Demography, Nest Site Selection, and Physiological and Behavioral Responses to Overflights and other Human Activities, of Wilson's Plover (*Charadrius wilsonia*) at Cape Lookout National Seashore, North Carolina

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ABSTRACT

There is little information on demographic trends of, or threats to the Wilson's Plover (*Charadrius wilsonia*), despite concerns that habitat degradation may be causing the species to decline. I studied Wilson's Plover demography, nest site selection, and physiological and behavioral responses to overflights at Cape Lookout National Seashore, North Carolina, where the National Park Service and U.S. Marine Corps recently lowered the altitude for overflights at tactical speeds. I monitored the responses of incubating Wilson's Plovers to overflights and other human activities and compared heart rate, incubation rate, and vigilance behaviors during time periods with and without these stimuli. I compared habitat use vs. availability at the island-scale, and nest placement relative to geomorphic features and vegetative cover, both on a local and island-wide scale. Wilson's Plovers increased vigilance during military rotary-wing and civilian fixed-wing overflights, but not during military fixed-wing overflights. Plovers were vigilant more and incubated less when researchers were present. Wilson's Plovers selected for interdune areas, flats and isolated dunelets on flats, and against beach and dunes. At the local scale, nests were more likely to be near dense vegetation than random points. Mayfield nest survival was 25%, and predation caused most of the nest failure. Daily nest survival was negatively correlated with nest age and initiation date. Nests with cameras and heart rate monitors had lower survival, and nests with predator exclosures had

higher survival. The mean number of chicks fledged per pair was 0.78.

ACKNOWLEDGEMENTS

TABLE OF CONTENTS

LIST OF TABLES

Chapter Three

LIST OF FIGURES

Chapter One

INTRODUCTION

The Wilson's Plover (*Charadrius wilsonia*) is a shorebird that occurs along the Atlantic and Pacific coasts of the Americas (Corbat and Bergstrom 2000). It is designated nationally and regionally as a Bird of Conservation Concern by the U.S. Fish and Wildlife Service (USFWS 2008). The U.S. Shorebird Conservation Plan listed Wilson's Plovers as a Species of High Concern for the Southeastern Coastal-Plains Caribbean Region (Prioritization Category 4, Brown et al. 2001). The population is estimated at 6,000 individuals in North America, however low confidence is placed in this estimate (Corbat and Bergstrom 2000, Brown et al. 2001). Population declines have been documented for other coastal temperate-zone breeding plovers, such as the Piping Plover (*Charadrius melodus,* Cairns and McLaren 1980) and Snowy Plover (*Charadrius nivosus*; Powell 2001), but there have been no broad-scale, systematic studies of Wilson's Plover population trends (Brown et al. 2001).

Loss of undisturbed coastal habitat has been implicated in the decline of many shorebird populations and it is suspected that Wilson's Plovers are also vulnerable to this habitat loss (Foster et al. 2009). In North Carolina, only 48 km of the 480-km coastline are not exposed to a roadway, beach driving and/or beach nourishment projects (NCWRC 2005). Even on these undeveloped beaches, plovers are exposed to recreational motorized vehicles, pedestrians, dogs, researchers and monitors, and aircraft traffic. Cape Lookout National Seashore (CALO) is one of these few remaining uninhabited barrier island systems in central North Carolina and is located about 1.5 km offshore. The island had no permanent residents during my study, but the NPS managed guest cabins and service facilities available for use by the public. The islands were accessible via public car/person ferries and by private vessel. Motorized vehicles, including all-terrain vehicles (ATVs) and off-road vehicles (ORVs), were allowed to drive on the beach.

At CALO, the U.S. Marine Corps (USMC) and National Park Service (NPS) recently altered human activities by agreeing to lower the permitted altitude for tactical speed (>250 kts) operations from 3048 m (10,000 ft) to 914.4 m (3,000 ft) in the Core Military Operations Area (Core MOA), the airspace above CALO. The floor for tactical speeds was lowered provisionally, from May–July, 2010–2012, so that the effects on beach-nesting waterbirds could be studied. The USMC had previously been permitted to fly at tactical speeds below 3048 m from August– April, the nonbreeding season for CALO's waterbirds. In addition to military aircraft using the Core MOA airspace, other civilian and military aircraft flew below the 914 m MOA floor, and in adjacent airspaces. When the Core MOA was not active, these aircraft could pass directly over the island at ≥914 m altitude.

My objectives were to assess Wilson's Plovers' responses to military aircraft using the Core MOA at tactical speeds, within the context of other environmental stimuli, including other military and civilian aircraft, ORVs, ATVs, pedestrians, predators and weather events, and to maximize the application of my data to the management needs of the National Park service and U.S. Marine Corps. In chapter 1, I documented physiological and behavioral responses to overflights and exposure to researchers. In chapter 2, I compared habitat characteristics between nest sites and random-selected unused points. In chapter 3, I estimated nest survival, apparent chick survival and productivity, and evaluated factors influencing population parameters. To evaluate a distributional response to Core MOA overflights, I compared the distribution of nesting Wilson's Plovers to the distribution of Core MOA overflights in Appendix B.

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CHAPTER ONE. Physiological and Behavioral Responses of Wilson's Plovers (*Charadrius wilsonia*) to Overflights and other Human Activities on North Core Banks, Cape Lookout National Seashore, North Carolina

ABSTRACT

The U.S. Marine Corps and National Park Service recently agreed to lower the altitude for tactical speed operations from 3048 m (10,000 ft) to 914 m (3,000 ft) in the airspace above Cape Lookout National Seashore, North Carolina. We studied the response of breeding Wilson's plovers to this change in aircraft traffic, within the context of other human activities, including other overflights. We compared heart rate, incubation rate and vigilance behavior during overflights and other human activities to time periods without those stimuli. Wilson's plovers increased vigilance behavior during military rotary-wing and civilian fixed-wing overflights, but did not respond to military fixed-wing aircraft. Plovers were vigilant more and incubated less when researchers were present. Heart rate did not change during overflights. Only 3 out of the 50 aircraft that used the lowered airspace floor during the 2 breeding seasons flew within 1.6 km of an active Wilson's plover nest. Therefore, we do not think that the lower altitude for tactical speed flights, at the current level and pattern of use, impacts breeding Wilson's plover.

KEY WORDS audio monitoring, aircraft noise, *Charadrius wilsonia*, disturbance, heart rate, incubation, North Carolina, overflights, vigilance, Wilson's plover.

INTRODUCTION

With a growing human population, increasing attention is being paid to the effects of human activities, including the use of aircraft, on wildlife. Most studies of avian responses to aircraft have been limited to raptors and waterfowl. Even within these groups, behavioral responses have differed widely, depending on reproductive state, activity, age, exposure frequency, and species (Kushlan 1979, Larkin 1996, Efroymson et al. 2000). Black et al. (1984) found that low-altitude overflights by military fixed-wing aircraft caused a higher frequency of alert posture in some species, but overall had little effect on waterbird colonies. Similarly, nesting osprey did not exhibit behavioral responses to low-altitude military fixed-wing aircraft (Trimper 1998). Military rotary-wing aircraft caused wintering bald eagles to flush (Stalmaster and Kaiser 1997). Harlequin ducks responded more strongly to fixed-wing aircraft than rotary-wing aircraft overflights (Goudie 2006), but military overflights did not alter time-activity budgets of the wintering duck species studied by Conomy et al. (1998a). A greater percentage of Brant flocks than Canada Geese flocks flushed during overflights, and both species flushed more during rotary-wing overflights than fixed-wing overflights (Ward 1999).

Ability to habituate to overflights appears to also be species-specific. Conomy et al. (1998b) found that black ducks habituated to overflights, but wood ducks did not. Red-tailed hawks reacted more strongly to overflights immediately after they were introduced, than they did later (Anderson et al 1986). Several studies have found that intensity of response was correlated with lateral distance, and perhaps to a lesser degree, with altitude (Ellis 1991, Delaney 1999, and Ward 1999).

Aircraft are a significant source of noise in remote and protected areas. As environments free of anthropogenic noise become increasingly rare, understanding how wildlife perceive and respond to noise stimuli is important for effective management of protected areas (Barber et al

2011, Lynch et al. 2011, Ortega 2012). Possible responses to noise include shifts in habitat use to avoid noisy areas, vocalization shifts, and behavioral changes such as fleeing in response to noise stimuli, increased vigilance, and physiological stress responses. Wildlife may perceive noise as a signal of predation risk and increase their investment in antipredator behavior at a cost to other activities (Frid and Dill 2002). Noise can mask vocal signals and cause behavioral changes that divert time and energy away from foraging, or reproductive behaviors (Ortega 2012, Schroeder et al. 2012). Physiological stress is energetically costly and can impair body condition and decrease reproductive success (Cyr and Romero 2007, Blickley and Patricelli 2010).

At Cape Lookout National Seashore, NC (CALO, Fig. 1) the U.S. Marine Corps (USMC) and National Park Service (NPS) agreed to lower the altitude for tactical speed operations (>250 kts) from 3048 m to 914 m in the Core Military Operations Area (Core MOA, Fig. 2), the airspace situated over a portion of CALO. The floor for tactical speeds was lowered provisionally, from May–July 2010–2012, so that the effects of low altitude tactical speed military overflights on beach-nesting shorebirds could be studied. We studied the impact of overflights and other human activities on the Wilson's plover, one of 6 state-protected bird species in North Carolina. The USMC already had permission to use the 914 m floor from August–April, when shorebirds were not breeding on CALO.

Our research objectives were 1) to compare incubation and vigilance behavior during overflights to time periods with no overflights, 2) to compare heart rate during overflights to time periods with no overflights, and 3) to compare incubation and vigilance behavior when researchers were present to time periods when researchers were absent.

STUDY AREA

Cape Lookout National Seashore (34° 23' N, 76° 17' W, Fig. 1) is located between Ocracoke

Island and Beaufort, NC, USA and is part of the barrier island ecosystem that extends along

much of the Atlantic seaboard from Massachusetts to Florida. The islands routinely change in

shape and number due to wind, waves and currents. During the study, CALO included the

islands of North Core Banks (NCB), South Core Banks (SCB), and Shackleford Banks (SFB),

which had about 90 km of ocean shoreline. Cape Lookout National Seashore had no permanent

residents, but NPS managed guest cabins and service facilities available for use by the public.

The islands were accessible via public car/person ferries and by private vessel. Motorized

vehicles, including all-terrain vehicles (ATVs) and off-road vehicles (ORVs), were allowed to

drive on the beach. In addition to military aircraft using the Core MOA airspace, other civilian

and military aircraft flew below the 914 m Core MOA floor, and in adjacent airspaces (R-5306A

and W-122, Fig. 2); these aircraft flew at $\geq$ 914 m in altitude over the islands when the Core

MOA was not active. We focused our study on NCB because this island was within the Core

MOA.

Wilson's plovers nested at 5 sites (Fig. 1) on NCB. At the northeastern end of the island,

Wilson's plovers nested on North Portsmouth Flats (NPF) and South Portsmouth Flats (SPF).

These flats were contiguous to each other, although habitat types used for nesting differed

between the two. At NPF plovers nested primarily on a small portion of the flat covered by an

algal mat and sparse vegetation, predominately *Salicornia* spp. At SPF there was very little

vegetation, and plovers nested in bare sand and shell substrates at dune edges or on the open flat.

At a third site, Kathryn-Jane (KJ), about 3.5 km southwest of SPF, Wilson's plovers nested on

the beach, and on a small vegetated flat. At the southwestern end of the island, nests were

associated with 2 recently closed inlets, New Drum Inlet (NDI) and Old Drum Inlet (ODI). At both sites plovers nested in interdune areas adjacent to flats that formed when the inlets closed.

North Portsmouth Flats, SPF, NDI and ODI were all closed to the public during the nesting season. At these sites, plovers nested mostly behind the primary duneline, and were not exposed to beach traffic or pedestrians. At SPF, where there was not a continuous primary duneline, the beach was wide and vehicles usually drove along the high tide line, so passing beach traffic was distant (usually > 250 m). At KJ, birds that nested on the beach were exposed to beach traffic.

METHODS
  Field Methods

We searched for Wilson's plovers' nests during the nesting season (Apr–Jul) by walking transects through all potential plover nesting habitat on North Core Banks (Fig. 1) every 3–4 days. If we observed a territorial pair or bird exhibiting nest defense, we hid in a blind or in vegetation and waited for the bird to resume incubation. When we located a nest, we recorded its location using a GPS unit (Garmin International, Olathe KS) and took a photograph of the nest and surrounding vegetation. We floated all eggs from nests found with 2 or 3 eggs to estimate incubation stage and hatch and initiation dates (Alberico 1995, Dinsmore et al. 2002).

We deployed auto-triggered cameras (Reconyx, Inc., Holmen, WI) at every nest we found in 2010, except at NPF, where we exclosed (Melvin et al. 2002) and deployed cameras at every other nest because we suspected that fish crows (*Corvus ossifragus)* were using the cameras as cues to find and depredate nests. In 2011, we deployed cameras at every nest we found except we used exclosures and put cameras at every other nest at NPF and SPF, because we observed fish crows at these sites. We visually checked nests all nests every 1–3 days. Cameras were encased in wooden housing for protection and camouflage, and placed

8

approximately 2 m from nests (Appendix A, Fig. 1). We found that a distance of about 2 m from the nest-site was ideal for capturing detailed images of the incubating bird for behavioral analysis. Cameras were set to take a photo every 5 secs and powered by an external battery (Tempest Batteries, San Jose, CA) buried in a watertight container near the nest. We changed battery units every 5–6 days in 2010 and every 4–5 days in 2011. We calibrated cameras' internal clocks to an atomic clock at each deployment.

We recorded ambient sound and sound levels during overflights using continuously recording Zoom H2 digital audio recorders (Samson Technologies Corp, Hauppauge, NY). Digital audio recording units were placed in weatherproof, wind and sand screened housing, and mounted on a wooden stake approximately 1.5 m off the ground, ≤ 150 m from nests being monitored with cameras. In 2010, we calibrated digital recording units to an atomic clock every 4–5 days. In addition, in 2011 we placed a wristwatch, calibrated to an atomic clock, inside the housing of each audio recorder. The wristwatches were set to sound an alarm every day at noon to aid in synchronizing the audio and visual data.

We built heart rate monitors by soldering a microphone (Digi-Key, Thief River Falls, MN) to an audio cable and embedding the microphone attached to one end of the cable in a 1¼''-long plastic egg. We painted the artificial egg to look realistic and used Parafilm® to weatherproof the embedded microphone. We connected the artificial egg microphone to a digital voice recorder (Olympus America, Inc., Center Valley, PA). We deployed artificial egg heart rate monitors at approximately half the nests that received cameras (Appendix A, Fig. 2a). We attempted to deploy a heart rate monitor at every other nest with a camera. If substrate type and dense vegetation prohibited deployment at a nest, we deployed the unit at the next nest we found. We sealed the digital voice recorder in a waterproof dry case and buried it 1–2 m from the nest

(Appendix A, Fig. 2b). We did not record heart rate continuously because recorder battery life was 26.5 hrs and we changed batteries every 1–3 days, coincident with a nest or equipment check.

The USMC provided us with the date, time, aircraft type, velocity, and ingress/egress coordinates of military aircraft traversing the Core MOA during the Wilson's plover breeding season. In addition, we opportunistically recorded the aircraft type, time, general location (site name or nearest mile-marker), direction and estimated altitude for all types of aircraft visible from the study area. These aircraft included military aircraft (turbofan jets, duel and single-rotor helicopters and turboprop transport planes) and civilian aircraft (twin and single-engine helicopters and light-weight piston-engine planes).

Behavior and Audio Sampling

We used Audio2NVSPL Audio Converter Version 1.3877 (National Park Service Sound Lab, Ft. Collins, CO) to convert mp3 files produced by audio recorders to text files. We then used Acoustic Monitoring Toolbox Version 1.3877 (National Park Service Sound Lab, Ft. Collins, CO) to view the text files as a spectrogram. We used the time and location, and direction of travel information from the USMC, or from our field observations to track aircraft throughout the island by finding changes in intensity identifiable as overflight noise on spectrograms of spatially sequential audio recorders.

We used two sound metrics, maximum sound pressure level (LEQ_{max}) and sound exposure level (SEL). The LEQ is the equivalent average peak energy level integrated over 1 sec; LEQ_{max} is the loudest 1 sec interval for the period sampled. Sound exposure level is the total sound energy integrated for the duration of the sample period. We quantified LEQ_{max} and SEL in decibels (dB) on an A-weighted scale. The A-scale is weighted for the range of frequencies

humans are able to hear, and the hearing range for most birds is similar to that of humans (Dooling 1982, Meyer 1986, Beason 2004).

We sampled camera and audio data for 5 min before an overflight (hereafter pre), for the variable time period during which the overflight was above the ambient sound level (hereafter during), and for 5 min after an overflight (hereafter post). Observers quantifying behavior did not know when they were sampling an overflight or a randomly selected control time with no overflight. We included control samples in the same pre, during, post pattern as outlined above, to avoid sampling bias that could result if observers knew that a particular sample was collected during an overflight.

We recorded 3 behaviors: incubation (including incubating, shading, manipulating the eggs or nest substrate, and preening on the nest bowl), posture (alert or relaxed), and frequency of scans. We defined alert posture for as 1) alert upright (head and neck extended above back with feathers lying flat giving the bird a slim appearance, or 2) alert hunkered (head and tail lowered hiding white throat and undertail markings, with feathers flat (Appendix A, Fig. 3). We defined a scan as a horizontal change in head position from one frame to the next.

For each pre, during, or post-overflight sampling period, we recorded the total number of frames observed and the number of frames a bird incubated or exhibited alert behavior, and estimated the proportion of time spent in each behavior. Because scanning was an instantaneous behavior rather than behavioral state, we compared changes between frames, using the frame just prior to a sample period as a reference for the first frame of the sample period. We then calculated scanning frequency by dividing scans by total frames.

We compared these 3 behavioral response variables during time periods when researchers were present vs. absent at a nesting site. Unlike the transient overflights, researcher presence

typically lasted several hrs, so the pre, during, and post sampling scheme was not appropriate. Instead, we analyzed all of the pre samples collected for overflights and compared behavior when researchers were present to behavior when researchers were absent.

We calculated heart rate for 3 20-sec intervals. One interval was during the overflight, and the others were 5 min before and after the overflight. In some cases we could not detect a heartbeat, likely because the bird was not in contact with the microphone, or because the sound of wind obscured the sound of the heartbeat. If we could not detect a heartbeat during the pre or post sample periods, but we did detect it in the during sample, we shifted the sample earlier (for pre) or later (for post) and sampled at the first 20-sec period of detectable heart rate we encountered. We used camera footage to verify that the bird incubated continuously between sample periods, so that we did not sample the heart rate of recently active birds when shifting the pre and post samples. Heart beats were counted visually in Adobe Audition (Adobe Systems, Inc., Mountain View, CA) by 2 independent observers (Appendix A, Fig. 4). When observer counts differed by ≤ 5, we averaged the 2 counts for analysis. We discarded samples for which counts differed by > 5, because we deemed the audio quality to be low.

Analytical Methods

We conducted separate analyses for each aircraft type. Because we thought the loudest flights might be more disturbing, when sample size allowed, we conducted a separate analysis for subsets of overflights where the LEQ_{max} was $> 80dBA$. We chose to subset loud flights $>80dBA$ LEQ_{max} because the upper 70dBA-80dBA range is considered annoying to humans (Pepper et al. 2003), and is presumably more disturbing to birds, as well.

We compared the proportion of time a bird spent in each behavior between pre, during, and post-overflight time periods for each aircraft type using multi-response permutation

procedures for blocked data (MRBP; Blossom Version W2008.04.02, www.fort.usgs.gov, accessed 5 May 2012). MRBP is a non-parametric permutation test that can be used in lieu of linear models when data do not meet the assumptions of parametric tests. We used MRBP to compare responses by group (i.e. pre, during, post) while blocking by nest. We blocked by individual nest for all analyses, to account for possible bird-to-bird variation in response to stimuli. When the overall MRBP test of significance among pre, during, and post-overflight time periods for each event type was significant ($p < 0.05$), we conducted MRBP on each pair of groups (i.e. pre vs. during, post vs. during, and pre vs. post) to assess how the behavior differed among the two-way comparisons.

