	**error**	**85% Upper CI**	**85% Lower CI**
ψ	-0.815	0.202	-0.523	-1.108
Humans 1	-0.665	0.349	-0.159	-1.171
Dense Veg	-0.594	0.337	-0.105	-1.082
Beach width 1*	0.117	0.0842	0.239	-0.005
γ1	-0.413	0.276	-0.013	-0.814
Humans 2	-1.747	0.850	-0.515	-2.979
Dense Veg	-1.052	0.392	-0.484	-1.619
Debris	0.483	0.220	0.802	0.164
γ2	-1.174	0.574	-0.342	-2.006
Humans3	-5.401	2.252	-2.135	-8.666
Dense Veg	-1.025	0.472	-0.341	-1.709
ε1	0.596	0.779	1.726	-0.534
Humans2	6.981	3.571	12.159	1.803
Beach width 2*	-0.272	0.204	0.024	-0.568
Bay	-0.780	0.491	-0.069	-1.491
$sinuoisty^2$	-0.639	0.345	-0.139	-1.139
ε2	-2.320	1.415	-0.269	-4.371
Humans 3	7.870	4.289	14.088	1.652
Dense Veg	3.613	1.632	5.979	1.246
Debris	-3.033	1.957	-0.195	-5.870
P	0.312	0.146	0.524	0.100
2010	-0.374	0.166	-0.133	-0.615

* Confidence Intervals cross 0

CHAPTER 2: DOES COASTAL ENGINEERING IMPACT SNOWY PLOVER (*CHARADRIUS ALEXANDRINUS)* HABITAT SELECTION?

Abstract

Snowy plovers (*Charadrius alexandrinus*) are listed as threatened by the State of Florida, and have been a species of growing concern among wildlife management agencies. The population of snowy plovers breeding along the Florida Panhandle has a patchy distribution, and large stretches of private and public land go virtually unused by plovers. Coastal engineering techniques are often used on these unused sections of beach. To better understand whether coastal engineering affects snowy plover habitat use, I examined the impacts of engineering projects on the topographical, substrate, and vegetation characteristics that predict plover habitat use. High vegetation density was negatively associated with snowy plover habitat selection throughout the entire study, while higher amounts of debris, dune sinuosity, and access to bay areas increased the probability of occupancy during nesting and brood-rearing periods. Beach nourishment projects were correlated with areas with low amounts of debris, and coastal engineering projects that repaired and stabilized primary dunes were associated with dense vegetation. As dense vegetation negatively impacted plover habitat use throughout the breeding season, dune stabilization techniques should be used with restraint in areas where snowy plovers are encouraged to breed.

Introduction

Human development of beach ecosystems typically requires extensive engineering to support coastal communities and tourism. Engineering projects alter or reduce the effects of coastal processes, such as storm overwash, sand erosion and accretion, and inlet migration, that otherwise threaten buildings, roads, and other permanent structures (Yozzo et al. 2003). Projects that stabilize beaches and dune systems are likely to affect early-successional open beach and mudflat habitats used by many shorebirds and other coastal species (Trembanis et al. 1999, Dean and Dalrymple 2002). Thus, beach-dependent species may be impacted by habitat loss and degradation as a result of engineering (Speybroeck et al. 2006, Defeo et al. 2009).

Several engineering techniques have been employed to stabilize beaches and buffer structures from coastal processes and storms. Hard engineering structures, like seawalls and jetties, may negatively affect wildlife and beach aesthetics, as well as increase the erosion of sandy beaches (Hsu et al. 2007). “Soft” engineering techniques that manipulate sand, like beach nourishment and dune restoration, have become a popular approach for stabilizing dynamic beaches (Nordstrom 2000, Speybroeck et al. 2006). Beach nourishment usually entails placing sand from offshore onto a beachfront. The new sand is moved and graded by bulldozers or other machinery and sand is manipulated to a prescribed gradient to fill the beach below mean high tide (Yozzo et al. 2003). Although nourishment project planners attempt to simulate the existing sediments on the beach, nourishment projects often result in beaches that are altered in both sediment size (m) and sorting (d) (Peterson et al. 2006). Nourishment creates a wider beach, which increases the distance between wave action and structures on the beach and provides some protection from future erosion and storms. Nourishment is a temporary solution and must be repeated to maintain a protective beach width. On the Florida Panhandle, beaches are predicted to be renourished about every 6 years (Trembanis et al. 1999). Similar to beach nourishment, emergency berms are generally created on a smaller scale by moving sand from an inland location to prevent imminent property damage (Gravens et al. 2006, Lott et al. 2009).