We used multiple linear regression (SAS Institute, Inc., Cary, NC) to fit a linear model with heart rate in beats per min as the response variable. Predictor variables were interval (pre, during or post-overflight), LEQ_{max}, SEL, and temperature (recorded by the nest cameras).

RESULTS

We detected 1107 overflights on spectrograms from audio data recorded during the plover nesting seasons from April–July, 2010–2011. Many of these overflights were the result of a single aircraft being detected on multiple recorders; based on our field records, we were able to distinguish 745 individual overflights at 67 different nests. In addition, the USMC provided data on 208 military aircraft using the Core MOA during the Wilson's plover breeding season. We detected 26 of the Core MOA overflights on at least one digital audio recorder, 11 of which were > 3048 m. We removed 1 of the 26 audible Core MOA overflights because it was a C-130 Hercules and the sound profiles from this type of aircraft were quieter and of differing frequencies than turbofan aircraft. This aircraft also was below tactical flight speed. Of the 25 remaining Core MOA overflights, only 1 flew within 1.6 km of nests at an altitude of ≤ 914 m, and 2 others flew within 1.6 km of nests at an altitude of < 3048 m.

13

We recorded > 28,000 hrs of camera footage at 83 Wilson's plover nests during the

nesting seasons in 2010 and 2011. From this footage we extracted 745 behavioral samples (each

sample consisted of a pre, during and post intervals). Blocking behavioral samples by nest

yielded 32 independent behavioral samples during Core MOA overflights, and 166 independent

behavioral samples during non-Core MOA overflights. Core MOA and non-Core MOA military

fixed-wing overflights had the highest LEQ_{max} of all overflights detected by our recorders;

however, the median LEQ_{max} values for military rotary-wing overflights were the loudest (Fig.

3). Military aircraft had higher median LEQ_{max} than civilian overflights (Fig. 3).

There was no difference in time spent incubating by Wilson's plovers between the pre,

during, and post samples for any type of overflight ($p > 0.05$, Table 1, Fig. 4). Plovers were alert

more during military rotary-wing overflights than in the pre-flight or post-flight periods (Table 1,

Fig. 5). Plovers scanned more during military rotary-wing overflights (Table 1, Fig. 6), and more

during the pre and during samples for civilian fixed-wing overflights (Table 1, Fig. 6). During

Core MOA overflights, plovers scanned more during the pre than post sample, but the time spent

scanning during the overflight was not different from the pre and post samples (Table 1, Fig. 6).

We found no differences in the behaviors among the pre, during, and post-overflight time

period for overflights > 80dBA (Table 1, Fig. 7). Wilson's plovers incubated less when

researchers were present at the nesting site and were alert more while incubating with researchers

present, but there was no difference in scanning frequency when researchers were present vs.

absent (Table 2, Fig. 8).

We sampled Wilson's plovers' heart rate during 43 overflights at 7 different nests; no

heart rate samples were recorded during Core MOA overflights. There was no difference in

heart rate between pre, during, and post-overflight periods, nor was the heart rate related to

LEQ$_{max}$ or SEL. Heart rate was negatively correlated with temperature within the range of our data (Fig. 9).

DISCUSSION
Behavior

Like wintering bald eagles (Stalmaster and Kaiser 1997), Wilson's plovers exhibited the strongest behavioral response to military rotary-wing aircraft. Because alert plovers were typically immobile, the increase in both time spent alert and scanning frequency during rotary-wing overflights likely subtracted cumulatively from time spent in non-vigilant activities. The sample means for military rotary-wing overflights >80dBA showed the same trend, however, the changes in behavior were not significant, possibly because our tests lacked power due to the small sample size. Wilson's plovers did not change incubation or vigilance behavior during military fixed-wing overflights. Although we saw a significant decrease in scanning frequency in the post sample compared to the pre sample for Core MOA overflights, it seems unlikely that this change was a response to the overflight, as we did not see this trend with other military fixed-wing overflights. On average, Core MOA overflights were among the most distant (altitude and lateral distance) because USMC data provided a record of overflights that we may not have detected in the field.

There is no clear trend in how birds respond to rotary-wing aircraft compared to fixed-wing aircraft (Efroymson 2000). The noise from rotary-wing aircraft is fundamentally different from that of fixed-wing aircraft because, in addition to the engine noise, the rotors cause vibrations that propagate differently than sound pressure waves (Larkin 1991). As with most other studies of aircraft disturbance (Conomy et al. 1998b, Trimper et al. 1998, Ward et al. 1999, Goudie 2006), noise and visual cues were confounded in our study. The increase in scanning frequency before and during civilian fixed-wing overflights may be because plovers were

responding to the aircraft itself, rather than the overflight noise. We often saw small low-altitude aircraft before hearing them, and birds, which are thought to have higher visual acuity than humans (Gill 2007), probably detected this type of aircraft visually before the overflight noise reached the recording unit. Most of the civilian fixed-wing air traffic at CALO was from piston-engine prop planes giving air tours of the National Seashore.

We do not expect that the increases in time spent alert and scanning frequency we documented impacted demographic parameters in the population of Wilson's plovers we studied, especially considering the low frequency of exposure to overflights relative to other environmental stimuli. However, the link between noise and behavioral and demographic responses can be complex and subtle. For example, noise can disrupt communication between mates, weakening the pair bond, and between chicks and parents, changing provisioning rates (Habib et al. 2007, Slabbekoorn and Ripmeester 2008).

Few studies have measured both behavioral and demographic responses to overflights. A study of raptors did not find a link between a behavioral response (flushing) and decreased reproduction or survival (Anderson et al. 1986). However, like most ground-nesting shorebirds, and unlike raptors, Wilson's plovers rely primarily on secrecy and the cryptic coloration of their eggs and body to protect their nests from predators. Thus, even a small increase in bird movement on or near the nest may increase the risk of being detected by a predator. Ground-nesting, cryptic shorebirds often do not flush from the nest when presented with an environmental stimulus. For example, we photographed plovers that continued to incubate while raccoons investigated the camera several meters away, and only flushed when the raccoon approached the nest directly. Given that plovers respond to threats to their nest in general by

remaining immobile until detection seems certain, they may not incubate less due to overflights, even if they perceive them as threatening.

Heart Rate

Measures of heart rate have been used in conjunction with behavioral monitoring as an additional index of response to environmental stimuli (Nimon et al. 1996, Stout and Schwab 1980). The fact that heart rate did not increase during overflights, and the lack of relationship between heart rate and LEQ_{max} or SEL, is further evidence that plovers did not perceive overflights as threatening. However, we were unable to sample heart rate during the loudest overflights because the overflight noise overwhelmed the sound of the heart beats on our recorders. Since low-altitude Core MOA overflights rarely occurred near Wilson's plover nests, even if they elicited a transient heart rate response, it likely contributed little to the stress these birds face from other, more common, environmental stimuli.

To our knowledge, this the first study to use artificial egg heart rate monitors to record the heart rate of a species as small as the Wilson's plover for extended periods in the field. Our design was based on a heart rate monitor built by Arnold et al. (2011) to monitor the heart rate of larger waterbird species. Our device cost <$5 (not including the mp3 recorder), and was simple to construct. Wilson's plover readily accepted the dummy egg, and sometimes continued to incubate it after the nest was predated.

Wilson's plover heart rate ranged from 180 to 708 beats per min. The birds we sampled were apparently below their thermoneutral zone (i.e. the temperature range at which no energy is expended to maintain body temperature), because heart rate was inversely correlated with ambient temperature, indicating that plovers increased heart rate to maintain body temperature at lower ambient temperatures. Avian temperatures are generally higher than mammalian

temperatures and are correlated with body mass, taxonomic group, behavior and environmental conditions (McNab 1966). We are not aware of any literature documenting body temperature for Wilson's plover, but body temperature is about 40°C for the golden plover, (Krijgsveld et al. 2003), a plover of slightly larger size that breeds in the Arctic and subarctic tundra. Although we documented ambient temperatures up to 53°C, we could not sample heart rate at these temperatures because plovers shaded their nests to allow airflow to help cool their eggs, and our heart rate monitors were not sensitive enough to record heart rate without direct contact. Temperature was recorded by the Reconyx cameras, which were in contact with the sand, thus recorded temperatures often exceeded the air temperature

Researcher Presence

For the most part, Wilsons' Plovers nested behind the primary dune line in areas designated as breeding bird sanctuaries by the NPS. These areas were closed to all motorized vehicles and to pedestrians. NPS staff and researchers were allowed into these areas on foot for the purpose of monitoring and conducting research. With the exception of 4 birds that nested on the front beach, and 3 birds that were exposed to motorized vehicles when a roadway was opened behind the dunes after nests were established, plovers were not regularly exposed to human activities, aside from researchers.

Based on our observations, Wilson's plovers were highly responsive to human presence, although they were probably more sensitive to researcher presence than they would have been to humans that did not approach their nests. It is not surprising that we saw a decrease in incubation and an increase in time spent alert when researchers were present because we visited sites to check nests and change and deploy nest monitoring equipment. We did not have information on

when other research teams and NPS staff were in nesting sites, so these results pertain only to Wilson's plover researchers.

MANAGEMENT IMPLICATIONS

Our data suggest that overflights from Core MOA aircraft, in the patterns of time, location, altitude and frequency observed during this study, do not pose a threat to the nesting Wilson's plovers at Cape Lookout National Seashore. Because our sample size for overflights near the floor of the Core MOA was limited, we were not able to directly assess the impacts of these overflights on Wilson's plover behavior or physiology. However, only 3 Core MOA aircraft flew within 1.6 km of the Wilson's plover nest during the 2-year study and the lack of exposure suggests that, currently, the lowered floor is not detrimental to Wilson's plovers. The fact that we did not see changes in behavior during non-Core MOA military fixed-wing overflights further suggests that an increase in low altitude overflights would be unlikely to cause behavioral changes that would result in a demographic response. Low altitude rotary-wing aircraft elicited the greatest behavioral response. Although we do not believe that the transient increase in vigilance observed during these flights was likely to have affected survival or reproductive success, a substantial increase in rotary-wing air traffic at Cape Lookout National Seashore would merit further investigation.

Additionally, it appears that ongoing management by the NPS, coupled with the distribution of nesting Wilson's plovers on NCB, provides an adequate buffer to protect plovers from demographic responses to humans using the beach. At present, the NPS does not close areas to protect the Wilson's plover nesting habitat, however, piping plover and colonial waterbird nesting area closures protect most of the areas where Wilson's plovers breed. Wilson's plovers that nested on the beach at KJ were not protected unless least terns (*Sternula antillarum)* established a colony at that site, which happened in both years, although the tern colony was

19

established after Wilson's plovers began nesting at the site in both years. The interdune area

south of Old Drum Inlet that was used by Wilson's plovers was not closed to the public, however

beachgoers seldom used this area unless the front beach was closed due to piping plover

breeding activity, resulting in vehicle traffic being routed to a roadway behind the dunes, as

happened in 2011.

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TABLES

Table 1. Mean proportion of time spent incubating and alert, and scanning frequency by Wilson's plover (*Charadrius wilsonia*) for 5 min before an overflight, during the overflight, and for 5 min after the overflight for Core MOA flights, non-Core MOA military fixed-wing flights, civilian fixed-wing flights, military and civilian rotary-wing flights, with relevant data subsets by maximum sound pressure level, at North Core Banks, Cape Lookout National Seashore, NC, USA, April–August 2010–2011.

Event	Mean proportion time incubating[b]				MRBP[e]		Mean proportion time alert[c]				MRBP[e]		Mean proportion scan frequency[d]			MRBP[e]	
	N[a]	Pre	During	Post	S	p	N[a]	Pre	During	Post	S	p	Pre	During	Post	S	p
All Core MOA flights	32	0.73	0.77	0.82	-0.79	0.18	30	0.04	0.04	0.02	0.74	0.75	0.53[A]	0.51[AB]	0.47[B]	-2.35	0.03
Core MOA flights >80dBA	4	0.73	0.49	0.42	-0.47	0.30	2										
All non-Core MOA military fixed-wing flights	57	0.70	0.67	0.72	-1.49	0.08	49	0.01	0.02	0.02	0.44	0.59	0.56	0.59	0.56	-0.58	0.22
Non-Core MOA military fixed-wing flights >80dBA	15	0.66	0.62	0.68	-0.43	0.28	9	0.04	0.01	0.00	0.71	0.74	0.49	0.53	0.48	0.95	0.85
All civilian fixed-wing flights	50	0.63	0.65	0.68	0.02	0.41	44	0.04	0.03	0.03	0.37	0.59	0.54[A]	0.57[A]	0.51[B]	-2.63	0.02
All military rotary-wing flights	52	0.72	0.69	0.72	0.74	0.75	49	0.01[A]	0.07[B]	0.01[A]	-3.72	<0.01	0.51[A]	0.60[B]	0.53[A]	-9.64	<0.01
Military rotary-wing flights >80dBA	13	0.67	0.51	0.58	-0.19	0.35	10	0.01	0.09	0.00	-1.34	0.10	0.57	0.32	0.81	-0.28	0.31
All civilian rotary-wing flights	7	0.83	0.79	0.96	0.13	0.47	6	0.01	0.02	0.00	1.80	1.00	0.56	0.69	0.57	-0.16	0.36

[a] Samples for overflight analyses were blocked by nest, such that a block for the MRBP analyses of overflight responses was the averaged response for each nest.

[b] Mean proportion of time spent incubating, defined as sitting on or shading eggs or chicks, was calculated as the number of frames incubating per total number of frames; 'pre' and 'post' samples were always 5-min in length, but the 'during' sample was variable in length as determined by the exposure (seconds) of the nest to the event.

[c] Mean proportion of time spent in alert posture, defined as upright or hunkered with feathers flat, was calculated in the same manner as above.

[d] Mean proportion frequency of scanning calculated in the same manner as above. Scanning was defined as a horizontal change in head orientation between frames.

[e] Results of Multiresponse Blocked Permutation Procedure comparison of mean proportion time incubating between pre-, during-, and post-event samples, where S = Pearson Type III test statistic and p = significance value of the test (alpha = 0.05). No capital letters are shown if there was no difference between pre, during, and post proportion time incubating. When there are significant differences, means with the same capital letter are not statistically significant among the pre, during, and post samples.

Table 2. Mean proportion of time spent incubating and alert, and scanning frequency by Wilson's plover (*Charadrius wilsonia*) when researchers were present vs. absent, at North Core Banks, Cape Lookout National Seashore, NC, USA, April–August 2010–2011.

Event	Mean proportion time incubating[b]		MRBP[e]		Mean proportion time alert[c]		MRBP[e]		Mean scan frequency[d]		MRBP[e]	
	N[a]	Mean	S	p	N[a]	Mean	S	p	N[a]	Mean	S	p
Researchers Present	47	0.46[A]	-12.8	<0.01	34	0.08[A]	-2.91	0.02	34	0.56[A]	-0.10	0.30
No Researchers Present	47	0.75[B]			34	0.02[B]			34	0.54[A]		

[a] Samples for the researcher presence analysis were blocked by nest, such that a block for the MRBP analyses of responses to researcher presence was the averaged response for each nest.

[b] Mean proportion of time spent incubating, defined as sitting on or shading eggs or chicks, was calculated as the number of frames incubating per total number of frames; 'pre' and 'post' samples were always 5-min in length, but the 'during' sample was variable in length as determined by the exposure (seconds) of the nest to the event.

[c] Mean proportion of time spent in alert posture, defined as upright or hunkered with feathers flat, was calculated in the same manner as above.

[d] Mean proportion frequency of scanning calculated in the same manner as above. Scanning was defined as a horizontal change in head orientation between frames.

28

[e] Results of Multiresponse Blocked Permutation Procedure comparison of mean proportion time incubating between pre-, during-, and post-event samples, where S = Pearson Type III test statistic and p = significance value of the test (alpha = 0.05). No capital letters are shown if there was no difference between pre, during, and post proportion time incubating. When there are significant differences, means with the same capital letter are not statistically significant among the pre, during, and post samples.

FIGURES

Figure 1. North Core Banks, Cape Lookout National Seashore, North Carolina with 5 nesting

areas of Wilson's plovers in 2010 and 2011 (top plate) and a detailed view of the 4 sites with the

most Wilson's plover nests during this study; North Portsmouth Flats, South Portsmouth Flats,

Old Drum Inlet, and New Drum Inlet.
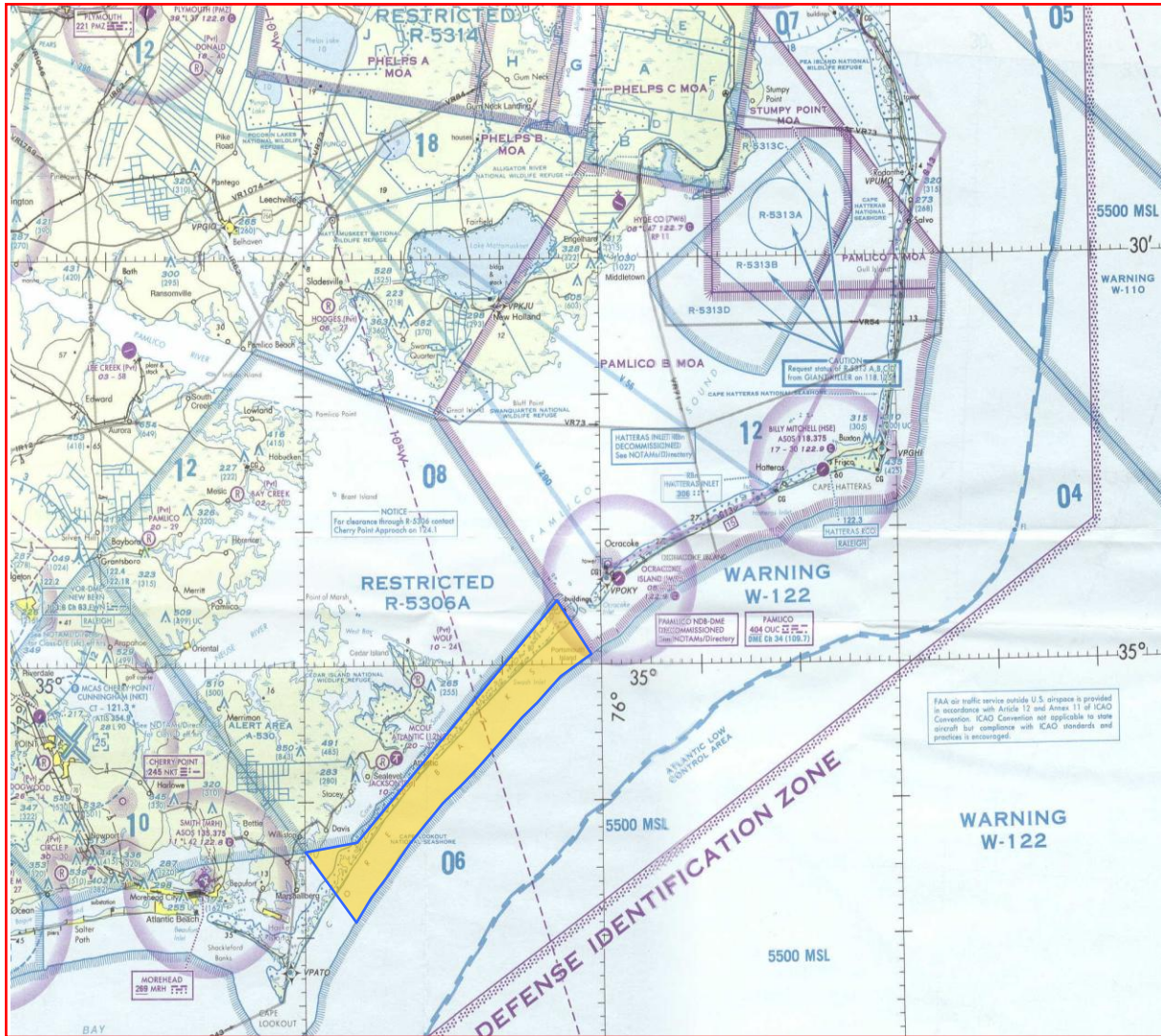
Figure 2. Core Military Operations Area (shaded in yellow), and adjacent airspaces, R-5306A