Dune restoration, also called assisted recovery, is a short-term approach for building dune systems. New dunes are created seaward of a building or seaward of the existing primary dune (Lott et al. 2009) by manipulating sand with heavy machinery. Frequently, vegetation planting and sand fencing is then used to promote future dune building (Yozzo et al. 2003). Dune restoration projects often intentionally create long, non-sinuous dunes, as low areas among dunes may not protect landward areas from high waves and flooding (Gravens et al. 2006). Some dune restoration projects may rely solely on planting dune vegetation, such as sea oats (*Uniola paniculata*), to assist in building up dune systems. Vegetation traps sand and create new dunes. While planting-only restorations may take more time, this technique may produce the most stable dunes because as the sand builds, vegetation continues to grow taller and the entire dune is stabilized.

Habitat selection during the breeding season has important consequences for avian reproductive success (Matessi and Bogliani 1999, Doligez et al. 2002, Sergio et al. 2009). Birds should select nesting areas that maximize access to resources (Sergio and Newton 2003, Preston and Rotenberry 2006, Crampton et al. 2011) while minimizing predation risk to nests (Ricklefs 1969, Martin and Roper 1988, Powell et al. 2002).

Conservation concerns merit analysis of preferred breeding habitat as the cumulative effect of each individual's reproductive success results in the overall population of a species (Martin 1993, Boettcher et al. 2007). Although coastal engineering attempts to mitigate erosion while matching the natural landscape as best as possible, some beach characteristics will be inherently different before and after the engineering occurs. Lott (2009) raised concerns of a strong negative correlation between these coastal engineering projects and occupancy of shorebirds along the Florida Panhandle. As the areas that had undergone coastal engineering projects did not have snowy plovers present, the question was raised as to whether it was the engineering itself that was creating unsuitable habitat or if the associated human activities were preventing occupancy.

Snowy Plovers (*Charadrius alexandrinus*) are territorial, ground-nesting precocial shorebirds that nests on beaches along the Pacific and Gulf coasts and the interior flats of North America (Page et al. 1995). Snowy plovers are listed as threatened by the state of Florida (Wood 1989) and Pacific coast populations are federally listed as endangered (Federal Register 1993). Population declines and subsequent listings were attributed to increased human development and recreational activities in the Snowy Plover's breeding and wintering grounds (Wood 1989, Federal Register 1993). Indeed, human disturbance discourages snowy plovers from occupying otherwise suitable habitat on the Florida Panhandle, and throughout the breeding season the birds emigrate from areas that had increasing human traffic (Chapter 1). Habitat selection based on avoidance of human traffic would result in a patchy distribution of nesting plovers along the Florida Panhandle (Chapter 1, Lott 2009). Snowy plovers on the Florida Panhandle select habitat based on beach characteristics that may influence in predation rates, such as high debris and low vegetation density. They also select habitat based on topographical characteristics, such as access to the bayside of barrier islands, and dune sinuosity (Chapter 1).

My objectives were to understand whether coastal engineering projects on Florida's Panhandle affected the beach characteristics that predict snowy plover habitat selection during the pre-breeding and breeding season. I predicted that engineering effects would depend on the type of engineering project and that engineering projects would, in general, have a negative impact on the beach characteristics driving plover habitat selection.

Study Area

I conducted this study along the coast of Florida's Panhandle. Study sites included Escambia (Perdido Key State Park and National Seashore, Ft. Pickens National Seashore), Santa Rosa (Santa Rosa Island), Okaloosa (Eglin Air Force Base, Ft. Walton Beach, Destin, Henderson Beach State Park), Walton (Topsail Hill State Park, Grayton Beach State Park, Deer Lake State Park), Bay (Camp Helen State Park, St. Andrews State Park, Tyndall Air Force Base), Gulf (St. Joseph Peninsula State Park), and Franklin (St. George Island State Park) counties. Most of the research was conducted on barrier islands. These are long, relatively thin islands (commonly less than 1 km across) that stretch parallel to the mainland. During storms, wave action can drastically change beach width, slope, and dune structure.

The Florida Panhandle's islands have been highly developed for human use except for protected areas such as Florida State Parks, Department of Defense land, and National Seashores. Adjacent to these preservation areas, condominiums, vacation houses, and hotels line the beaches just behind the primary dunes. Roads run along the center of most islands and numerous parking areas allow pedestrian access to the beaches.

Methods

A field assistant and I collected information on plover distributions, human activity and beach characteristics from January thru July, 2009 and 2010. In 2009, we used a stratified random approach to select 101 sites, which consisted of a 200 m stretch of coastline that extended to the bay side of the island (or major obstruction like a building or forest). In 2010, we systematically selected 243 sites, 40 of which were the same site as the previous year. These sites represented a total of 165 km of the approximately 330 km of sandy beach shoreline of the Florida Panhandle. We sampled sites with relatively natural beaches (Florida State Parks, National Seashore, and Department of Defense land) and developed beaches adjacent to these areas.

We measured beach width (distance between high tide and dune toe), and beach slope (the % slope of beach 1.5 m above high tide) (Emery 1961). We estimated a measurement of dune sinuosity as the percentage of dunes in the site that rose above half the height of the dunes. A long, bench-like dune had a sinuosity score close to 100%. Evenly undulating dunes had a sinuosity score close to 50%, and sparse dunes had a low score (<20%).

Access to the bayside of the island, a lake or permanent pool was represented as a binomial presence or absence of the bay. Bay access was recorded in order to account for the availability of prime brood-rearing and foraging habitat in the area.

We recorded information on substrate and vegetation characteristics, such as vegetation density, sand color, sand size, sand sorting, and the amount of debris. Vegetation density was a categorical estimation of the presence or absence of high vegetation density. High vegetation density was recorded in sites where sea oats (*Uniola paniculata*) or shrubby vegetation was evenly and densely distributed behind the dunes. Many sites had dense patches of vegetation on dunes, but had large unvegetated areas between the dunes. These were not considered to have high vegetation density. The amount of debris (shells, asphalt fragments, dead vegetation) on the beachfront was measured using a tape 25 m long and 1 cm wide. We stretched the tape along the beach surface and any shell, and tallied dead vegetation or other detritus 1 cm or larger that touched the tape. Each sample consisted four debris transects centered on one spot, each leg radiating at 90º angles to form a "+". Occasionally, on a narrow beach, one or more legs were shorter than 25 m, so the sum of shells counted for all four legs were divided by the sum of meters measured (max 100). This gave an average measurement of debris per m.

At the center of the "+", we also measured sand color. This was done in the shadow of the observer, with sunglasses off, and in dry sand to account for changes in lighting, sunglass color, and precipitation. The Munsell color palettes 2.5Y and 5Y were too dark for the beaches, so we used nine color swatches from Ace Hardware (Light: China Beach, Artist's Canvas, and Cottonwood Fluff; Medium: Lonesome Dove, Los Lunas, and Oatmeal Bath; Dark: Sedona Sand, Penny Hill, and Cocoa Beach), and the overall sand color matched to the closest paint swatch. Sand color was ultimately recorded as a categorical variable. The nine shades were divided into three categories, the three lightest shades were considered "light sand," the three darkest shades were recorded as "dark sand," and the remaining three were "medium sand."

We measured sand size (m) and sorting (d) from samples (at least 20 ml) collected at the toe of the primary dune. We washed samples with distilled water and let them dry for at least 72 hours. We weighed samples then shook the sand with a sieve shaker (Gilson Company, model SS-15) for 15 minutes through 6 (-2ɸ, -1ɸ, 1ɸ, 2ɸ, 2ɸ and 4ɸ) sieves (Folk 1974). The individual size classes were re-weighed to 0.01g. We included samples that were between 98% and 102% of their original weight in analyses.

I referred to Lott et al. (2009) for information on coastal engineering projects. Lott et al. (2009) created a publicly available Geographic Information System layer with location, type, and year of engineering project for all Panhandle counties. Other engineering events were noted in the field.