and W-122, at Cape Lookout National Seashore, NC.
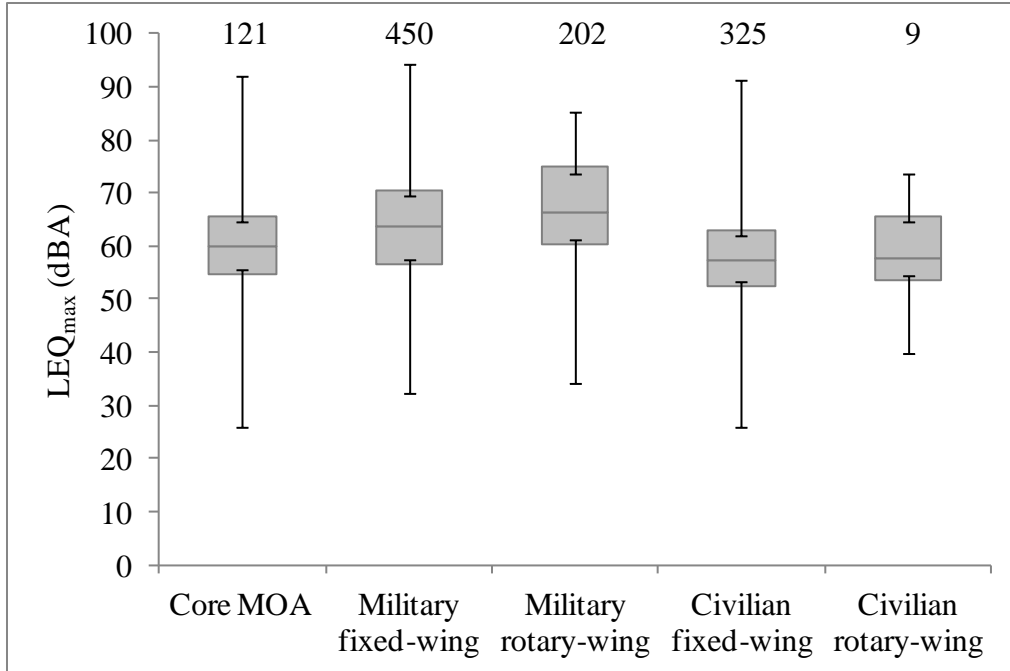
Figure 3. Maximum equivalent average peak energy level of the loudest 1 sec interval for the period sampled (LEQ_{max}) of overflights (sample sizes above box plots) recorded from digital audio recorders at Wilson's plover (*Charadrius wilsonia*) at North Core Banks, Cape Lookout National Seashore, NC 2010-2011. The boxes represent the values from the lower to upper quartile (25th to 75th percentiles). The middle horizontal line represents the median, and the ends of the vertical lines represent the maximum and minimum values. Audio data were calibrated and post-processed using Larson Davis 831 Sound Level Meters, and A2NVSPL and Acoustic Monitoring Toolbox software programs (Natural Sounds Program, US National Park Service).
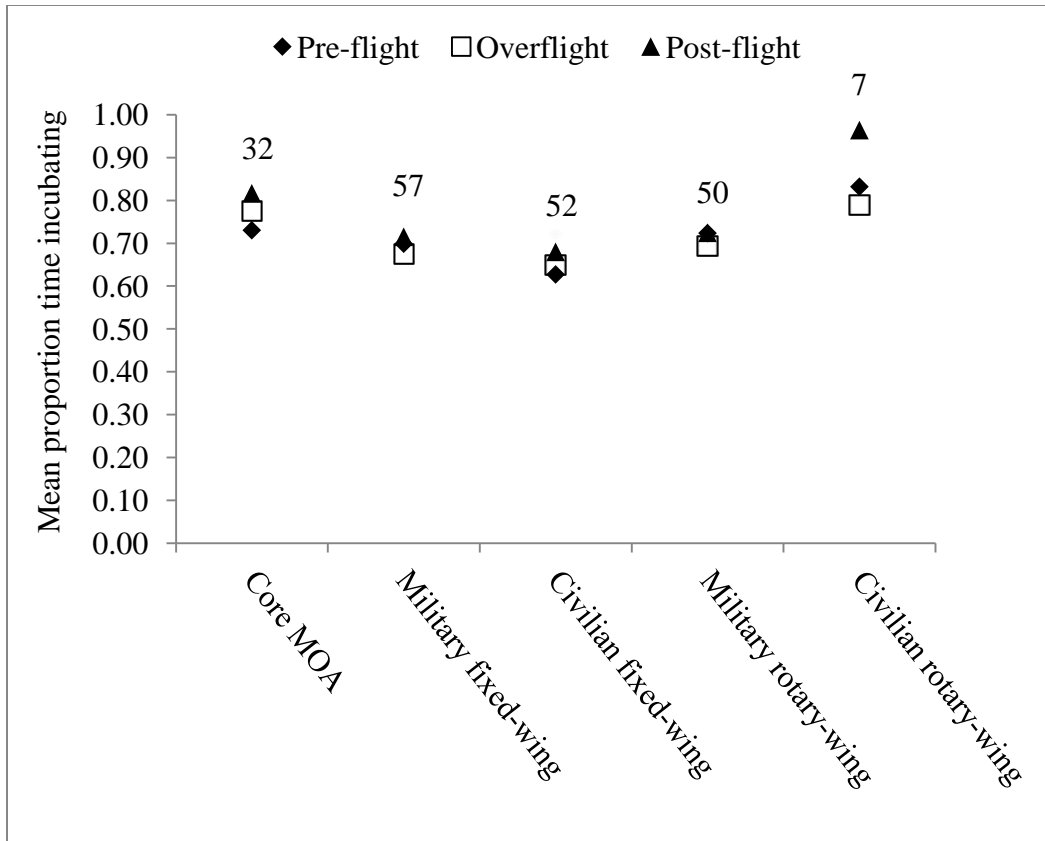
Figure 4. Mean proportion of time Wilson's plovers were incubating (out of total time possible) pre, during, and post overflight event that occurred over North Core Banks, Cape Lookout National Seashore, NC, 2010-2011. The numbers above symbols indicate sample size.
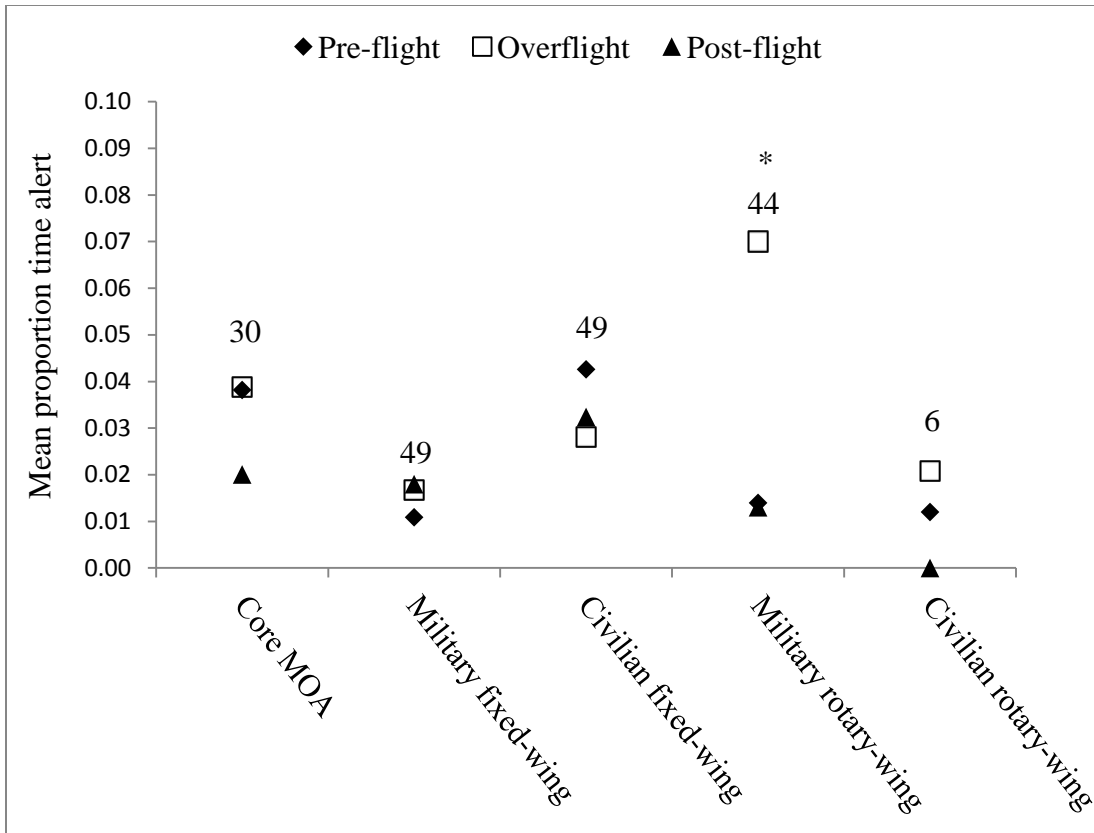
Figure 5. Mean proportion of time Wilson's plovers were alert pre, during, and post overflight events that occurred over Cape Lookout National Seashore, NC, 2010-2011. The numbers above symbols indicate sample size. *Indicates $p < 0.05$ for MRBP test among pre, during and post samples.
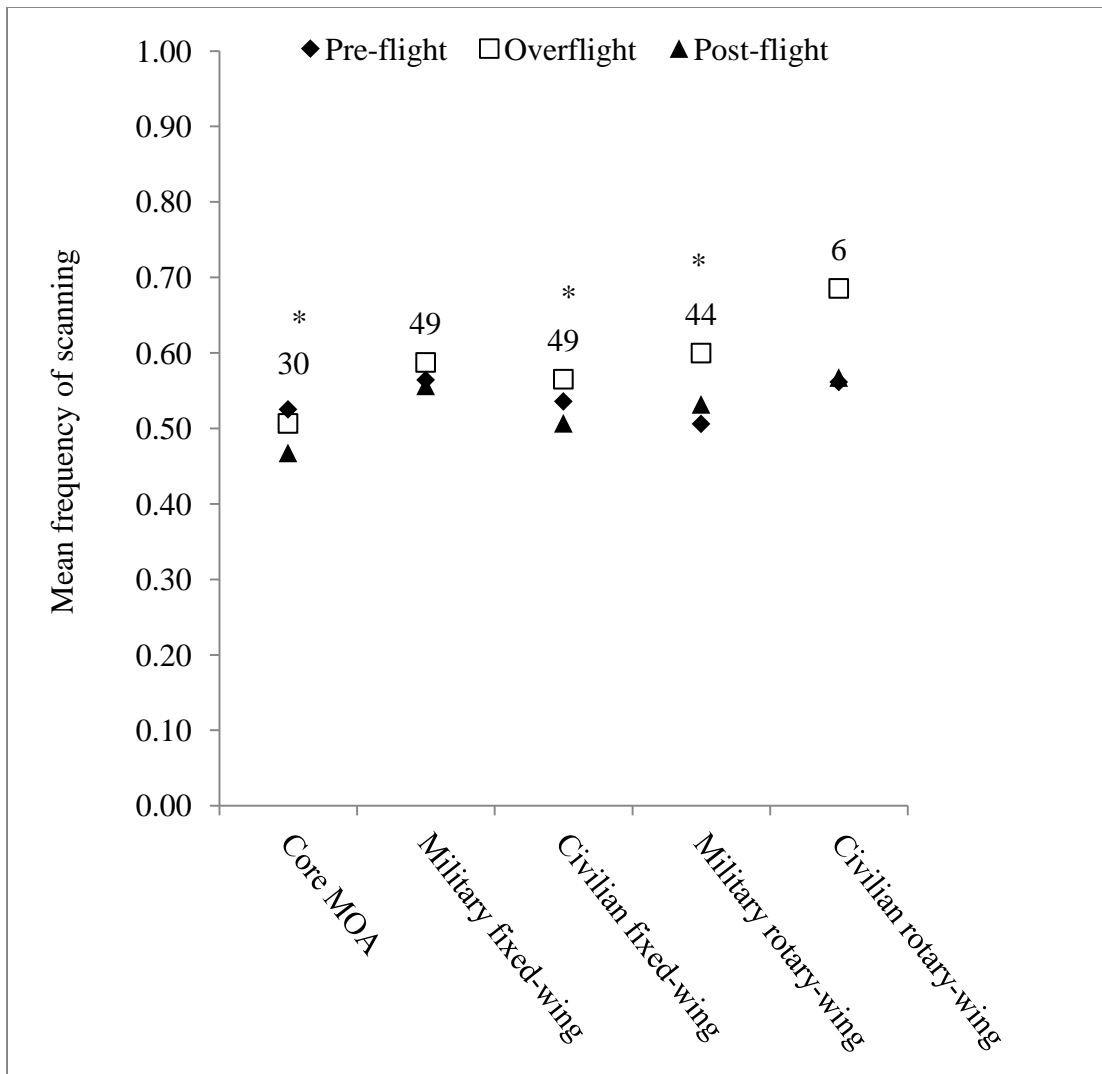
Figure 6. Mean scan frequency for Wilson's plovers pre, during, and post overflights that occurred at North Core Banks, Cape Lookout National Seashore, NC, 2010-2011. The numbers above symbols indicate sample size. *Indicates $p < 0.05$ for MRBP test among pre, during and post samples.
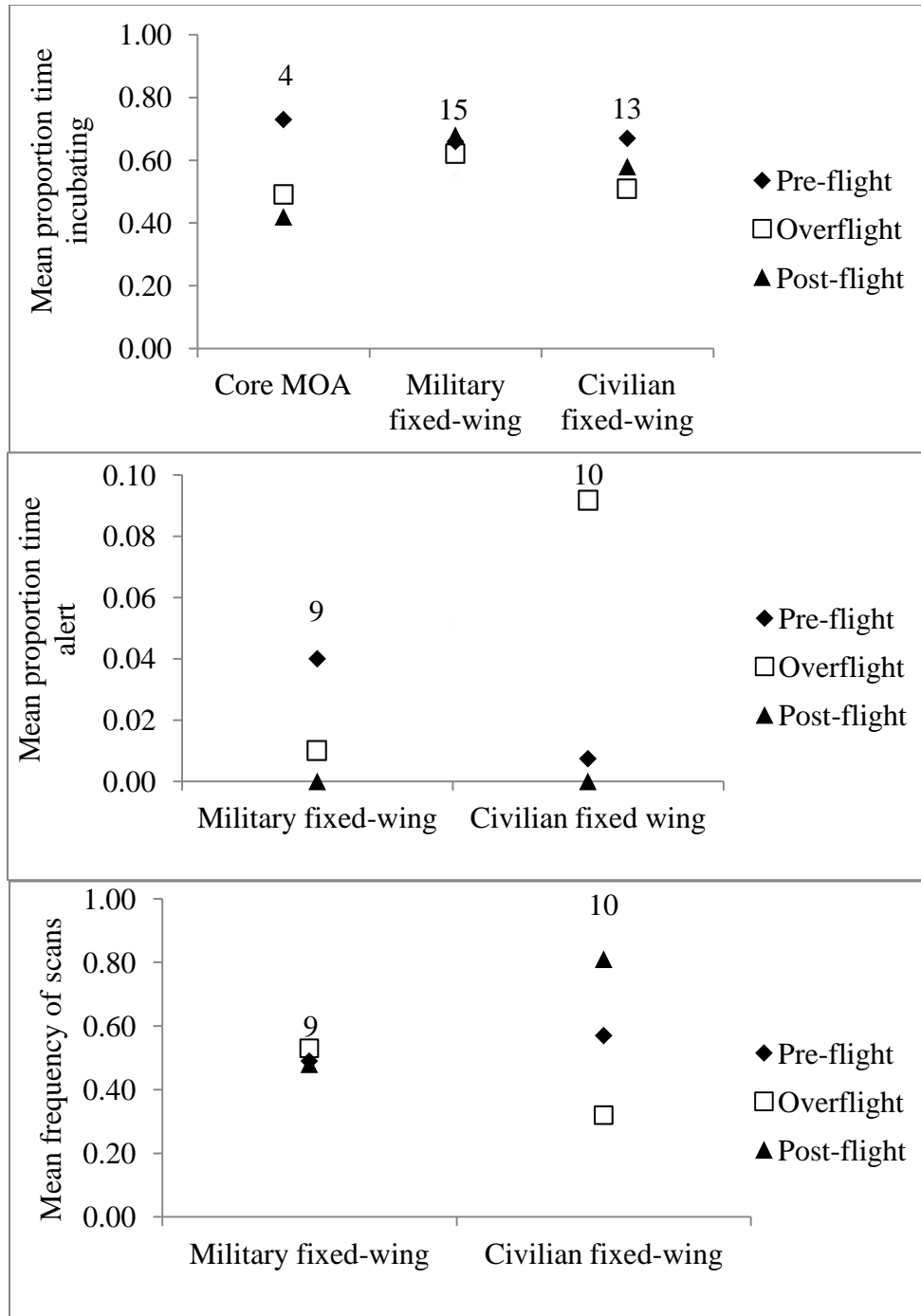
Figure 7. Mean proportion of time spent incubating and alert, and scanning frequency were not different from pre and post samples during loud overflights (> 80dBA LEQ_{max}) by Wilson's plovers at North Core Banks, Cape Lookout National Seashore NC, 2010-2011.
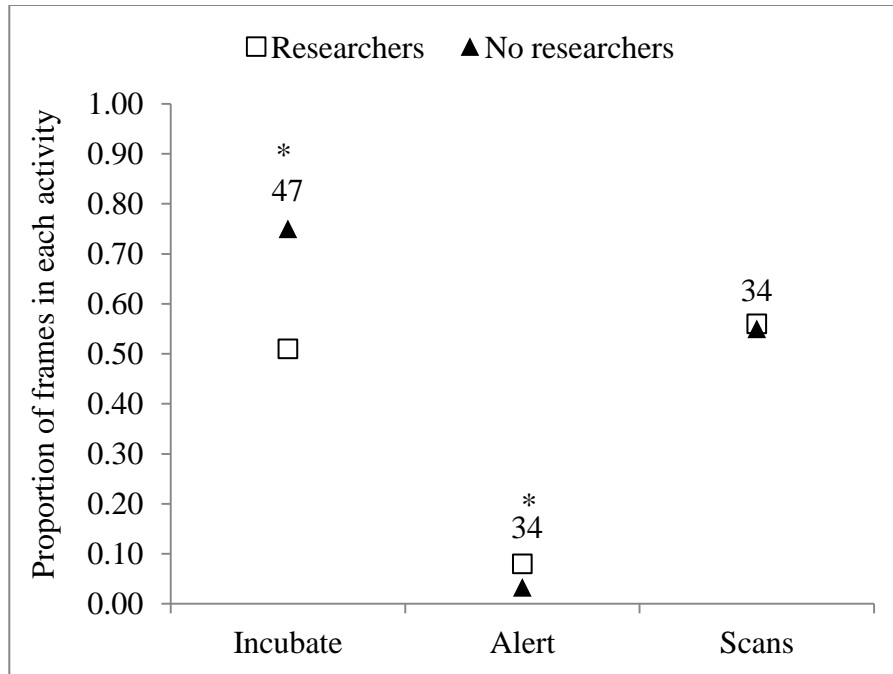
Figure 8. Proportion of frames Wilson's plovers were incubating and alert, and scanning frequency of Wilson's plovers during periods when researchers were present vs. absent at a nesting site at Cape Lookout National Seashore, NC, 2010-2011. The numbers above symbols indicate sample size. *Indicates $p < 0.05$.
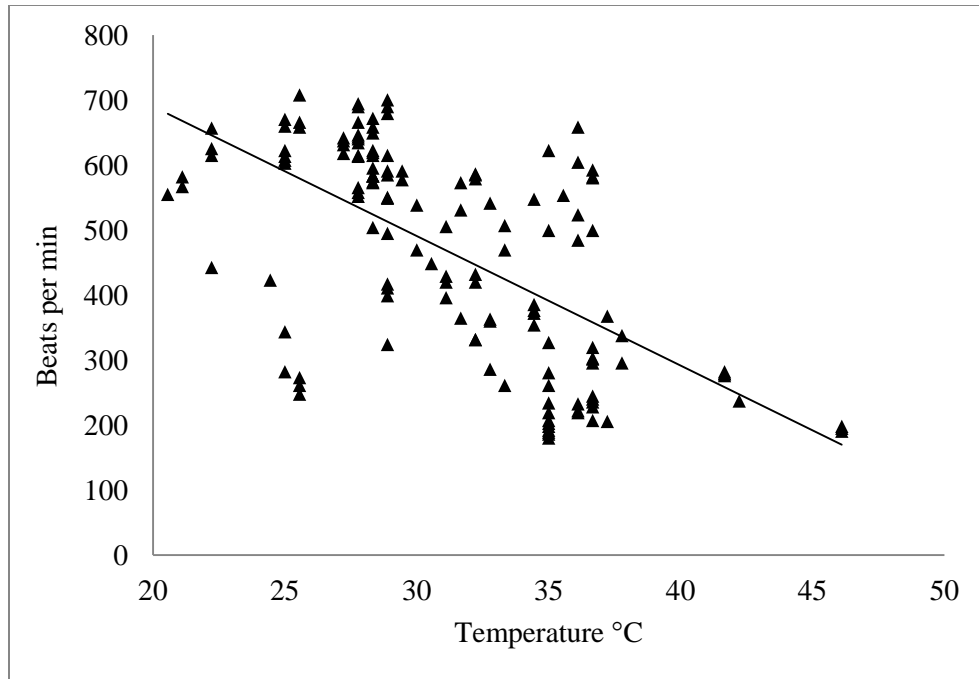
Figure 9. Heart rate was negatively correlated with ambient temperature ($R^2 = 0.44$, $p < 0.01$, RMSE =125.15, heart rate = 1119.46 – 20.71*temperature) for incubating Wilson's plover at North Core Banks, Cape Lookout National Seashore, NC, 2010-2011.

CHAPTER TWO. Nest Site Selection of Wilson's Plovers (*Charadrius wilsonia*) on North Core Banks, Cape Lookout National Seashore, North Carolina

ABSTRACT.— The Wilson's Plover (*Charadrius wilsonia*) is listed as a Species of Concern throughout its breeding range in the southeastern United States. There is little information on population trends of Wilson's Plovers, but there is concern that, as has happened with other coastal temperate-zone breeding plovers, habitat loss and degradation is causing the population to decline. There are few published studies of Wilson's Plover habitat selection, and most of the studies have focused on characteristics of the nest microhabitat. Our objectives were 1) to compare habitat use vs. availability on an island-wide scale for nesting Wilson's Plovers, 2) to understand how distance to geomorphic features and vegetative cover influenced nest-site selection on an island-scale, and 3) to understand how distance to geomorphic features and vegetative cover influenced nest-site selection locally, in areas used by nesting Wilson's plovers at Cape Lookout National Seashore, North Carolina. We classified and mapped six different nesting habitats and estimated use vs. availability. To understand how distance to geomorphic features and vegetative cover influenced nest site selection, we compared the distance of nest points and random, unused points to geomorphic features on an island-scale and on a local-scale at sites used for nesting. Wilson's Plovers selected for interdune areas, flats and isolated dunelets on flats and against beach and dunes. Distance to geomorphic features did not influence nest-site selection at the island-scale. At the local scale, the probability of a location being used for nesting increased as distance from dense vegetation decreased; none of the other variables affected the probability of site being used for nesting. Proximity to dense vegetation at this scale may be important to nest-site selection because it provides refuge for chicks immediately after hatching, when they are most vulnerable.

INTRODUCTION

The Wilson's Plover (*Charadrius wilsonia*) is listed as a Species of Concern throughout its breeding range in the southeastern United States, and as a Species of High Concern in the U.S. Shorebird Conservation Plan (Brown et al. 2001). The North American population is estimated at 6,000 individuals, however no broad scale, systematic studies have addressed population trends of Wilson's Plovers, so low confidence is placed in this estimate (Corbat and Bergstrom 2000, Brown et al. 2001). Population declines of other coastal temperate-zone breeding plovers, such as the Piping Plover (*Charadrius melodus,* Cairns and McLaren 1980) and Snowy Plover (*Charadrius nivosus;* Powell 2001), have been largely attributed degradation and loss of coastal breeding habitat, and there is concern that, like these beach-nesting shorebirds, Wilson's Plover breeding habitat is being lost to and degraded by beach modification projects, and coastal recreation and development. In order to manage coastal ecosystems to minimize the impact of these activities on Wilson's Plover breeding habitat, it is important to understand which habitat characteristics influence nest-site selection and reproductive success.

Birds select habitat at several spatial scales (Johnson 1980, Mayor et al. 2009). At the landscape scale, plovers select a general location (e.g. barrier island or mainland beach). They then establish a nesting territory within a general habitat type (e.g. a beach or sandflat), and finally they select a specific location to place their nest. Birds are thought to make choices about habitat characteristics at each spatial scale to optimize nesting success and chick survival (Orians and Wittenberger 1991).

Wilson's Plovers nest in a variety of habitats on mainland beaches and barrier islands along the Atlantic and Gulf of Mexico coasts (Corbat 1990, Bergstrom 1988). They have been observed nesting on open sandflats and beaches, dunes, at the edges of ponds, and in sparsely vegetated salt flats (Tomkins 1944, Bergstrom 1988, Corbat 1990, Hood 2006, Dikun 2008 and

40

Ray 2010). Most studies of Wilson's Plovers have described general habitat types (e.g. interdune, sandflat) used for nesting, and studied factors affecting nest site selection at the microhabitat scale. Wilson's Plovers often place nests near vegetation (Bergstrom 1988, Corbat 1990), and at some study sites, nests near or within vegetation were more likely to be successful than nests placed away from vegetation (Corbat 1990, Ray 2010). Conversely, Hood (2006) found that nests near dense clumps of vegetation had lower survival than nests in sparse vegetation.

Wilson's Plover nest site selection has rarely been studied at the scale of territory placement. Dikun (2008) reported habitat selection for habitat types categorized by topography and frequency of overwash for Wilson's Plovers at site in South Carolina, and Hood (2006) estimated ground cover up to 25 m from Wilson's Plovers' nests in Texas. Previous studies have suggested that selection at this scale may be a function of trade-offs between areas of high flood risk (beaches and sandflats) and dunes where risk of predation is higher (Dikun 2008, Ray 2010). The Piping Plover, a congeneric temperate nesting plover, appeared to respond to an increase in predation by shifting their nests away from the dunes, in a study by Burger (1987). The presence of adequate foraging territory may also influence nesting territory placement. Piping Plovers select nest sites close to bay side intertidal flats and ephemeral pools which have higher invertebrate densities than the adjacent beaches (Loegering and Fraser 1995, Cohen et al. 2009). Ray (2010) found that Wilson's Plovers used foraging territories closer to dense vegetation and water than expected at random, however a similar relationship has not yet been demonstrated with Wilson's Plover nesting territories. To understand selection at the scale of nesting territories we used the nest location as proxy for the territory, but measured habitat characteristics beyond the immediate nest area. Our objectives were 1) to compare habitat use vs. availability for

nesting Wilson' s Plovers at the island-scale, 2) to understand how distance to geomorphic

features and vegetative cover influenced nest-site selection on an island-scale, and 3) to

understand how distance to geomorphic features and vegetative cover influenced nest-site

selection locally, in areas used by nesting Wilson's Plovers.

METHODS

   Study Area.— Cape Lookout National Seashore (CALO; 34° 23' N, 76° 17' W, Fig. 1) is

located between Ocracoke Island and Beaufort, NC, USA and is part of the barrier island

ecosystem that extends along much of the Atlantic seaboard from Massachusetts to Florida. The

islands routinely change in shape and number due to wind, waves and currents. During the

study, CALO included the islands of North Core Banks (NCB), South Core Banks (SCB), and

Shackleford Banks (SFB), which had about 90 km of ocean shoreline. Cape Lookout National

Seashore had no permanent residents, but NPS managed guest cabins and service facilities

available for use by the public. The islands were accessible via public car/person ferries and by

private vessel. Motorized vehicles including all-terrain vehicles (ATVs) and off-road vehicles

(ORVs) were allowed to drive on the beach.

   Cape Lookout National Seashore is relatively pristine compared to other Atlantic barrier

islands, most of which are inhabited by humans and are subject to beach and dune stabilization

projects that interrupt natural processes, such as dune erosion and the formation of inlets, that

create shorebird habitat. Because natural processes are not interfered with on CALO, there may

be a broader range of habitats available to shorebirds than on barrier islands that are more

influenced by humans. We studied Wilson's Plover nest site selection on NCB, the northern-

most of CALO's three islands.

   Field Methods.— We searched for Wilson's Plovers' nests during two nesting seasons

(Apr–Jul) by walking transects through all potential plover nesting habitat on North Core Banks

42

(Fig. 1) every two to three days. When we observed a territorial pair, or bird exhibiting nest defense, we hid in a blind or vegetation and waited for the bird to resume incubation. When we found a nest, we recorded the nest's location using a GPS unit. After nests failed or hatched, we returned and measured distances from the nest bowl to geomorphic features and vegetative cover.

Use versus Availability.— To understand Wilson's Plover nest site selection we compared habitat use to habitat availability at the island-scale. We used ground transects and 0.3 m-resolution digital aerial imagery collected by the United States Geological Survey in 2009 to classify habitat as suitable or unsuitable for Wilson's Plover nesting. In May 2010, we sampled habitat at 100 m intervals on 73 transects, each covering a cross section of the island, starting on the beach side of the primary dunes, and running toward the sound. Transects were spaced 500 m apart along the entire island (Fig. 2). We recorded percent vegetative cover and general habitat type (beach, dunes, dunelet, flat, marsh, interdune, or vegetated flat) within a 1x1 m^2 quadrat every 100 m on the transects. We ended transects when we encountered continuous, dense (> 75% vegetative cover) vegetation because we deemed densely vegetated areas to be unsuitable for plover nesting. We marked each sample point with a GPS unit (Garmin International, Olathe KS), and projected these points on the 2009 aerial imagery in ArcGIS (Environmental Systems Research Institute, Redlands, CA). We used the habitat information associated with sampling points combined with the imagery to digitize a layer of potentially suitable habitat. In addition, we mapped the boundaries of some suitable habitats (beach, dunelet, flat, marsh, and interdune) by driving (to delineate the beach from the intertidal zone) or walking (all other habitats) the perimeter of each habitat type with a continuously recording GPS unit to accurately represent

edges and small features like dunelets (Fig. 1). We defined six potentially suitable nesting

habitats based on geomorphic structure and vegetative cover:

1. Beach: open sandy area with no vegetation between the intertidal zone and primary dune or

   vegetation line.

2. Dunes: the primary duneline and smaller hind dunes bordering the marsh.

3. Dunelet: isolated dune on a flat.

4. Flat: open areas behind the primary duneline. Where the duneline was not continuous, we

   defined the flat boundary as a straight line level with the dunes at either end of the flat.

5. Interdune: small sand and shell flats behind the primary dunes, interspersed with dunelets and

   low, sparse vegetation.

6. Marsh: moist flat area with <75% tall clumped vegetation, primarily *Spartina spp.*

Unsuitable habitat consisted of the intertidal zone, marsh with ≥75% vegetative cover, and

maritime forest (Fig. 1). We calculated the area for each of the six suitable habitats across the

whole island, and considered this an estimate of the area available to nesting Wilson's Plovers.

We calculated proportion of habitat use as the proportion of nests initiated in each habitat type.

We compared the expected use with the observed use using a chi-square test and Bonferronized

confidence intervals to determine selection for or against each habitat type (Neu et al. 1974,

Byers and Steinhorst 1984).

       Distance Analysis.—To understand how distance to geomorphic features and vegetative

cover influenced nest site selection at the island and local-scales, we compared the distance of

nest points and random, unused points from dunes, the high tide line, water, and dense vegetation

at both scales. We used Hawth's Analysis Tools for ArcGIS to generate random points

constrained to the area of the 6 habitats we defined as potentially suitable for Wilson's Plover nesting for the use vs. availability analysis.

At both nest sites and random points we measured the straight line distance to the nearest dunes, the high tide line, continuous, dense vegetation, and water. We made most measurements with a measuring tape, or GPS unit in the field, but measured the distance to some of the more distant geomorphic features using the habitat maps we created in ArcGIS. Water included ponds and mud flats, or tidal creeks that provided access to the sound. Ponds were small and brackish, maintained by rainfall and washover events. Pond size varied throughout the season, and by year. Tidal creeks flowed through the marsh between the flat and the sound. Mud flats extended into the sound at the recently closed inlets. Water levels fluctuated with tide, rainfall and wind, but these changes resulted only in meters of difference in horizontal measurements, between the high and low measures because deep channels held some water throughout the season. We did not include the ocean in our water measurements. The sound also was excluded from measurements where it was bordered by shrubs and/or dense marsh vegetation because we considered it to be inaccessible to plover broods. We measured to the nearest continuous duneline; isolated dunes (dunelets) were not included. For high tide, we measured the distance to the wrack line approximating the highest spring tide for the current season. Dense vegetation was defined as >75% vegetative cover.

We used logistic regression (SAS Institute Inc., Cary, NC) to compare habitat characteristics associated with nest-sites and unused, random sample points. We tested the fit of the global model with a Hosmer and Lemeshow goodness-of-fit test (Hosmer and Lemeshow 1989). We examined biologically plausible models with distance to nearest dunes, high tide line, continuous, dense vegetation, and water as explanatory variables. We included a categorical

variable called substrate that included the six habitat types defined in the use vs. availability

analysis, as a control variable. We used Akaike's Information Criterion adjusted for small

sample size (AIC_c) to rank models (Akaike 1973, Burnham and Anderson 2002). We considered

models with $\Delta AIC_c \leq 2.00$ as top models. We did this analysis twice, once on an island-wide

scale, and then on a local scale including only random points in areas used by nesting Wilson' s

Plovers.

RESULTS

Wilson's Plovers nested at five sites on NCB (Fig. 1). At the northeastern end of the

island, plovers nested on North Portsmouth Flats (NPF) and South Portsmouth Flats (SPF).

These flats were contiguous to each other, however, nesting Wilson's Plover's habitat use

patterns differed between the two flats. At NPF plovers nested primarily on a small portion of

the flat covered by an algal mat and vegetation, predominately *Salicornia* spp. This flat was

adjacent to SPF, and bounded by *Spartina* marsh, and maritime bush and forest on three sides. At

SPF, there was very little vegetation, and plovers nested on a bare sand and shell substrate at

dune edges or on the open flat. South Portsmouth Flats was bordered by open beach, marsh, and

tidal creeks that flowed through the marsh.

At the third site, Kathryn-Jane (KJ), about 3.5 km southwest of SPF, Wilson's Plovers

nested on the beach, and on a small vegetated flat. There was no direct access to the sound from

Kathryn-Jane Flats; primary dunes interfaced with the sound-side marsh (*Spartina* spp.*).* At the

southwestern end of the island, nests were associated with two recently closed inlets, New Drum

Inlet (NDI) and Old Drum Inlet (ODI). At both of these sites plovers nested in interdune areas

adjacent to flats that formed when the inlets closed. Interdune areas consisted of shell and sand

substrate interspersed with low dunes (≤1.5m) and low, sparse vegetation. Dominant plant

species at these sites were sea rocket (*Cakile harperi*), seashore-elder (*Iva imbricate*), seaside

pennywort (*Hydrocotyle bonariensis*), marsh pinks (*Sabata stellaris*), seabeach evening primrose (*Oenothera humifusa*), and American beach grass (*Ammophila breviligulata*). With the exception of KJ and parts of ODI, all of the nesting sites were closed to the public for the entire breeding season. The NPS closed KJ to the public when Least Terns (*Sternula antillarum*) began using the site, which resulted in closures for the latter part of the breeding season in both years. The main nesting area at ODI was south of the inlet and was not closed to the public, however beachgoers rarely went behind the dunes where Wilson's Plovers nested. In 2011, Wilson's Plovers nests were exposed to beach traffic when the NPS routed vehicles to roadway behind the dunes to avoid driving on the beach.

We sampled habitat at 108 nests and 100 random points in 2010 and 2011. We distributed 100 random points (50 in each year) within all potentially suitable habitats. Ray (2010) never saw broods move more than 2 km from nesting to final foraging territory, and at our site, we did not observe Wilson's Plovers nesting > 2 km from a pond, tidal creek, or inlet. Thus, we applied a 2 km radius buffer to water features and excluded parts of the island that fell outside of the buffer zone. This resulted in the exclusion of 16 random points from the narrow middle portion of the island (Fig. 1) from the local-scale analysis. In 2011, we increased time and effort spent searching for nests and found 72 nests, compared to only 36 in 2010. We estimated that about 40 breeding pairs used NCB in both years (see Chapter Three).

Wilson's Plovers used interdune areas, flats and isolated dunelets on flats more than expected based on their availability (Table 1). They used beach and dunes less than expected based on availability. At the island-scale, distance to dense vegetation and water were in all of the top models (Table 2). However, support was similar for the top four models, which included the global model (Table 2). There was no evidence that distance from geomorphic features

affected nest placement at the island-scale, as the 95% confidence limits encompassed 1 for all variables (Table 3). At the local scale, distance to dense vegetation was in all of the top models (Table 4). Support was similar for the top seven models, which included the global model (Table 4). The probability of a location being used for nesting increased as distance from dense vegetation decreased (the confidence limits did not encompass 1). The 95% confidence limits included 1 for all other variables, indicating that distance from dunes, water and high tide line did not affect probability of a site being used for nesting at the local-scale (Table 5).

DISCUSSION

Our findings that Wilson's Plovers selected for interdune areas and open flats were consistent with previous studies that have described habitat use by Wilson's Plovers (Bergstrom 1982, Bergstrom 1988, Corbat 1990, Hood 2006, Ray 2010, and Brown and Brindock 2012). Like Wilson's Plovers in South Carolina, (Dikun 2008), Wilson's Plovers on NCB selected for interdune areas with active overwash. Nearly one quarter of all nests were in interdune habitat, although interdune accounted for a small percentage of the total suitable habitat at our study site. At NPF, nests were concentrated on a portion of the flat covered by an algal mat substrate and vegetated with *Salicornia* spp. During the breeding seasons of both years of this study, the algal mat was dry, but at other times of the year it was inundated. The primary nest predators at NPF were fish crows (*Corvus ossifragus;* see Chapter Three) and we think that the short, but thick *Salicornia* helped conceal nests from areal predators while still allowing incubating plovers to see their surroundings. Plovers that nested in the *Salicornia* often raised their broods along the edge of the *Spartina* marsh near their nest-site, suggesting that the *Salicornia* flat, *Spartina* marsh border provided adequate cover and food resources, while pairs that nested on sand flats always moved their chicks to foraging territories near water or vegetation. In 2011, subterranean termites *(Rhinotermitidae spp*.) swarmed on the Salicornia flats, and broods appeared to be

48

foraging on the termites. In 2010, we did not see termite swarms, but the broods used the same areas. The Salicornia flat and Spartina marsh interface may be a rich source of insects for Wilson's Plovers broods on NCB, which lacks abundant Fiddler Crabs, which are thought to be an important food resource for breeding Wilson's Plovers at other sites (Bergstrom 1982, Ray 2010).

At the local-scale, the probability of site being used for nesting was influenced by distance to continuous, dense vegetation. Previous studies of nest site selection have focused on distance to vegetation in the immediate area of the nest bowl (Hood 2006, Dikun 2008, Ray 2010), while we measured nest distance from geomorphic features and vegetative cover, which were often several hundred meters from the nest bowl. Proximity to dense vegetation at this scale may be important to nest site selection because it provides refuge for chicks immediately after hatching, when they are most vulnerable. Conversely, vegetation can decrease the distance at which incubating birds can detect predators by blocking the line of sight and by providing cover for mammalian predators (Koivula and Ronka 1998, Amat and Masero 2004). Our results may have been driven by nest distribution at NPF, where nearly a third of the nests occurred. Avian predation accounted for most the nest failure at this site, so vegetation may have helped conceal Wilson's Plover nests and chicks, rather than predators. Strategies for hiding nests and chick may differ for different predators, thus, nest site selection is probably highly site-specific and dependent on habitat resources and predator community.