Statistical Analysis

I used canonical correlation analysis (Proc CANCOR, SAS 9.2) to examine the group associations between different engineering techniques and the beach characteristics included in the snowy plover habitat selection analysis. Canonical correlation evaluates the relationships among two groups of variables (James and McCulloch 1990). Canonical correlation attempts to maximize correlations between canonical variables from each set of groups, which in this case are represented by engineering projects and beach characteristics. This test allows simultaneous examination of correlations among all beach characteristics, with the potential for interactive effects. In Chapter 1, I used categorical variables to account for vegetation density and access to the bayside of islands. Canonical correlation analysis performs best if each variable within a dataset (engineering or beach characteristics) is the same data type (categorical or meristic) (McGarigal 2000). To meet this requirement, I used meristic measures of vegetation. For vegetation density, I used the measurement of the lowest percent cover of vegetation recorded in the dune cover photos. There were no meristic variables that represented access to bay and access to bay was not included in the analysis. All of the parameter measurements that were not normally distributed were log transformed.

Results

Of the 304 sites, 57 were nourished, 40 had emergency berms, 53 had assisted recovery and 56 had dune restoration. Because assisted recovery and dune restoration are similar, 64 of the sites had at least one of these treatments, which I will refer to collectively as dune engineering. Sixteen of the sites had planting, a treatment that involves no manual manipulation of the sand, but planting of sea oats will build dunes over time. These treatments were not mutually exclusive. No engineering projects occurred on 217 sites; and conversely, there were 91 sites that had engineering of any type (any engineering).

Beach width at the 304 sites was averaged 45.0 m (± 25.3). Beaches with no engineering (n = 217) averaged 48.2 m (± 26.7) and beaches with any type of engineering (n = 91) averaged 37.4 m (± 19.5). Minimum % vegetation cover was 9.4 (± 17.4) overall. At sites with no engineering, % vegetation averaged 9.7 (± 18.3) and minimum % vegetation in a site with any engineering was 8.6 (± 14.4). The average debris/m was

0.82 (± 0.84). Sites with no engineering averaged 0.86 (± 0.9) debris/m and sites with any engineering averaged 0.73 (± 0.67) debris/m. Dune sinuosity was 65.1 % (24.3 %) averaged over all the sites, within sites with no engineering was 61.2 % (± 23.7 %), and was 74.5 % (± 23.2 %) with beaches with any engineering.

High vegetation density was present in 112 (37%) of all sites, 53 were located on no engineering sites (26% of no engineering) and 59 were on sites with any engineering(58% of any engineering). Bay access was available within 102 (34%) of the sites. Of the 202 sites with no engineering, 76 sites had access to the bay (38%). Of the 102 sites with any engineering, 26 had access to the bay (25%). Dark sand was predominant in 71 (23.4%) and light sand was in 52 (17.2%) of the sites.

I ran a canonical correlation analysis between the engineering projects (nourishment, emergency berm, dune engineering, and planting) and the meristic beach variables that most affect snowy plover habitat selection and sand sorting (d). The first two canonical correlations were significant and accounted for over 93% of the variability within and among these parameters (Table 2.1). The first canonical variable based on engineering projects (Eng 1) had relative strong (>0.5) eigenvector loadings on dune engineering and planting projects. The first canonical variable based on beach characteristics (Beach 1) had relatively strong eigenvector loadings on beach width (negative), vegetation density (positive), and dune sinuosity (positive). The canonical variables Eng 1 and Beach 1 were positively correlated ($r = 0.42$, Table 2.2), indicating that dune restoration and planting was associated with narrow beaches, long non-sinuous dunes, with high amounts of vegetation (Table 2.3 and Table 2.4). The second canonical variable based on engineering projects (Eng 2) had relative strong (>0.5) eigenvector loadings on beach nourishment and emergency berms projects. The second canonical variable based on beach characteristics (Beach 2) had relatively strong eigenvector loadings on debris (negative), and sand sorting (positive). The canonical variables Eng 2 and Beach 2 were positively correlated ($r = 0.30$, Table 2.4), indicating that beach nourishment and emergency berm projects were associated with less debris and poorer sand sorting (Table 2.3 and Table 2.4).