Predation caused most of the nest failure at NCB, while flooding posed a relatively minor threat during this study (see Chapter Three). Most of the nesting sites were on wide parts of the island where flooding was more often caused by rain pooling on the flat and overflowing inland ponds, or by high tides in the sound that pushed water through tidal creeks and onto the flats,

than by high ocean tides. Other studies have described Wilson's Plovers nesting at the edge of dunes (Corbat and Bergstrom 2000, Dikun 2008, Ray 2010). While we did find some nests at the toe of the dunes, especially in interdune areas, nests on flats were usually placed away from dunes, in open areas or associated with isolated dunelets.

Piping Plovers and Snowy Plovers can be more productive when nesting in association with tern colonies (Burger 1987, Powell 2001). Presumably this is because they benefit from the defensive behaviors by the terns. However, at NCB, Wilson's Plovers avoided the flats at NDI and ODI where terns, primarily the Least Tern, nested. We found two Wilson's Plover nests on these flats. Both were initiated early in the season before the terns had established a colony. One nest was depredated before terns arrived, and the other was abandoned after terns began to use the flat. At SPF, Wilson's Plovers nested in a tern colony, however nest predation was high at this site (see Chapter Three).

Wilson's Plovers used a variety of nesting habitats on NCB, but selected for flat, sparsely vegetated areas that are maintained by overwash and storm events. Wilson's Plovers on NCB probably benefit from the fact that the NPS does not interfere with natural erosion and depositions processes on the island, and thus they are able to use a broader range of habitats on NCB than they would on other barrier islands or mainland beaches where beach management may not allow for the formation of extensive flats and interdune areas. An understanding of habitat selection on a barrier island with little human interference can help inform management decisions about habitat modification so as to benefit the Wilson's Plover in less pristine environments.

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TABLES

Table 1. Proportion of use (P_u) vs. availability (P_a) and Bonferronized 95% confidence intervals on proportion of use (P_u) for different substrates used by nesting Wilson's Plovers (*Charadrius wilsonia*; n=108) at Cape Lookout National Seashore, North Carolina, 2010–2011. Use was defined as number of nests initiated in each type of substrate. Selection for (+), against (-) and no selection (=) each substrate is shown in final column.

Substrate	Area (ha)	P_a	P_u	Lower 95% CI	Upper 95% CI	Select
Beach	325.82	0.32	0.05	-0.01	0.10	-
Dunelet	1.33	0.00	0.08	0.01	0.15	+
Dunes	349.63	0.34	0.07	0.01	0.14	-
Flat	306.91	0.30	0.56	0.43	0.68	+
Marsh	22.93	0.02	0.01	-0.02	0.03	=
Interdune	10.95	0.01	0.23	0.12	0.34	+

Table 2. Top-ranked models ($\Delta AIC_c \leq 2.00$) from 14 single-and multi-variable logistic regressions for an island-scale analysis of habitat characteristics at Wilson's Plover (*Charadrius wilsonia*) nest sites (n=108 nests) and random unused points (n = 100 points) on North Core Banks, Cape Lookout National Seashore, North Carolina, 2010–2011.

Variables[e]	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]	Model Likelihood
HabType, DistDenseVeg, DistWater, DistDune	10	221.63	0.00	0.28	1.00
HabType, DistDenseVeg, DistWater, DistDune, DistTide(Global)	11	221.85	0.22	0.25	0.90
HabType, DistDenseVeg, DistWater	9	222.40	0.77	0.19	0.68
HabType, DistDenseVeg, DistWater, DistTide	10	222.61	0.98	0.17	0.61

[a] K = No. of model parameters

[b] AIC_c = Akaike's Information Criterion corrected for sample size.

[c] ΔAIC_c = difference between any given model's AICc and the best-fit model.

[d] w_i = Akaike model weight based on model likelihood divided by total of all model likelihoods.

[e] DistDenseVeg = distance to nearest continuous, dense (75% vegetative cover) vegetation measured in field with a tape measure or GPS unit, or in ArcGIS; DistDune= distance to the nearest continuous duneline, isolated small dunes (dunelets) were not included; DistTide= distance to the maximum normal high tide line for the current season; DistWater; distance to nearest pond, tidal creek, or inlet.

Table 3. Model-averaged parameter estimates and 95% confidence limits from the four top-ranked models ($\Delta AIC_c \leq 2.00$) from 14 single-and multi-variable logistic regressions for an island-scale analysis of habitat characteristics at Wilson's Plover (*Charadrius wilsonia*) nest sites (n=108 nests) and random unused points (n = 100 points) on north Core Banks, Cape Lookout National Seashore, North Carolina, 2010–2011.

Variable[a]	Parameter Estimate	SE	Log-odds ratio	Lower 95% CL	Upper 95% CL
DistDenseVeg	-0.00239	0.00124	0.99761	0.99519	1.00005
DistDune	0.00060	0.00065	1.00060	0.99933	1.00187
DistTide	-0.00004	0.00029	0.99996	0.99940	1.00052
DistWater	-0.00068	0.00043	0.99932	0.99848	1.00016

[a] DistDenseVeg = distance to nearest continuous, dense (75% vegetative cover) vegetation; DistDune= distance to the nearest continuous duneline, isolated small dunes (dunelets) were not included; DistTide= distance to the maximum normal high tide line for the current season; DistWater; distance to nearest pond, tidal creek, or inlet.

Table 4. Top-ranked models ($\Delta AIC_c \leq 2.00$) from 14 single-and multi-variable logistic regressions for a local-scale analysis of habitat characteristics at Wilson's Plover (*Charadrius wilsonia*) nest sites (n=108 nests) and random unused points (n=84 points) at sites used by nesting Wilson's Plovers on North Core Banks, Cape Lookout National Seashore, North Carolina, 2010–2011.

Variable[e]	K[a]	AIC_c[b]	ΔAIC_c[c]	w_i[d]	Model Likelihood
HabType, DistDenseVeg, DistWater, DistDune	10	216.63	0.00	0.19	1.00
HabType, DistDenseVeg, DistWater, DistTide, DistDune (Global)	11	216.80	0.16	0.18	0.92
HabType, DistDenseVeg, DistWater	9	217.34	0.70	0.14	0.70
HabType, DistDenseVeg, DistDune	9	217.43	0.79	0.13	0.67
HabType, DistDenseVeg, DistWater, DistTide	10	217.59	0.95	0.12	0.62
HabType, DistDenseVeg	8	218.06	1.42	0.09	0.49
HabType, DistDenseVeg, DistTide	9	218.26	1.63	0.09	0.44

[a] K = No. of model parameters

[b] AIC_c = Akaike's Information Criterion corrected for sample size.

[c] ΔAIC_c = difference between any given model's AICc and the best-fit model.

[d] w_i = Akaike model weight based on model likelihood divided by total of all model likelihoods.

[e] DistDenseVeg = distance to nearest continuous, dense (75% vegetative cover) vegetation; DistDune= distance to the nearest continuous duneline, isolated small dunes (dunelets) were not included; DistTide= distance to the maximum normal high tide line for the current season; DistWater; distance to nearest pond, tidal creek, or inlet.

Table 5. Model-averaged parameter estimates and 95% confidence limits from the seven top-ranked models ($\Delta AIC_c \leq 2.00$) from 14 single-and multi-variable logistic regressions for a local-scale analysis of habitat characteristics at Wilson's Plover (*Charadrius wilsonia*) nest sites (n=108 nests) and random unused points (n =84 points) at sites used by nesting Wilson's plovers on north Core Banks, Cape Lookout National Seashore, North Carolina, 2010–2011.

Variable[a]	Parameter Estimate	SE	Log-odds ratio	Lower 95% CL	Upper 95% CL
DistDenseVeg	-0.00253	0.00127	0.99747	0.99500	0.99995
DistDune	0.00054	0.00061	1.00054	0.99936	1.00173
DistTide	-0.00002	0.00026	0.99998	0.99947	1.00049
DistWater	-0.00030	0.00038	0.99970	0.99896	1.00044

[a] DistDenseVeg = distance to nearest continuous, dense (75% vegetative cover) vegetation; DistDune= distance to the nearest continuous duneline, isolated small dunes (dunelets) were not included; DistTide= distance to the maximum normal high tide line for the current season; DistWater; distance to nearest pond, tidal creek, or inlet.

Figure 1. North Core Banks, Cape Lookout National Seashore, North Carolina with five nesting
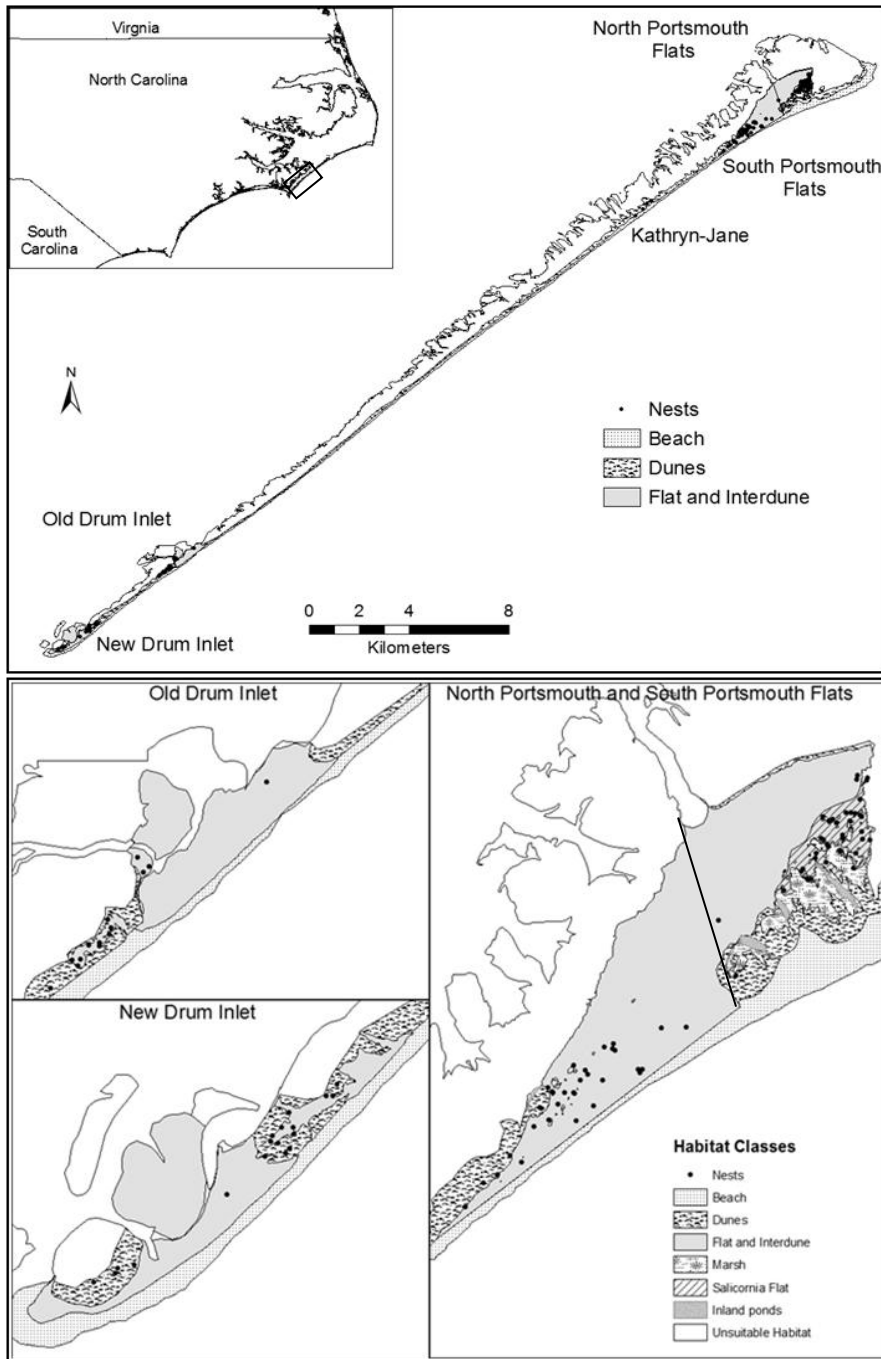
sites of Wilson's Plovers (*Charadrius wilsonia*) in 2010 and 2011, and a detailed view of the

four largest nesting sites: North Portsmouth Flats, South Portsmouth Flats, Old Drum Inlet, and

New Drum Inlet.
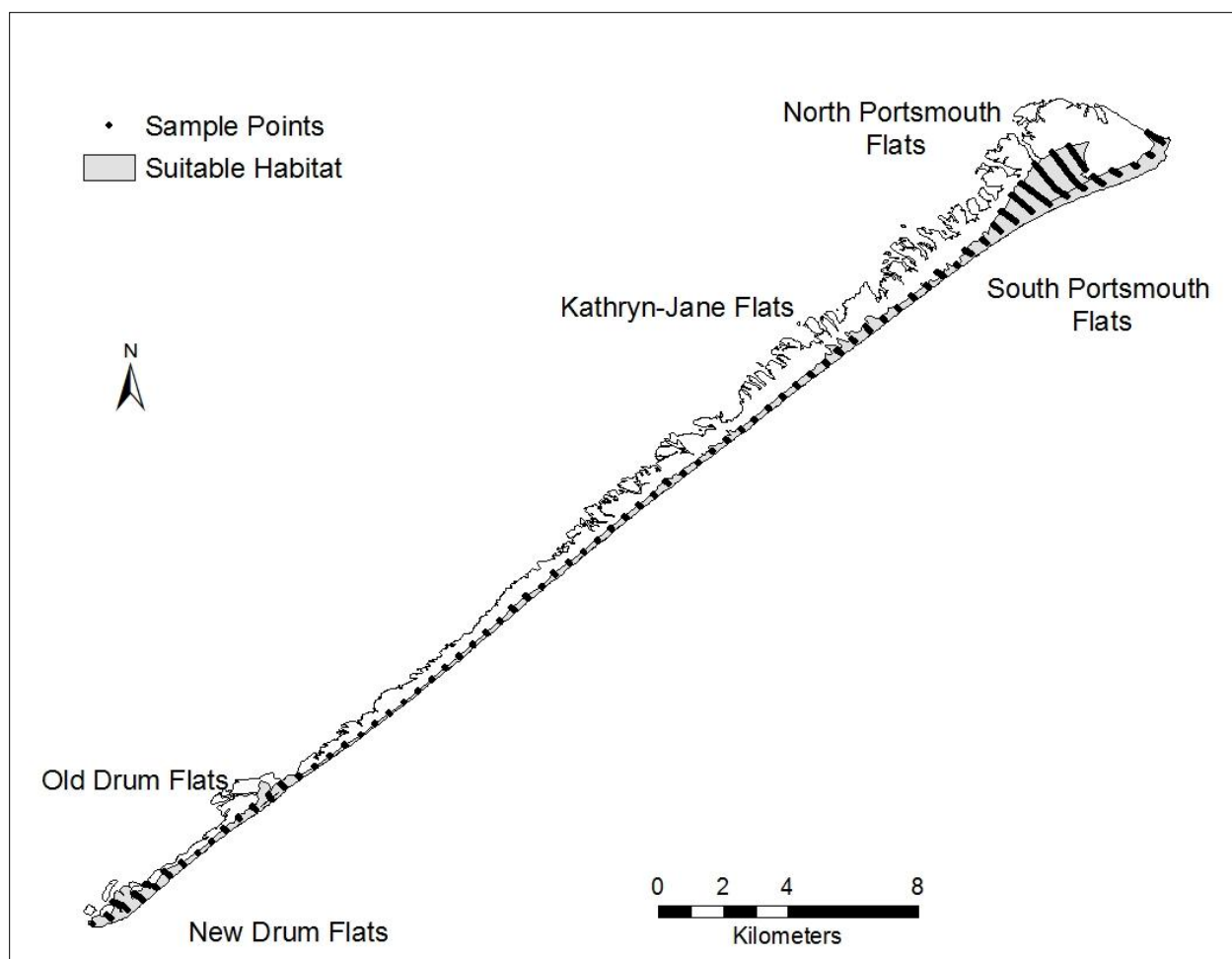
Figure 2. Seventy-three habitat transects sampled at 100 m intervals on North Core Banks, Cape Lookout National Seashore, North Carolina in May 2010. Transects were spaced 500 m apart along the entire island, and each transect covered a cross section of the island, starting on the beach side of the primary dunes, and running toward the sound. We recorded percent vegetative cover and general habitat type (beach, dunes, dunelet, flat, marsh, interdune, or vegetated flat) within a 1x1 m^2 quadrat every 100 m on the transects. We ended transects when we encountered continuous, dense (> 75% vegetative cover) vegetation. We marked each sample point with a GPS unit (Garmin International, Olathe KS), and projected these points along with associated habitat information on 2009 aerial imagery in ArcGIS (Environmental Systems Research Institute, Redlands, CA) to digitize a layer of potentially suitable habitat.

CHAPTER THREE. Demography of Wilson's Plovers (*Charadrius wilsonia*) on North Core Banks, Cape Lookout National Seashore, North Carolina

ABSTRACT.— The Wilson's Plover has been designated nationally and regionally as a Bird of Conservation Concern by the U.S. Fish and Wildlife Service. Population declines have been documented for other temperate-zone breeding plovers, such as the Piping Plover (*Charadrius melodus*) and Snowy Plover (*Charadrius nivosus*), but little demographic information is available for the Wilson's Plover. Estimates of productivity (chicks fledged/pair), and annual survival rates for adults and juveniles are needed from throughout the Wilson's Plovers range to determine the productivity levels needed to maintain a stationary population. Our objectives were to estimate nest survival, chick survival and productivity for a breeding population of Wilson's Plovers at Cape Lookout National Seashore, North Carolina. We monitored nests with remote cameras and observer visits, and used the Mayfield method to estimate mean overall survival, and a logistic exposure model to estimate daily survival and relate nest age, hatch date, year, location, and equipment covariates to survival rate. We banded and resighted chicks, and used a Cormack-Jolly-Seber model to estimate chick survival. Mayfield nest survival was 22% and 26% in 2010 and 2011, respectively, and predation was the leading cause of failure for both years. Fish crows *(Corvus ossifragus)*, raccoons *(Procyon lotor)*, and feral cats were the primary nest predators at the northern end of the island, while raccoons were the primary nest predator at the southern end of the island. Camera presence decreased survival and the addition of a heart rate monitor further decreased survival. Exclosed nests had a higher daily survival rate than nests that were not exclosed. Nests initiated later in the season and older nests had lower survival, and nest survival was higher in 2010 than 2011. The daily survival rate was lower for nests at the north end of the island than for nests at the southern end

of the island. We resighted 47 of the 100 chicks we banded as fledglings, for a minimum known survival rate of 47%, while estimated apparent overall chick survival was 88%. Chick survival was negatively correlated with hatch date. In addition to contributing to the sparse demographic data available for this species, this is the first study of which we are aware to document the effects of nest monitoring equipment on nest survival in a shorebird breeding along the Atlantic Coast.

INTRODUCTION

The Wilson's Plover (*Charadrius wilsonia*) occurs along the Atlantic and Gulf coasts of the United States (Corbat and Bergstrom 2000). It is designated nationally and regionally as a Bird of Conservation Concern by the U.S. Fish and Wildlife Service (USFWS, 2008). The U.S. Shorebird Conservation Plan (Brown et al. 2001) listed Wilson's Plovers as a Species of High Concern for the Southeastern Coastal-Plains Caribbean Region (Prioritization Category 4, Brown et al. 2001). The population is estimated at 6,000 individuals within the U.S., however low confidence is placed in this estimate (Corbat and Bergstrom 2000, Brown et al. 2001). Population declines have been documented for other temperate-zone breeding plovers, such as the Piping Plover (*Charadrius melodus*) and Snowy Plover (*Charadrius nivosus*), but no broad-scale, systematic studies have studied population trends of Wilson's Plovers (Brown et al. 2001). Estimates of productivity (chicks fledged/pair), and annual survival rates for adults and juveniles are needed from throughout the Wilson's Plovers range to determine the level of productivity needed to maintain a stationary population. Several studies have estimated demographic parameters for Wilson's Plovers in the southern United States (Bergstrom 1982, Bergstrom 1988, Corbat 1990 and Hood 2006), but there is little current information on Wilson's Plover productivity throughout its range. Ray (2010) estimated demographic parameters for a population of about 20 breeding pairs of Wilson's Plover in North Carolina, where the predator

population was controlled, thus parameter estimates from this study may not be applicable to sites without predator control. We estimated nest survival, chick survival, and hatching and fledging rates for a population of Wilson's Plover on North Core Banks of Cape Lookout National Seashore.