Discussion

Development of coastal areas changes beaches from their original state. Because these landscapes are dynamic, the investments associated with coastal developments inevitably come in danger of being lost to natural processes. To preserve these investments, coastal engineering has been used to combat the encroaching shoreline. Besides the financial burden placed on communities, as well as local and federal governments, environmental drawbacks may occur if coastal engineering encroaches into conserved land. These drawbacks include the possibility of reducing the quality of existing habitat for threatened or endangered species.

Vegetation density plays a significant role in plover habitat selection and likely contributes to snowy plovers' ability to detect and distract predators from nest sites (Chapter 1, Muir and Colwell 2010). In dense vegetation, predators may be more difficult to spot. Moreover, the adults plovers may have more difficulty maneuvering through dense vegetation to a point where a predator can notice their distraction display. For management purposes, open areas may be crucial for snowy plover habitat. However, even these areas should have some amount of vegetation. Plover broods will hide in clumps of vegetation in response to adult alarm calls (personal obs.) and plovers will forage among sparse vegetation.

High vegetation density was correlated to dune engineering and planting. The plausible mechanism for this association is that in both of these shoreline protection techniques, dune establishing plants are brought into an area to stabilize or create dunes. While fresh plantings themselves do not represent the highest density level, over time the plants establish themselves and spread. Also, the dense vegetation measurement did not only include the primary (closest to the shore) dune system where most dune restoration occurs. The measurement was an estimate of the density of vegetation within the entire site behind the dunes. Dense vegetation inland may once have had dune engineering or planting with subsequent new primary dunes created shoreward of the existing ones. The increased stabilization on the primary dunes also may provide protection for the secondary dunes. With less wind and wave action penetrating past the primary dune system, the vegetation has fewer disturbances and more opportunity for growth. This process could potentially turn a system that was once prone to erosion by storms and wind into an area that is relatively stable. This stabilization of secondary dunes would gradually decrease the amount of open habitat, which is important for snowy plovers (Chapter 1, Muir and Colwell 2010).

The amount of debris on the beachfront was positively associated with snowy plover presence during the nesting and brood-rearing periods. Other studies have found that a higher percentage of shell or pebble cover is positively associated with habitat selection for other Charadriiformes (Winton et al. 2000, Colwell et al. 2005, Hood and Dinsmore 2007, Nguyen et al. 2003). A nest placed among debris on the beach may be less likely to be depredated, as shells and vegetation act as camouflage for the nest itself. Nourishment and emergency berms are negatively associated with beach debris. This association, however, may be a confounded effect because of the amount of human and vehicular traffic on developed beaches. With increasing disturbance to the surface of the beach, all shell and dead vegetation gets churned into the loosened sand.

Beach topography, in general, did not play a strong role in the process of snowy plover habitat selection. Dune sinuosity and access to bay each had a negative effect on the emigration between pre-breeding and nesting. Consequently, long dunes and access to bay areas decrease the likelihood that birds will leave before nesting. While dune engineering had a positive association with long dunes, the relative positive impact of dune creation maybe counteracted by the string negative effect of dense vegetation with dune engineering.

Management Implications

Snowy plover habitat selection along the Florida Panhandle is driven strongly by human disturbance, vegetation density, and the amount of shell and debris on the beach (Chapter 1). The coastal engineering techniques of dune restoration and planting are positively associated with high vegetation density. Dune restoration projects are often associated with other coastal engineering and development, but vegetation planting occurs independently in numerous state parks along the Panhandle. Stable, well-vegetated coastal dune systems are critical for maintaining infrastructure, such as roads and buildings, as well as viable populations of threatened and endangered beach mice (*Peromyscus polionotus* spp.) (Pries et al. 2009). However, vegetation planting should be done conservatively to address the habitat needs of snowy plovers. Planting in patches instead of continuous rows may allow some breaks in the dunes, which would allow storm water to clear out the vegetation between the dune “islands” in large storm events. Long-term studies on the methods of vegetation planting are needed to determine the effectiveness of building a dune system that has large open areas between hummocks of vegetation.