METHODS

Study Area.— Cape Lookout National Seashore (34° 23' N, 76° 17' W, Fig. 1) is located between Ocracoke Island and Beaufort, North Carolina, USA and is part of the barrier island ecosystem that extends along much of the Atlantic seaboard from Massachusetts to Florida. The islands routinely change in shape and number due to wind, waves and currents. During the study, CALO included the islands of Shackleford Banks (SFB), South Core Banks (SCB), and North Core Banks (NCB). These islands combined had about 90 km of ocean shoreline and averaged about 800 m in width (CALO 2008). Cape Lookout National Seashore had no permanent residents, but NPS managed guest cabins and service facilities available for use by the public. The islands were accessible via public car/person ferries and by private vessel. Motorized vehicles including all-terrain vehicles (ATVs) and off-road vehicles (ORVs) were allowed to drive on the beach. We studied Wilson's Plovers on North Core Banks (NCB).

Cape Lookout National Seashore is relatively pristine compared to other Atlantic barrier islands, most of which are inhabited by humans and are subject to beach and dune stabilization projects that interrupt natural processes, such as dune erosion and the formation of inlets, that create shorebird habitat. Because natural processes are not interfered with on CALO, there may be a broader range of habitats available to shorebirds than on barrier islands that are more influenced by humans.

We conducted out study on the northern-most of CALO's three islands, NCB, where Wilson's Plovers nested at five sites (Fig. 1). North Portsmouth Flats (NPF) and South

63

Portsmouth Flats (SPF) were extensive flats at the northern end of the island. A third northern site, Kathryn-Jane (KJ), was about 3.5 km south of SPL. At KJ, Wilson's Plovers nested on the front beach and in a small vegetated flat behind the primary dunes. At the southwestern end of the island, nests were associated with two recently closed inlets, New Drum Inlet (NDI) and Old Drum Inlet (ODI). At both sites, plovers nested in interdune areas adjacent to flats that formed when the inlets closed.

Field Methods.— We searched for Wilson's Plovers' nests during the nesting season (April to July) by walking transects through all potential plover nesting habitat on North Core Banks (Fig. 1) every three to four days. If we observed a territorial pair or bird exhibiting nest defense, we hid in a blind or vegetation and waited for the bird to resume incubation. When we located a nest we recorded its location using a GPS unit and took a photograph of the nest cup and surrounding substrate and vegetation. We floated all eggs from nests found with two or three eggs to estimate incubation stage and hatch and initiation dates (Alberico 1995). We visited nests every one to three days until failure or hatching.

We deployed auto-triggered cameras (Reconyx, Inc., Holmen, WI) at every nest we found, except at North Portsmouth Flats, where we exclosed (Melvin et al. 2002) and deployed cameras at every other nest because we suspected that fish crows (*Corvus ossifragus)* were using the cameras to find nests. In 2011, we used exclosures and put cameras at every other nest at NPF and SPF, because we observed fish crows at these sites. To determine if crows were using cameras to find nests, we deployed eight experimental cameras for about 24 hours on the flat at NPF. We placed an artificial nest with plastic eggs about 2 m in front of four of the cameras; the other four cameras were deployed with no eggs. Cameras were encased in wooden housing for protection and camouflage, and placed approximately 2 m from nests. Cameras were set to take a

photo every five secs and were powered by an external battery (Tempest Batteries, San Jose, CA) buried in a watertight container near the nest. We visually checked all nests every one to three days. We changed battery units every five to six days in 2010 and every four to five days in 2011.

To achieve other study objectives (see Chapter One), we deployed artificial egg heart rate monitors at approximately half the nests that received cameras. We attempted to deploy a heart rate monitor at every other nest with a camera. If substrate type and dense vegetation prohibited deployment at a nest, we deployed the unit at the next nest we found. We sealed the digital voice recorder in a waterproof dry case and buried it 1–2 m from the nest. Battery life was 26.5 hrs and batteries were changed every one to three days, coincident with a nest or equipment check.

We considered nests to be successful if ≥1 chick hatched. We determined the fate of nests based on camera footage, signs of flooding or predators before the predicted hatch date, or by the presence of newly hatched chicks in the nest area. We used camera footage to determine the failure date for abandoned nests with cameras. We deemed nests without cameras abandoned if we did not observe adults at the nest for 72 hours. Failure dates for abandoned nests were assigned as the first date no birds were detected at the nest, based on camera footage (six nests) or visual observations (one nest). For both camera and non-camera nests we examined the nest-site for tracks, eggshell fragments or other signs of the cause of failure.

After nests failed or hatched, we photographed the nest-site to record the vegetation type within 15 cm from the center of the nest. We categorized vegetation based on structure (none, low forb/shrub, clumped grass, or *Salicornia* spp.). We used the photo taken when we found the nest to verify that vegetation structure had not changed enough to affect the categorization during the nesting period. We used a modified vegetation density board (Higgins et al. 2005, Ray 2010)

to estimate horizontal vegetation density in the four cardinal directions at 10 m from the nest bowl. In the field, we photographed the density board with a camera held at incubating Wilson's Plover height over the nest bowl. We then read the density board scores from the photos and summed rectangles that were ≥ 70% obstructed by vegetation. We used the average reading from the four cardinal directions to calculate an obstruction index (Ray, 2010).

We captured incubating adults using a drop-box or drop-door trap, and uniquely marked each bird with a total of four plastic color bands, two on each tarsometatarsus. We captured chicks by hand in or near the nest within a few hours of hatching and banded them with the same scheme we used for adults. We attempted to locate broods and resight chicks and adults every other day until fledging. In addition to targeted brood searches, we conducted resighting surveys along established routes at the five Wilson's Plover breeding sites once per week from April through June, and twice per week in July and August. In addition to surveying known breeding sites, we surveyed the north tip of the island where we frequently saw Wilson's Plovers foraging, but never found a nest, and other areas that looked suitable, but where we never observed Wilson's Plovers. These unused, but potentially suitable, sites were small enough that we could survey the entire site from one location using a spotting scope. During surveys, we counted all banded and un-banded adults, chicks and fledglings and recorded all nesting territories on a hand-drawn map in order to estimate how many breeding pairs used NCB.

Analytical Methods.— To facilitate comparisons with previous studies, we used the Mayfield method, a survival estimation method that accounts for nests that fail before detection, and assumes constant survival over time (Mayfield 1961, 1975) to calculate an overall estimate of nest survival. We used a logistic-exposure model (Rotella et al. 2004, Shaffer 2004) to estimate the daily survival rate (DSR) and relate time, habitat and equipment covariates to DSR.

We included heart rate monitor presence, camera presence, exclosure use, initiation date, nest age, site, year, vegetation presence and structure type within 15 cm of the nest bowl, horizontal vegetation density, and location (north vs. south end of the island) to generate a final model set. We constructed the top model in three stages starting with time and equipment effects, then adding vegetation effects, and finally a location effect. Models that were > 3 ΔAIC_c values better than competing models served as template models for following stages. First, we examined all possible single and multivariable models with the following variables: heart rate monitor presence, camera presence, exclosure use, initiation date, nest age, site, and year. Second, we added the nest microhabitat variables: vegetation presence and structure type within 15 cm of the nest bowl, and horizontal vegetation density. We then added a variable called location which distinguished northern sites from southern sites, to the resulting top models to generate the final model. We tested the fit of the global model with a Hosmer-Lemeshow goodness-of-fit test (Hosmer and Lemeshow 1989). We used SAS (SAS Institute, Inc., Cary, NC) to fit the logistic-exposure models, and Akaike's Information Criterion corrected for small sample size (AIC_c) to rank models (Akaike 1973, Burnham and Anderson 2003).

We used a Cormack-Jolly-Seber recapture model in program MARK (White and Burnham 1999) to estimate chick survival and resight rates. We estimated daily survival rate using seven encounter intervals, the first six intervals were five days long, and encompassed the time from hatch until 30 days of age. Because we were often unable to resight chicks until after they fledged, we counted birds as seen in the final interval if we saw them anytime after 30 days. In addition to models where survival and resight rates varied with time, we constrained the variation in resight rate in some models to allow for different resight rates in the first one or two weeks, and in the final post-fledging interval. We included year, site and hatch date as individual

covariates. We used the quasi-likelihood Akaike's Information Criterion corrected for small sample size ($QAIC_c$) to rank models (Burnham and Anderson 2003). We estimated chick daily survival from the resulting best model, and estimated apparent overall chick survival by raising the mean daily survival estimate to the 30th power and calculated the associated deviance using the delta method (Powell 2007).

RESULTS

Nest Survival.— We estimated that about 40 breeding pairs used NCB in both years; the maximum number of territorial pairs observed concurrently was 39 in 2010 and 41 in 2011. We monitored 35 nests in 2010 and 72 nests in 2011. Nest initiation began in mid to late April, and peak hatching lasted from late May through June in both years (Fig. 2). Clutch sized ranged from one to three, with a median clutch size of three; we only documented five nests with two eggs, and one nest with one egg (Table 1). We observed a laying period of four to eight days, with a median of six days (Table 1, Fig. 3). Raw hatching success (% of nests that hatched ≥ 1 chick) was higher than Mayfield nest survival estimates in both years (Table 1). Predation was the leading cause of nest failure (Table 2). Fish crows, raccoons *(Procyon lotor)* and feral cats were the primary nest predators at northern sites, while raccoons were the primary nest predator at southern sites (Table 3). All eight of the experimental cameras were visited by crows within 24 hours of deployment.

In 2011, we recorded re-nests by 10 pairs that had at least one member banded at the beginning of the breeding season. Both the male and female were banded in two pairs, and the other eight pairs consisted of a female paired to an un-banded male (or potentially multiple un-banded males if multiple nesting attempts took place). One banded pair stayed together for three nesting attempts; their third nest hatched (it was exclosed). The other banded pair made two nesting attempts and hatched their second nest (it was exclosed). Four females paired with un-

banded males and successfully hatched and raised a brood from their first nests (two were exclosed and two were not). Two females made two nesting attempts with un-banded males and successfully hatched their second nests (one exclosed, one, not). One banded female made three unsuccessful nesting attempts at nests that were not exclosed with un-banded males, and another banded female and un-banded male made one unsuccessful nesting attempt (not exclosed). For this subset of nests, all exclosed nests produced ≥ one chick. This should be considered a minimum number of re-nests as it is likely, based on the timing of the initial nests and the re-nesting attempts we documented, that we missed some nesting attempts.

We used the top daily nest survival model to estimate parameters because it had 89% of AIC_c weight, and was > 3 AIC_c values better than competing models (Table 4). Nest exclosures, camera and heart rate monitor presence, initiation date, nest age, year and location (north end vs. south end of island) affected nest survival (Table 4). Daily survival rate was lower for nests at northern sites than nests at the southern end of the island (Table 5). Exclosed nests had a higher DSR (Table 5). Only 4.0% (1 nest) of nests without cameras were abandoned, while 7.2% (6 nests) with cameras were abandoned, however, a Fisher exact test showed no statistically significant relationship between camera presence and abandonment ($P = 0.37$). Camera presence decreased DSR, and the addition of a heart rate monitor further decreased DSR (Table 5). Nests initiated later in the season had lower DSR (Table 5). Nest survival decreased with nest age, and survival was higher in 2010 than in 2011 (Table 5). Neither horizontal vegetation density nor vegetation structure within 15 cm of the nest bowl impacted survival.

Chick Survival.— Of the 100 chicks we banded in 2010 and 2011, we resighted 47 as fledglings, for a minimum known survival rate of 47% (Table 1). The top model four models had 90% of the $QAIC_c$ weight (Table 6) and included effects of hatch date and year on apparent

survival, and a time effect on resight rate. We model-averaged parameters estimates across the

entire model set for resight and 5-day apparent survival rates. Estimated apparent 5-day survival

was 99.5% and overall apparent survival for a 30 day period was 88% (Table 1). Hatch date was

in the top four models, and had a negative correlation with survival, but the confidence intervals

encompassed one, ($\beta_x = -0.121$, SE = 0.080, parameter estimate = 0.886, 95% CI =0.757, 1.036).

Year was in one of the top models, and the survival estimate was higher in 2010, but, again, the

confidence intervals encompassed one, ($\beta_x = 0.1152$, SE = 0.142, parameter estimate = 1.220,

95% CI =0.850, 1.482). Resight rate was lowest from 11–25 days of age, and increased when

chicks began to fledge (Figure 4). Neither time nor site effects were in any of the top models

(Table 6), so we reported a single resight rate from a representative site.

DISCUSSION

Nest Survival.— The mean incubation period of 25 days observed in this study was

similar to that reported by Bergstrom (1988), Corbat (1990) and Ray (2010). Some nests at our

site hatched at 22 days while others hatched at 29 days. We calculated the incubation period

from the laying of the final egg to the date the first chick hatched, so if birds began incubating

regularly when the first egg was laid, this could result in our calculating a shorter incubation

period than actually occurred. We observed that some birds regularly incubated incomplete

clutches in nests located behind the dunes where restricted airflow increased ambient

temperatures, on sand flats where blowing sand would bury unattended eggs, and later in the

season when the weather was warmer. The mean laying period of six days that we observed was

similar to that reported by Bergstrom (1988), and our mean clutch size of 2.9 was similar to

clutch sizes reported in other studies (Bergstrom 1988, Corbat 1990, and Ray 2010).

It is possible that the higher DSR for nests in 2010 was due to changes in search effort

between the years. In 2010, we found and monitored about half the Wilson's Plover nests, and

were more likely to find nests that survived for longer. In 2011 we devoted more time to nest searching, which allowed us to find nests earlier and monitor more nests. Weather conditions were similar for both years, with the exception of a storm surge in late May 2010 that flooded five nests.

Mayfield nest survival in our study was lower than Mayfield nest survival at another site in North Carolina where the predator population was controlled (44% and 46%; Ray 2010), but close to estimates from studies in southern Texas and Georgia (23% and 27% respectively; Bergstrom 1988, Corbat 1990). Our findings that vegetative cover type near the nest bowl did not affect nest survival differed from previous studies in Georgia and North Carolina, which found that nests near vegetation clumps had higher hatch success (Corbat 2006, Ray 2011), and a study in Texas that found that nest survival was lower near clumped vegetation (Hood 2006).

Despite exclosure use at northern sites, nests at these sites had a lower DSR. The two largest northern sites, NPF and SPF, were adjacent to maritime forest and extensive marsh, habitats which may have supported a higher density of predators than sites at the narrower, southern end of the island. The forest also provided nesting habitat for fish crows, which caused most of the nest failure at NPF. In addition to the common nest predators (fish crows, raccoons, and feral cats), we documented nests being depredated by an American Oystercatcher (*Haematopus palliatus*) pair and a nutria (*Myocastor coypus*). In 2010, we could not identify the cause of failure for two nests that failed before we deployed cameras at them, and in 2011 we could not identify the cause of failure for 10 nests that failed before camera deployment, or were not assigned a camera. It is likely that these nests were depredated since physical signs of overwash were easy to detect, and we did not see adults defending chicks nearby.

Unlike Hood (2006), who found no effect of time on nest survival, at our study site, older nests, and nests initiated later in the season had lower survival. In both years we observed that the first wave of nest predation coincided with the beginning of the Least Tern (*Sternula antillarum*) nesting season. Other studies have found that Piping Plovers and other shorebirds benefit from nesting within colonies of birds that aggressively defend their nests (Burger 1987, Powell 2001, Lauro and Tanacredi 2002, Nguyen et al. 2003). However, at most of our nesting sites, Wilson's Plovers nested adjacent to tern colonies instead of among the terns, and so may not have benefited from colony defense. Instead, they may have experienced higher predation as predators switched from other food sources to eggs in response the higher nest density when terns begin nesting (Abrams and Matsuda 1996, Lecomte et al. 2008, Norbury and Heyward 2008). Wilson's Plovers nested within a tern colony at SPF, and in both years, initial Wilson's Plover nest depredation at SPF coincided with the beginning of tern nesting season. This is also when we began seeing raccoon tracks on the flats. In 2011, two pairs of Wilson's Plovers initiated nests in the sand and shell flats at ODI and NDI (tern colony sites in both years). The nest at ODI was depredated before terns begin nesting, and the nest at NDI was abandoned on 15 May when terns began to arrive at the site. We recorded multiple incidences of Least Terns harassing Wilson's Plovers on the nests monitored by cameras at SPF, where tern nests were sparse in comparison to other tern colonies on the island. Harassment by terns may be the reason Wilson's Plovers avoided nesting in higher density colonies.

Nests initiated later in the season may be more likely to be abandoned than earlier nests. In 2010, we did not observe any abandoned nests, but in 2011, seven nests were abandoned, one on 15 May (within a tern colony), two from 1 to 15 June, and four after 26 June. Two of these nests were exclosed; however the birds incubated for two to three weeks within the exclosure

before abandoning their nests, so we do not think that the deployment of the exclosure caused abandonment. Roche (2010) found disappearance of one of the adults was the primary reason for nest abandonment in Piping Plovers, but we do not think that adult mortality was the cause of abandonment in our study, because we resighted all banded birds from abandoned nests post-abandonment. However, both members of the pair were banded only at one abandoned nest; only one member was banded at five abandoned nests, and neither bird was banded at one abandoned nest. Thus we were unable to verify this.

Contrary to our findings, most of the studies of the effect of camera monitoring on nest survival have found that camera presence increased daily survival rates (Thompson et al. 1999, Buler and Hamilton 2000, Pietz and Granfors 2000, Small 2005, Richardson et al. 2009) or had no effect (Stake and Cimprich 2003, Coates et al. 2008, Richardson et al. 2009). These studies were conducted on grassland and forest birds which nest in more complex environments and have different suites of nest predators than shorebirds. The decrease in depredation rate seen in these studies may be attributed to avoidance of nest monitoring equipment by nest predators (mainly rodents) due to neophobia (Richardson et al. 2009). Because shorebirds nest in areas with little to no cover, and because coastal environments may harbor more generalist predators, an object near the nest may attract predators to the vicinity of the nest from some distance away. We are not aware of other studies that have documented the effect of nest monitoring cameras on nest survival in a temperate, coastal ecosystem. In a study of Arctic shorebirds, McKinnon and Bêty (2009) found that daily survival rates of nests with cameras did not differ from nests without cameras. Another study in the Arctic found that nests with cameras were more likely to be depredated, however unlike McKinnon and Bêty (2009), this study did not control for the effects of observer visits, and nests with cameras experienced more frequent visits by researchers

than nests without cameras, which could have accounted for the increased depredation rate (Tulp et al. 2000). In our study, nest visit intervals were about the same for nests with and without cameras but nests with cameras experienced a slightly longer visit interval on average (1.4 days vs. 1.2 days).

Nest predators may habituate to novel items and even come to associate them with nests (Johnson and Oring 2002, Murphy et al. 2003, Niehaus et al. 2004). Our experimental cameras confirmed that fish crows were attracted to cameras. Although corvids can be deterred by human objects (Herranz et al. 2002), increasing the density of cameras and duration of the study may increase the likelihood that they associate cameras with nests (Lenington 1979, Richardson et al. 2009).

Monitoring nests with cameras allows for the collection of detailed behavioral data, and limits uncertainty in assigning nest fates (Lariviere 1999, Pietz and Granfors 2000, Williams and Bohall Wood 2002). For instance, predators may be attracted to recently depredated nests, perhaps by egg remains or increased activity at the nest and the signs of the original predator can be obscured by these later visitors. After depredation by another predator species, we often found ghost crab (*Ocypode quadrata*) holes with eggshell in them near the nest bowl, and without camera footage we may have assumed that ghost crabs were common nest predators, when in fact, ghost crabs did not cause any nests to fail in our study. Ghost crabs did sometimes remove an egg from a nest, however, plovers always retrieved these eggs and continued incubating, so we did not attribute any depredation of nests to ghost crabs. In one case, the plover rejected an egg from the nest after retrieving one from a ghost crab; likely it was the same egg removed by the ghost crab, and it had been damaged. Camera monitoring may also decrease the need for observer visits to the nest, which could lower predation risk (Bêty and Gauthier 2001). However,

leaving monitoring equipment near the nest can effect nest survival leading to biased demographic estimates, an inaccurate understanding of natural causes of nest failure (Thompson et al. 1999, Pietz and Granfors 2000, Herranz et al. 2002), and an effect on population demography. The effects of nest monitoring equipment on nest survival probably depend on the sensitivity of the species being monitored, habitat and predator suite, and the duration of the study. Although camera monitoring can provide valuable information, cameras should be used with caution, and steps such as limiting visit rate and increasing the distance of the camera from the nest (McKinnon and Bêty 2009) should be taken to minimize effects of cameras on nest survival. It is important that studies that place objects at nest sites document the effects of these objects on nest survival. The use of artificial egg heart rate monitors further decreased survival even though the recording device and cable were buried and the birds appeared to incubate normally with the artificial egg in the nest. The possibility that the addition of the artificial egg decreased incubation bouts or otherwise increased the incubating plover's activity level, and attracted predators, is something we will investigate in future analyses.

Chick Survival.— We believe that our estimate for overall, apparent survival was biased high because our detection rate was low until the final post-fledging interval. During the first 10 days of age we detected nearly all of the chicks in the analysis at least once in order to band them (two chicks were banded after 15 days of age). We were sometimes able to resight chicks at this stage while they were still in the vicinity of the nest, or while moving across open areas to a final foraging territory. For the next 20 days, we were very unlikely to resight chicks as they stayed in dense vegetation until after fledging. After 30–35 days chicks emerged from the vegetation and foraged in open areas, and our odds of resighting them were higher. When chicks emerged from the vegetation, they could fly well, thus we were unable to determine the exact fledging age.

Although we couldn't resight chicks during most of the brood-rearing period, we feel that we could accurately tell if a brood was still active ($\geq$ 1chick alive) by the parents' defensive behavior. If we deemed a brood active until day 30, we always re-sighted at least one fledgling from that brood, however, we never later resighted a fledgling from any of the 11 broods that we deemed failed prior to day 30. Chicks are most vulnerable immediately after hatching, and the broods that failed usually did so in the first week after hatching. Although time (age) did not affect chick survival in our analysis, this is probably because we did not detect chicks frequently enough between hatching and fledging to tell when mortality occurred. Based on this evidence, we believe that the raw survival rate of about 50% survival for chicks was probably closer to reality than the 88% survival estimate from the Cormack-Jolly-Seber model. The number of chicks hatched per pair at our site was similar to the number of chicks hatched per pair recorded during a 2-year study by Ray (1.47 and 1.64; 2010), but our estimate of chicks fledged/pair (0.78) was lower than Ray's (0.88 and 1.00; 2010). It appears that throughout all parts of the breeding cycle predation pressure was higher at our site than at Ray's (2010), however we speculate that plovers may be compensating for a lower nest survival rate by re-nesting more than plovers in Ray's (2010) study. Ray (2010) documented 17 initial nests and three re-nests in 2008, and 22 initial nests and four re-nests in 2009.

Although survival was lower for chicks with later hatch dates, this trend was not significant in our study. The trend toward lower survival later in the season has been documented previously in Wilson's Plovers (Ray 2010) and other shorebirds (Moreno 1998, Arnold et al. 2006, Catlin 2011). This may be because experienced breeders arrive earlier in the season and establish higher quality territories than the late-arriving, less experienced birds (Aebischer et al. 1996, Møller et al. 2004). Food resources may also become scarce later in the season, and

predation pressure may increase with an influx of juvenile predators (Loegering and Fraser 1995, Elias et al. 2000).

Wilson's Plovers are thought to forage primarily on fiddler crabs (Bergstrom 1988, Corbat and Bergstrom 2000, Ray 2010). However, our study site did not have extensive fiddler crab flats, and broods foraged primarily in dry vegetation. Several broods foraged on moist sand or mud flats, but use of these habitat types appeared to be limited to a few broods for only part of the brood-rearing period, despite their apparent availability. It is possible that we underestimated the use of open foraging sites for broods because Wilson's Plovers were extremely sensitive to our presence and may have retreated to vegetation before we could detect them. Plovers that nested in the *Salicornia* often raised their broods along the edge of the *Spartina* marsh near the nest-site, suggesting that the *Salicornia* flat, *Spartina* marsh border provided adequate food resources. In 2011, subterranean termites *(Rhinotermitidae spp.)* swarmed on the *Salicornia* flats, and broods appeared to be foraging on the termites. In 2010, we did not see termite swarms, but the broods used the same areas, and presumably ate other insects. Ray (2010) found that broods thrived foraging on the front beach when a tidal anomaly inundated fiddler flats, and suggested that Wilson's Plover foraging strategies are flexible and adapted to the dynamic coastal environment they inhabit.

Although predation pressure was high, Wilson's Plovers at our site managed to produce the same number of chicks per pair as at another site where nest failure rates were lower (Ray 2010), probably through multiple nesting attempts. However, higher chick mortality probably decreased our fledging rate compared to Ray's (2010). Our study expands our limited understanding of Wilson's Plover breeding performance, and provides an estimate of productivity at a site that is geographically similar to Ray's (2010), yet has a different predator

community, lower predation pressure, and less habitat modification by humans. Additional studies of productivity and population dynamics throughout the Wilson's Plovers range, including estimates of wintering adult and juvenile survival, are needed to understand if productivity of 0.78 is sufficient to produce a viable population in North Carolina.

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TABLES

Table 1. Demographic estimates and standard errors for Wilson's Plovers (*Charadrius wilsonia)* at Cape Lookout National Seashore in 2010 and 2011. Estimates are missing for some parameters in 2010 because we lacked sufficient sample size (laying and incubation days), or because we did not monitor all broods (chick hatched and fledged/pair). Sample size of nests, chicks, and pairs used in calculating estimates in parentheses after value.

Year	Clutch size[a]	Laying days[b]	Incubation days[c]	Hatch Success[d]	Mayfield nest survival[e]	Chick apparent survival[f]	Chicks hatched/pair[g]	Chicks fledged/pair[h]	Percentage banded chicks to fledge
2010	2.97±0.03 (35)			37% (35)	22% (35)				49% (35)
2011	2.91±0.04 (70)	6.03±0.20 (32)	24.62 ±0.58 (13)	31% (72)	26% (72)		1.8±0.02 (41)	0.78±0.02 (41)	46% (65)
Total	2.93±0.03 (105)			33% (107)	25% (107)	0.90±0.15 (100)			47% (100)

[a] Estimates based on no. of nests not depredated during the laying period.

[b] Estimate based on no. of nests found with one egg and not depredated during the laying period.

[c] Estimate based on no. of nests we observed from the time the clutch was complete to the hatch date.

[d] Estimates based on total no. of nests found.

[e] Estimates based on total no. of nests found.

[f] Estimates based on no. of chicks banded.

[g] Estimate based on maximum no. pairs (banded and un-banded) observed holding nesting territories, and no. of chicks (banded and un-banded) counted in all broods that we observed.

^{h} Estimate based on maximum no. pairs (banded and un-banded) observed holding nesting territories, and no. of fledglings (banded and un-banded) that we observed at near a brood territory at 30–35 days post hatching date. Hatching date was known for most broods, but estimated based on chick age for some.

Table 2. Nest fates and causes of failure for Wilson's Plovers (*Charadrius wilsonia)* at Cape Lookout National Seashore in 2010 and 2011. Failure cause was identified from camera footage or physical signs.

Year	Hatched		Depredated		Abandoned		Flooded		Not viable		Unknown	
	n	%	n	%	n	%	n	%	n	%	n	%
2010	13	37%	15	43%	0	0%	4	11%	1	3%	2	6%
2011	22	31%	34	47%	7	10%	0	0%	0	0%	10	14%
Total	35	32%	49	45%	7	6%	4	4%	1	1%	12	11%

[a] Nests assigned an unknown fate were likely depredated since physical signs of overwash were easy to detect, and we did not see adults defending chicks nearby. Avian predators may leave very little sign, and tracks and other signs of predators can be obscured by wind and rain.

Table 3. Nest predators of Wilson's Plovers *(Charadrius wilsonia)* at the north and south end of North Core Banks, Cape Lookout

National Seashore in 2010 and 2011. Predators were identified on camera and/or by physical signs. Percent represents the percentage

of all nests for a year depredated by each predator species. Other = an American Oystercatcher (*Haematopus palliatus*) pair and a

nutria (*Myocastor coypus*).

		Total Depredated		Fish Crow (*Corvus ossifragus*)		Raccoon (*Procyon lotor*)		Feral Cat		Other	
Year	Location	n	%	n	%	n	%	n	%	n	%
2010											
	North	12	34%	3	9%	3	9%	4	11%	2	6%
	South	3	9%	0	0%	3	9%	0	0%	0	0%
	Total	15	43%	3	9%	6	17%	4	11%	2	6%
2011											
	North	24	33%	13	18%	7	10%	4	6%	0	0%
	South	10	14%	1	1%	9	13%	9	13%	0	0%
	Total	34	47%	14	19%	16	22%	4	6%	0	0%
Grand Total		49	45%	17	16%	22	31%	8	7%	2	2%

Table 4. Top-ranked models for examination of factors affecting daily nest survival of Wilson's Plover (*Charadrius wilsonia*) nests at Cape Lookout National Seashore, North Carolina, 2010-2011. We constructed the top model in three stages starting with time and equipment effects, then adding vegetation effects, and finally a location effect. Models that were > 3 ΔAIC_c values better than competing models served as template models for following stages. The presence of an artificial egg heart rate monitor is indicated by the variable "HR monitor". Location distinguishes sites at the northern end of the island from sites at the southern end of the island. K = no. of parameters.

Models, by variable type	Deviance	K	AIC_c	ΔAIC_c	Model likelihood	w_i
Location effects						
Exclosure, Nest age, Initiation date, Year, Camera, HR Monitor, Location	507.30	8	523.40	0.00	1.00	0.89
Microhabitat vegetation effects						
Exclosure, Nest age, Initiation date, Year, Camera, HR Monitor	525.70	7	539.70	0.00	1.00	0.31
Exclosure, Nest age, Initiation date, Camera, HR Monitor	527.90	6	539.90	0.20	0.90	0.28
Exclosure, Nest age, Initiation date, Year, Camera, HR Monitor, Veg type	521.40	10	541.40	1.70	0.43	0.13
Exclosure, Initiation date, Camera, HR Monitor	532.20	5	542.30	2.60	0.27	0.08
Time and equipment effects						
Exclosure, Nest age, Initiation date, Year, Camera, HR Monitor	525.70	7	539.70	0.00	1.00	0.39
Exclosure, Nest age, Initiation date, Camera, HR Monitor	527.90	6	539.90	0.20	0.90	0.35
Exclosure, Initiation date, Camera, HR Monitor	532.20	5	542.30	2.60	0.27	0.11

Table 5. Parameter estimates, standard error, log-odds ratios, and 95% confidence intervals from the best model predicting Wilson's Plovers (*Charadrius wilsonia*) nest survival (N=107 nests) at Cape Lookout National Seashore, North Carolina, 2010-2011. The presence of an artificial egg heart rate monitor is indicated by the variable "HR monitor". Location distinguishes sites at the northern end of the island from sites at the southern end of the island.

Effect	Parameter Estimate	*SE*	Log-odds ratio	Lower 95% CL	Upper 95% CL
Intercept	6.19	0.70	NA	NA	NA
Camera	-1.18	0.38	0.31	0.15	0.64
Exclosure	3.54	0.66	34.63	9.47	126.67
HR monitor	-0.92	0.33	0.40	0.21	0.76
Initiation date	-0.03	0.01	0.97	0.95	0.99
Location	-1.10	0.34	0.33	0.13	0.48
Nest age	-0.05	0.01	0.96	0.93	0.98
Year	-0.91	0.33	0.40	1.31	4.76

Table 6. Top-ranked models (90% of QAIC$_c$ weights) estimating resight rate (p) and apparent daily survival rate (φ) for Wilson's Plover (*Charadrius wilsonia*) chicks at Cape Lookout National Seashore, North Carolina, 2010–2011.

Model[a]	QAIC$_c$	ΔQAIC$_c$	w_i	Model likelihood	K	Deviance
φ (hatch) p(interval_2)	297.2	0.0	0.57	1.00	5	286.8
φ (hatch) p(t)	300.2	3.0	0.13	0.22	8	283.3
φ(hatch) p(interval_1)	300.6	3.4	0.11	0.19	5	290.2
φ (hatch, yr) p(t)	300.7	3.5	0.10	0.17	9	281.6

[a] Hatch = number of days after 19 May that a chick hatched, interval_2 = estimates for the first two resight intervals are different from next three intervals, which are different from estimates for the last interval, interval_1 = estimates for the first and last resight intervals are different from the other four intervals, (t) time-specific variation, c-hat = 1.68.
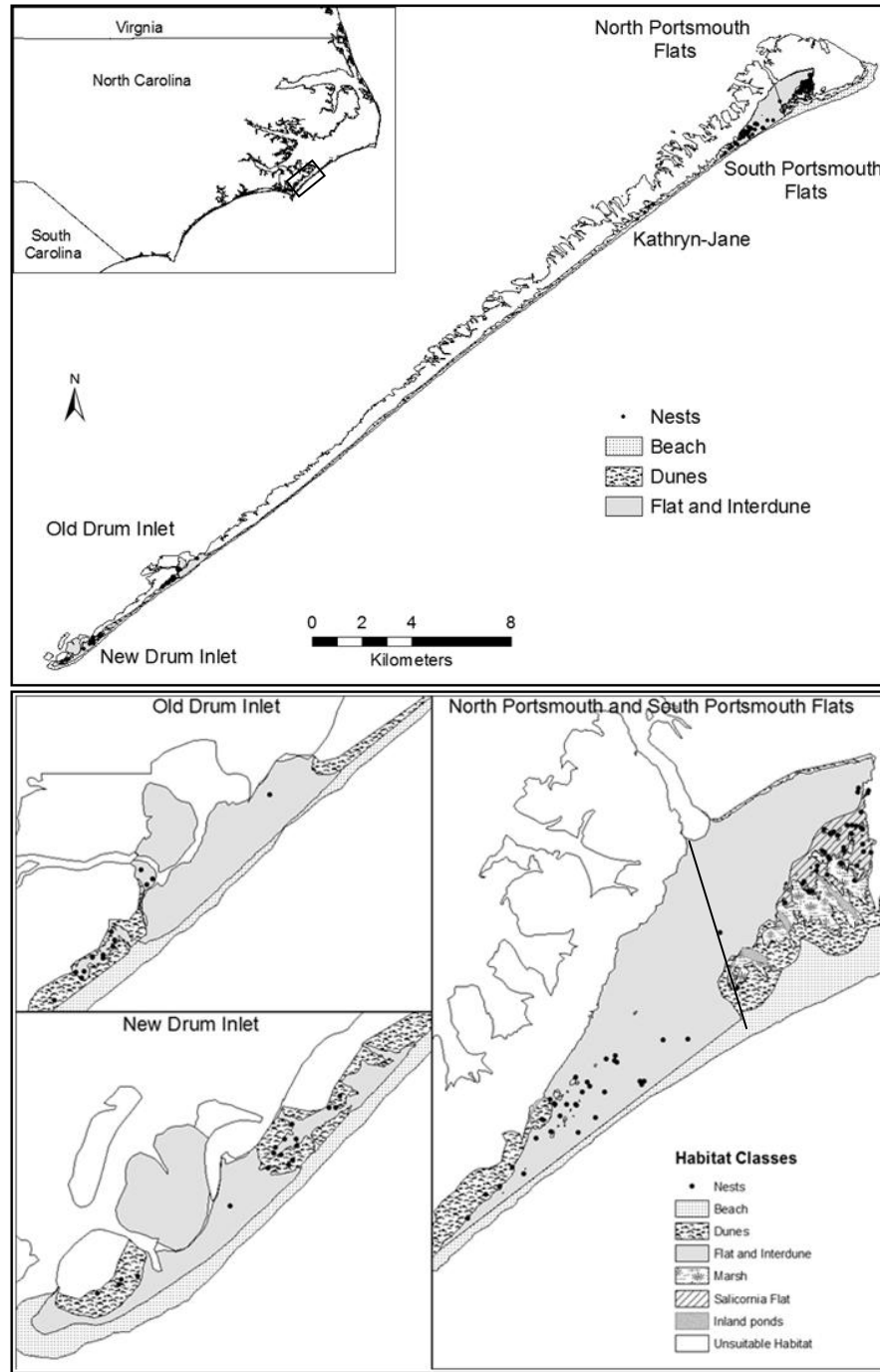
FIGURES

Figure 1. North Core Banks, Cape Lookout National Seashore, North Carolina with five nesting sites of Wilson's Plovers (*Charadrius* wilsonia) in 2010 and 2011, and a detailed view of the four largest nesting sites: North Portsmouth Flats, South Portsmouth Flats, Old Drum Inlet, and New Drum Inlet.
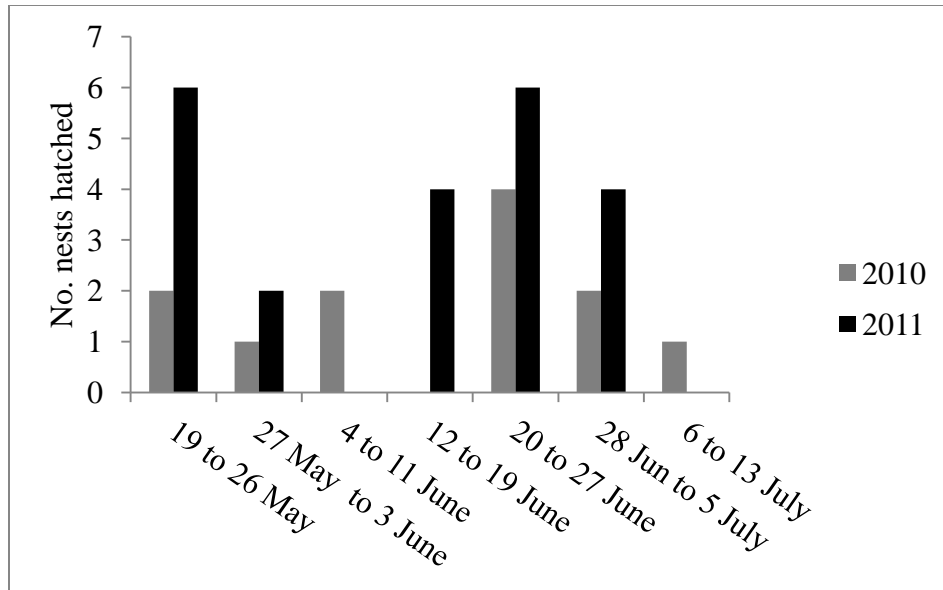
Figure 2. Hatch dates for Wilson's Plover (*Charadrius wilsonia*) nests at Cape Lookout National
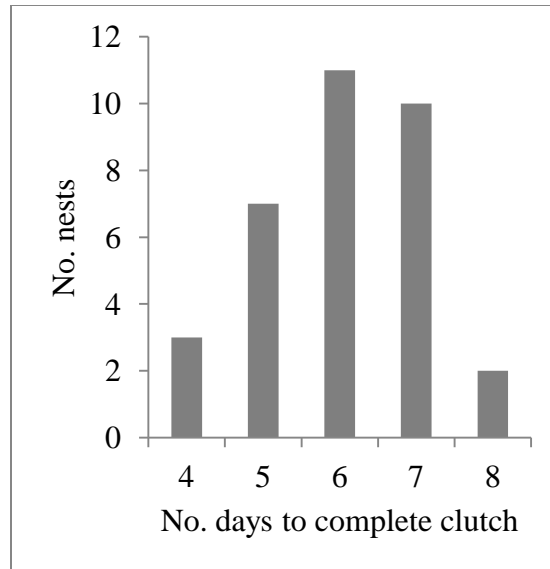
Seashore, North Carolina, 2010–2011.