It should be noted that although beach nourishment and emergency berms did not have strong associations with beach characteristics that affected snowy plover habitat selection, this does not necessarily indicate that these measures would have no effects on snowy plovers or other shorebirds. Beach nourishment has been shown to drastically reduce the number of benthic macroinvertebrates (Colosio et al. 2007, Peterson et al. 2006), which are an important food source for many shorebird species. The amount of time between beach nourishment and this study may have contributed to the lack of effect. More studies are needed to determine whether these results are limited to the scope of the Florida Panhandle, as types of beach and sand characteristics may be only locally applicable. The Florida Panhandle is a reflective type of beach, which is relatively steep with quick drainage, which has lower numbers of invertebrates than dissipative beaches, which are more like mudflats (Defeo et al 2009). Beach nourishment may have stronger effects on coastal species in a dissipative system.

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Tables

Table 2.1 Eigenvalues for the canonical correlation between coastal engineering and beach characteristics.

Canonical Correlation	Eigenvalue	Difference	Proportion	Cumulative
1	0.216	0.119	0.6464	0.6464*
2	0.097	0.076	0.2899	0.9363*
3	0.021	0.021	0.0629	0.9992
4	0.000		0.0008	1

* $p<0.05$

Table 2.2: Canonical Correlation values for the relationship between the Eng and Beach variables.

Canonical Correlation	Canonical Correlation value
1	0.4217
2	0.2974

Table 2.3: Canonical Structure of the correlation of engineering types with their canonical variable. The canonical variable Eng1 corresponds to Beach1 and Eng2 corresponds with Beach2 with the strength indicated by the canonical correlation value in Table 2.7. Bold type indicates heavy contribution to the canonical variable. * Indicates a greater correlation from the beach characteristic with the engineering canonical variable.

	Engineering Canonical Variables	
Engineering type	Eng1	Eng2
Nourishment	0.2586	**0.8777**
Emergency Berm	0.2779	**0.7184**
Dune Engineering	**0.8131**	0.4059
Planting	**0.6163**	-0.3507
Beach Characteristics		
logWidth	-0.2932*	-0.0074
logVegMin	0.2379*	-0.0039
Debris	-0.0505	-0.1600
logSinuosity	0.3514*	0.0374
d	-0.0736	0.25*

Table 2.4: Canonical Structure of the beach characteristics' correlation to the Beach canonical variables. Canonical variable Beach1 corresponds with Eng1 and Beach2 corresponds with Eng2. Width is beach width, VegMin is the minimum % vegetative cover, debris is debris per meter, sinuosity is the % dune above half height and D is sand sorting. Bold type indicates a heavy contribution to the canonical variable. * Indicates a stronger correlation between the beach canonical value and engineering type.

	Beach Characteristic Canonical Variables	
Beach characteristic	Beach1	Beach2
Log Width	**-0.6953**	-0.0249
Log VegMin	**0.5642**	-0.0132
Debris	-0.1198	**-0.538**
Log Sinuosity	**0.8334**	0.1256
d	-0.1745	**0.8408**
Engineering types		
Nourishment	0.1091	0.261*
Emergency Berm	0.1172	0.2136*
Dune Engineering	0.3429*	0.1207
Planting	0.2599*	-0.1043

GENERAL CONCLUSIONS

Occupancy modeling has become a powerful tool in determining habitat associations with species (MacKenzie et al. 2002). Much of its power comes from its ability to account for imperfect detections of species. For this method to work, repeated visits are required in order to estimate detection probability. The organism being surveyed for is assumed to not have colonized or vacated the area between surveys (closure assumption). Under many survey protocols, surveys are repeated with days or weeks between visits causing a possible bias in the occupancy estimation (Rota et al. 2009).

A species that does not meet the closure assumption is moving in or out of a survey site, but why? Habitat characteristics change over time and an individual may move accordingly, or an individual’s needs change over time and it moves to seek out habitat that meets the new requirements. My results indicate that for snowy plover populations on the Florida Panhandle, individuals may colonize and emigrate from areas for both of these reasons.