Figure 3. Number of days for Wilson's Plover (*Charadrius wilsonia*) to complete a clutch at Cape Lookout National Seashore, North Carolina, 2010–2011. We calculated the incubation period as the time from the laying of the final egg to the date the first chick hatched.
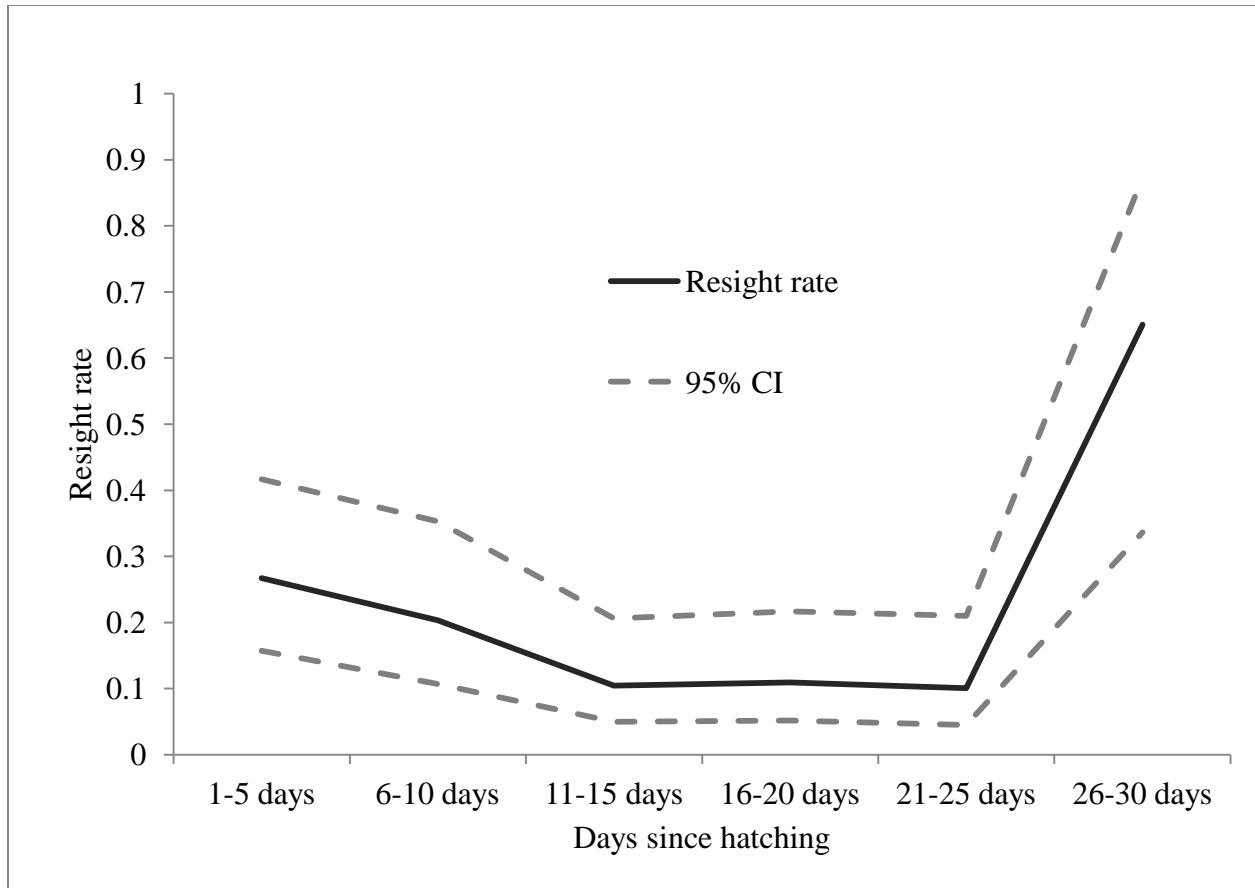
Figure 4. Resight rate for Wilson's Plover (*Charadrius wilsonia)* chicks at Cape Lookout

National Seashore, North Carolina, 2010–2011.

CONCLUSION

There is little peer-reviewed information available for the Wilson's Plover. Population estimates are uncertain and reproductive parameter estimates come from a few small-scale studies. Range-wide surveys of potential habitat are needed to generate a better estimate of the breeding population. Many of the Atlantic and Gulf states already conduct breeding season window counts of shorebirds, including Wilson's Plovers, but these data are not collected and organized across states.

North Carolina conducts state-wide window counts of Wilson's Plovers from $1 - 10$ June each year. During our study, we conducted the Wilson's Plover window census on North Core Banks (NCB), and the National Park Service (NPS) censused the rest of Cape Lookout National Seashore; the NPS counted 22 breeding pairs on South Core Banks in both years, and 17 and 13 breeding pairs on Shackleford Banks in 2010 and 2011, respectively (Altman 2010, 2011). Window census pair counts for NCB in years prior to our study (Altman, 2007, 2008, 2009) counted 30-32 pairs, while we counted 36 and 41 pairs during 2010 and 2011 window counts, respectively. In 2010, we counted 39 pairs breeding on NCB during biweekly surveys, but the window census occurred after a storm surge in late May that caused nests to fail, so many birds that had been paired up were single as they established new territories. While single surveys may not produce and exact count of pairs, a coordination of window census protocols and data across states will almost certainly produce a better population estimate than exists currently for Wilson's Plovers.

In addition to an accurate population estimate, adult and juvenile overwintering survival estimates are needed to determine what reproductive output is needed for a stationary population. To date, adult survival and juvenile wintering survival have not been reported for this species. I banded adults in 2010 and 2011, and conducted resighting surveys from 2010 to 2012. The 2012

96

data were not available in time to include these survival estimates in my thesis, however, I plan to do these analyses for future publications.

On NCB, we found Wilson's Plovers nesting in interdune areas, on sand flats, flats vegetated with *Salicornia,* beaches, in sparse marsh, and in small vegetated flats behind the primary dunes. Most nests were in interdune areas on flats; nests on flats were often placed at the edge of an isolated dunelet. North Core Banks did not have abundant fiddler crab (*Uca spp.*) flats, and at the north end of the island Wilson's Plover broods foraged in dense vegetation around ponds and at the *Spartina* marsh *Salicornia* flat border. At the south end of the island broods appeared to forage in dry vegetated areas. Cape Lookout National Seashore is unique among Atlantic barrier islands in that it is not inhabited, and that the NPS does not stabilize the beach or dunes and instead allows natural erosion and deposition processes to modify the island. This probably results in broader range of suitable shorebird nesting habitats than are available at other sites with more human interference.

Our study was designed to determine the effects of Core MOA overflights specifically, but was not ideal for determining how overflight characteristics and aircraft type in general impacted Wilson's Plovers. In order to understand which characteristics of overflight provoke a response, it would be necessary to record slant distances between overflights and nests, aircraft type, velocity, direction of approach, and whether or not the aircraft passed directly over the nest. Although we had some of these data for Core MOA overflights, they were all military fixed-wing aircraft, and the overflights that flew near nests were mostly > 3048 m, so it was not possible to use these overflights to compare responses to different overflight characteristics. Ideally, a visual verification would be used to assess closest approach distance rather than projected tracks paired with audio data. Because many factors can affect how sound travels, visual and audio stimuli may not reach an incubating bird at the same time. To assess

97

distributional and demographic effects of overflights on plovers, an estimate of exposure frequency for all overflights types would be necessary.

Although the Wilson's Plover is not actively monitored or protected by the NPS, areas used by Piping Plovers and colonial waterbirds are closed to the public during the shorebird breeding season, and this protects most of the Wilson's Plover breeding habitat. With the exception of 4 pairs that nested on the front beach, and 3 pairs that were exposed to motorized vehicles when a roadway was opened behind the dunes after nests were established, during our study nesting Wilson's Plovers were not exposed to human activity, aside from researchers and NPS staff. Overall, we found no evidence that human activities were having a direct negative effect on productivity of Wilson's Plovers on North Core Banks. The greatest local impact on demography appears to be from predation on nests and young. Most nest predation is by raccoons and fish crows. The degree to which this predation may be exacerbated by human activities (e.g. leaving garbage on the beach; Liebezeit 2009) is unknown.

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APPENDIX A. Wilson's Plover (*Charadrius wilsonia*) supplemental figures for physiological and behavioral responses to overflights, Chapter 1.

Figure 1. Wilson's Plover (*Charadrius wilsonia*) nest bowl with eggs and Reconyx PC90 camera in wooden box at Cape Lookout National Seashore, North Carolina.
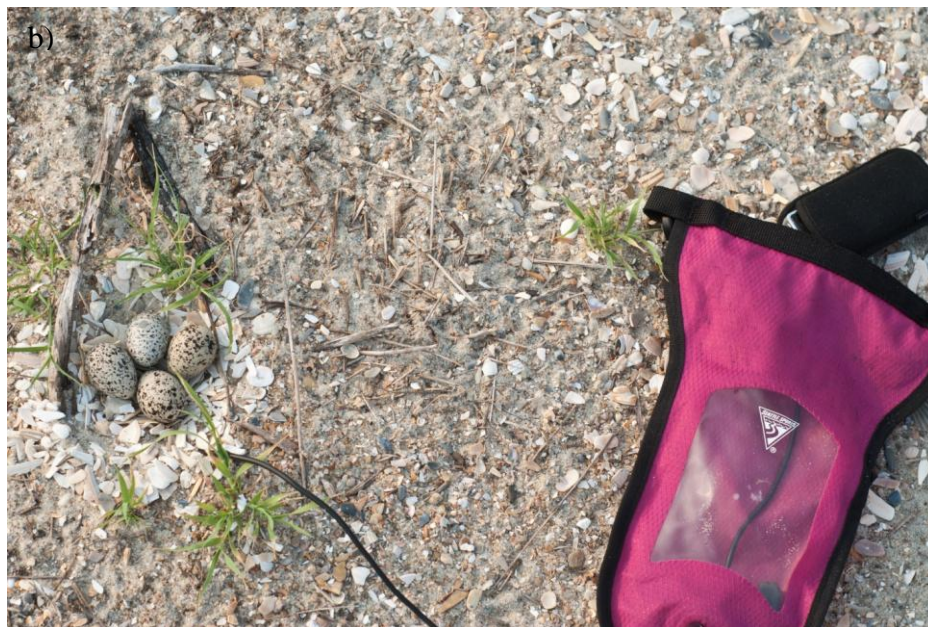
Figure 2. a) Artificial heart rate monitor egg (top center egg) in a Wilson's Plover (*Charadrius wilsonia*) nest with three real eggs at Cape Lookout National Seashore, North Carolina. b) The digital voice recorder was attached to the artificial egg and buried in a waterproof case 1–2 m from the nest.
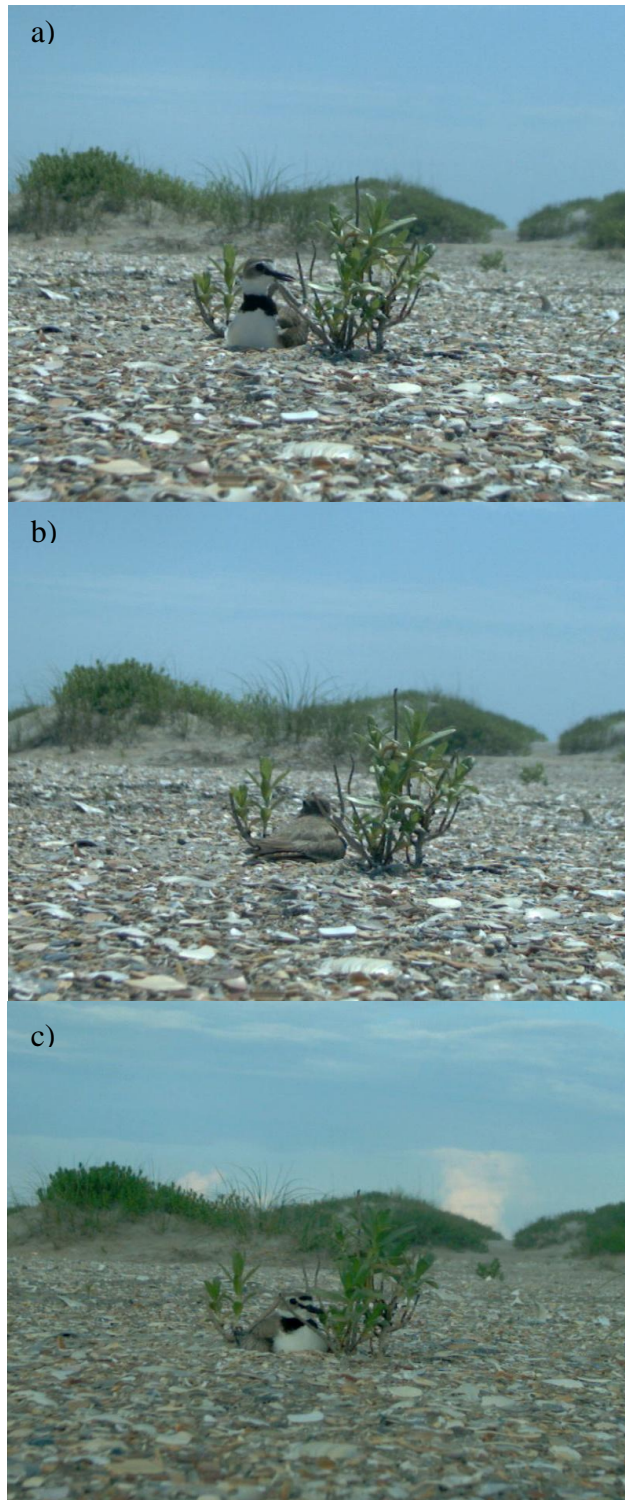
Figure 3. Wilson's Plover (*Charadrius wilsonia*) on nest in at Cape Lookout National Seashore, NC, a) alert upright posture, b) alert hunkered posture, and c) relaxed posture.
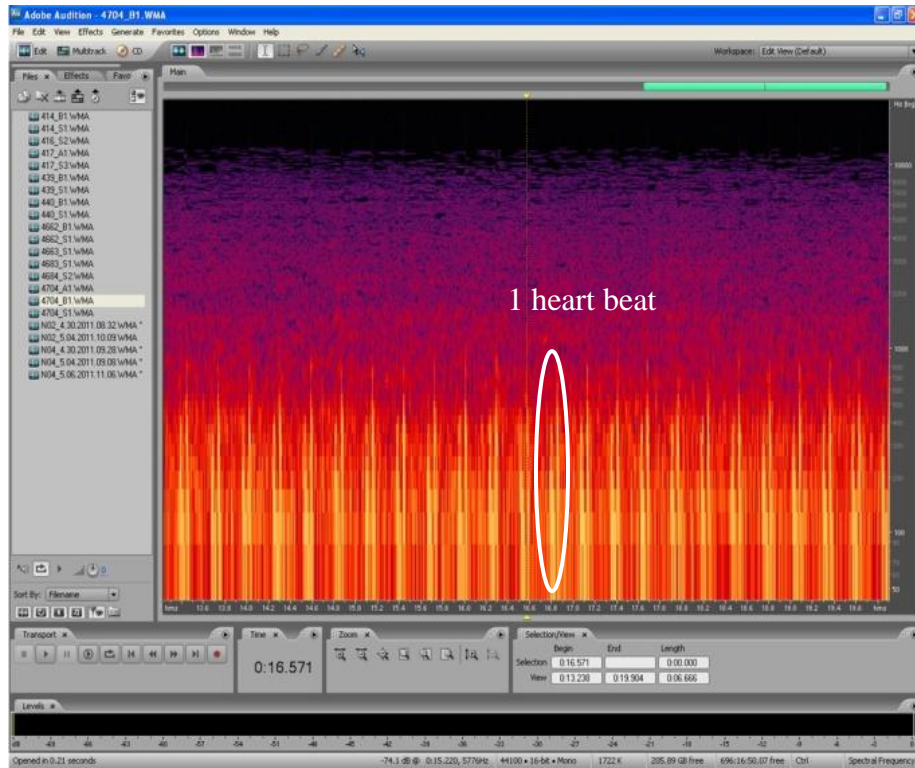
Figure 4**.** Spectral frequency display of a series of Wilson's Plover (*Charadrius wilsonia*) heart

beats over 6 seconds; a 6 s interval is shown here so that the heart beats can be magnified and

visible, but sampling was done for three 20 s intervals pre, during, and post overflight. A single

heart beat is shown in the white oval.

APPENDIX B. Wilson's Plover (*Charadrius wilsonia*) supplemental information on distributional response to Core MOA overflights, Chapter 2.

Core MOA overflights occurred at a fairly even distribution throughout our study site (Fig. 1), therefore we lacked a reference area to compare Wilson's Plover (*Charadrius wilsonia*) nest distribution patterns with and without Core MOA overflights. Furthermore, the majority of the overflights at our study site were not from Core MOA aircraft, and because we recorded non-Core MOA overflights opportunistically, we lacked information on the distribution of these overflights. If Wilson's Plovers showed a distributional response to overflights, they would likely respond all overflights, or the ones to which they exhibited a behavioral response (see Chapter One), rather than Core MOA overflights.
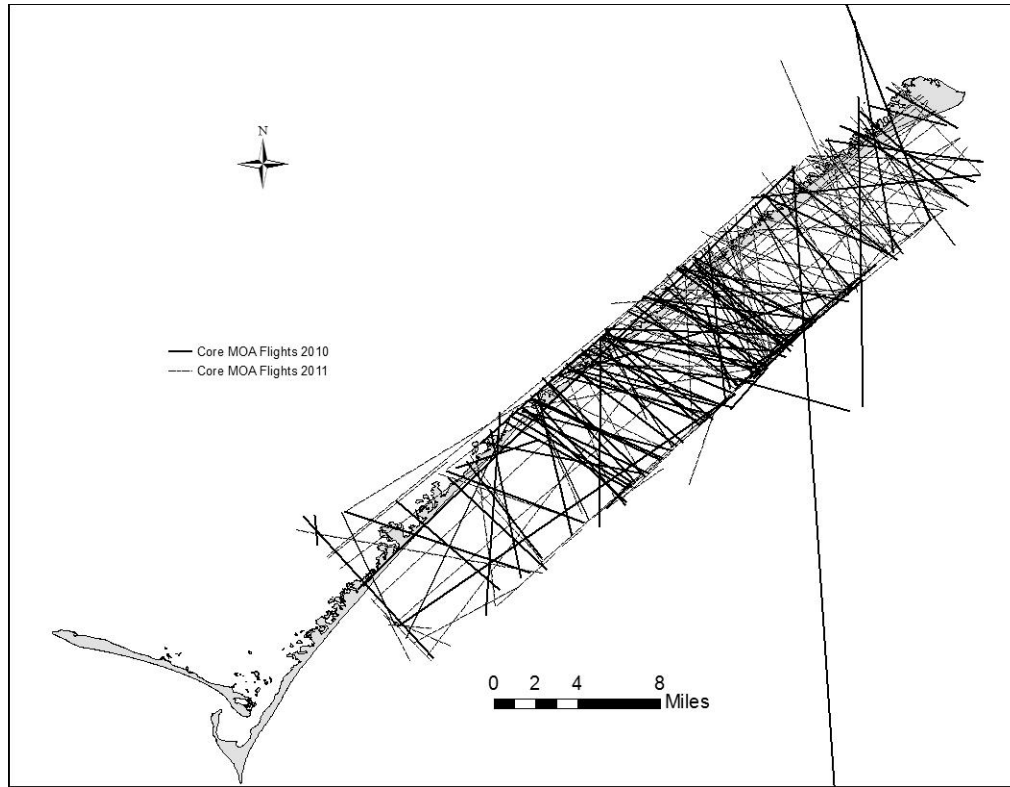
Figure 1. Lines depicting all Core Military Operations Area (MOA) overflight paths as provided

to us by the U.S. Marine Corps (USMC) Cherry Point in 2010 (dark line) and 2011 (light line). A

subset of these overflights was used in the analyses as not every overflight occurred during the

active nesting period for Wilson's Plovers, or over North Core Banks, our study area within

Cape Lookout National Seashore, NC. Lines are estimated flight paths and were constructed by

drawing a straight line between the entry and exit Core MOA coordinates provide by the USMC.