Human disturbance rates changed over the course of the study period. Although snowy plovers were negatively associated with human presence at all stages, the strongest association was emigration from a site. This result implies that snowy plovers are reacting more strongly to disturbance in a site that they have been occupying than to disturbance in sites they are colonizing. Other beach characteristics that are less dynamic became predictors of snowy plover habitat during certain breeding stages. For example, debris was a predictor of snowy plover presence only during the nesting and brood-rearing stages. Thus, instead of assuming that an area occupied by a species at one point during the year is quality breeding habitat, multi-season occupancy analysis can be useful in identifying parameters specific to different life stages.

Snowy plover habitat selection along the Florida Panhandle is driven strongly by human disturbance, vegetation density, and the amount of debris on the beach. These habitat characteristics are related to predation avoidance and disturbance levels. The threat of predation, therefore, is the largest driving factor in snowy plover habitat selection, greater than food availability and preventing nest flooding. The effects of these predation avoidance characteristics are strongest during the nesting and brood-rearing periods.

The coastal engineering techniques of dune restoration and planting are positively associated with high vegetation density. High vegetation density can disrupt the natural defenses of snowy plover by impeding the view of approaching predators, or impeding a predator’s view of a plover’s distraction display. While dune restoration projects are often associated with other coastal engineering and development, vegetation planting occurs in numerous state parks along the Panhandle. There is a large-scale planting project planned for Gulf Islands National Seashore in the near future on areas of the beach that are currently used by snowy plovers during breeding periods. According to the results of this study, vegetation planting should be done conservatively in regards to snowy plover habitat. For example, planting in patches instead of continuous rows may allow some breaks in the dunes, which would allow storm waves to clear out the vegetation between the dune "islands." Long-term studies on the methods of dune plantings are needed to determine the effectiveness of building a dune system that has large open areas between hummocks of vegetation.

Although my results indicate that beach nourishment and emergency berms would have little effect on the beach characteristics that predict snowy plover habitat selection, they are limited to the scope of the Florida Panhandle. Types of beach and sand characteristics may only be locally applicable, and these results may not represent other beaches accurately. Because the Florida Panhandle is a reflective type of beach, which is relatively steep with quick drainage, it has lower numbers of invertebrates than dissipative (flat, slow draining) beaches (Defeo et al. 2009). Beach nourishment may have a more drastic and lasting effect on coastal species in a dissipative system than a reflective system.

My study could have been greatly improved if I could have accounted for autocorrelation between individuals. Site-Fidelity is known to occur in Charadriiforms (Rioux et al. 2011). Nests on the Panhandle were likely to occur in the same areas (within 200m) between the years 2009 and 2010. Therefore, it is possible that there are also behavioral aspects to habitat choice. My data was collected in a way that did not allow for any spatial autocorrelation component in the models (Betts et al. 2008), and may have some deficiencies as a result. My research also does not take into account any conspecific attraction that may come into play. This may be a useful strategy to incorporate on a smaller study area, but was not practical at the scale in this study.

The next logical step in this research is to examine source and sink populations along the Florida Panhandle. This would require tracking individual nest outcomes, but would also identify habitat characteristics associated with reproductive success. Although my research identifies habitat characteristics that encourage plover presence during breeding, it does not identify characteristics that increase reproductive success. For the purpose of my study, I assumed that a species would occupy the most quality habitat before others. However, Colwell et al. (2005) observed western snowy plovers preferentially breeding in areas that lowered nest survival.

Before successful breeding can occur in an area, however, birds must first colonize the area. By keeping human traffic low or providing a buffer using symbolic fencing, disturbance effects may be kept to a minimum. Land managers should maintain characteristics that encourage snowy plover colonization during the breeding season, such as open areas between dunes, and leaving debris on the beach. It may be possible to introduce debris, although further research would be recommended as to size and color of debris that would be most beneficial. With respect to snowy plover habitat, coastal engineering projects should be done with restraint. To date, there have been only a few small nourishment projects that have occurred in current breeding areas on the Florida Panhandle. These occurrences will most likely be increasing, which will open up opportunities for scientists to examine short- and long-term effects of beach nourishment within existing breeding areas. Although my data gives no strong support for nourishment projects affecting snowy plover distribution, my results indicate that dune stabilization techniques may be detrimental to the continuation and creation of snowy plover habitat.

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Map 1. Locations of natural areas on the Florida Panhandle. 304 Sites were systematically distributed throughout the natural areas and their adjacent developed beaches.