Factors affecting Wilson's Plover (*Charadrius wilsonia*) demography and habitat use at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina

Kacy Lyn Ray

Thesis submitted to the faculty of the Virginia Polytechnic Institute and State University in partial fulfillment of the requirements for the degree of

Master of Science

In

Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University

Sarah M. Karpanty
James D. Fraser
Jeffrey R. Walters

January 7, 2011
Blacksburg, VA

Keywords: beach accretion, *Charadrius wilsonia*, fiddler crab, foraging territory, hatching success, nest success, predation, productivity, reproduction, sea level anomaly, survival, Wilson's Plover

Abstract

Factors affecting Wilson's Plover (*Charadrius wilsonia*) demography and habitat use at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina

The Wilson's Plover (*Charadrius wilsonia*) is a species of concern in most southeastern U.S. coastal states, where it breeds and winters. The U.S. Shorebird Conservation Plan listed this species as a Species of High Concern (Prioritization Category 4), and the U.S. Fish and Wildlife Service has designated it as a Bird of Conservation Concern (BCC). Despite its conservation status, Wilson's Plover population trends are poorly understood and little research has been conducted examining habitat factors affecting this species' breeding and foraging ecology. I collected Wilson's Plover demographic data and explored which habitat characteristics influenced breeding success and foraging site selection among three coastal habitat types (i.e. fiddler crab (*Uca* spp.) mud flats, beach front, and interdune sand flats) at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. I observed little difference between years in nest success ($\geq$ 1 egg hatched), failure, and overall nest survival. The majority of nest failures were caused by mammalian predators. For those nests that hatched successfully, greater proportions were located in clumped vegetation than on bare ground or sparsely vegetated areas. In-season chick survival for both years was higher for nests that hatched earlier in the season, and for nests farthest from the broods' final foraging territory. Productivity estimates (chicks fledged per breeding pair) were not significantly different between years (0.88 $\pm$ 0.26 fledged/pair in 2008, 1.00 $\pm$ 0.25 fledged/pair in 2009) despite a shift in foraging behavior, possibly related to habitat alterations and availability in 2009. My findings indicate that Wilson's Plover adults and broods were flexible in establishing final foraging territories; in 2008 all final brood foraging territories were on fiddler flats while in 2009, final foraging territories were sometimes split between fiddler flats, beach front, and interdune sand flats. For those Wilson's Plovers establishing territories on fiddler flats, area of the flat was the

most important feature explaining use versus non-use of a particular flat; area ≥ 1250 m^2 was preferred. Close proximity to water and vegetative cover were also important habitat features in foraging site selection on fiddler crab mud flats, and in all habitat types combined. My findings will directly contribute to population and habitat research goals outlined in the U.S. Shorebird Plan and will supplement limited data about foraging and habitat use related to Wilson's Plover breeding ecology.

Intended authorship and target journals for manuscripts included in the thesis:

Chapter Two

Demography of Wilson's Plovers (*Charadrius wilsonia*) in southeastern North Carolina

Kacy L. Ray[1], Sarah M. Karpanty[1], James D. Fraser[1]

[1]Virginia Polytechnic Institute and State University, Blacksburg, VA

*To be submitted to *Journal of Field Ornithology*

Chapter Three

Habitat characteristics affecting nest hatching success, brood territory establishment, and foraging site selection of Wilson's Plovers (*Charadrius wilsonia*) in southeastern North Carolina

Kacy L. Ray[1], Sarah M. Karpanty[1], James D. Fraser[1]

[1]Virginia Polytechnic Institute and State University, Blacksburg, VA

*To be submitted to *Condor*

Acknowledgements

Funding for this project was provided by the Strategic Environmental Research and Development Program (SERDP), administered by the Research Triangle Institute (RTI), and is part of the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL), North Carolina, USA. The radio telemetry portion of the study was funded in part by the E. Alexander Bergstrom Memorial Research Fund administered by Association of Field Ornithologists, Inc.

I would like to thank the following people at Marine Corps Base Camp Lejeune for their assistance and invaluable input throughout my research efforts: Environmental Management Division staff and interns (especially Lindsey Moss), Susan Cohen, Vaughn Fulton, Chad Gerber, Martin Korenek, Sam O'Leary, Les Pearson, Craig Tenbrink, base Range Control (for keeping me safe from LCACs, AAVs, guns, and bombs), and all the U.S. Marines that assisted me with this project.

I am honored to have been given the opportunity to work side by side with so many talented scientists on the DCERP project, and within the Coastal Barrier research module. Thanks to Pat Cunningham, the DCERP Principal Investigator (PI), who I know has put in many long hours and exhaustive effort (and continues to do so) to coordinate this huge research project, act as a liaison between all the scientists, module PIs, and RTI administrators to ultimately produce a solid scientific product that I know will be invaluable to Camp Lejeune, the Department of Defense, all furred and feathered creatures great and small, long-leaf pine forests, rivers and streams, estuaries, marshes, beaches, the Atlantic Ocean, the water we drink, and the air we breathe. I would like express my gratitude to DCERP's Coastal Barrier group fearlessly led by C. Pete Peterson and Antonio Rodriguez, and competently supported by Stephen Fegley and his infectious laugh, along with many others who I have not yet had the opportunity to know, but hope to in the future.

I especially want to thank my field technicians Sarah Boucher, Kira Newcomb, and Chris Latimer, who devoted endless hours in the field in making this project a success. We faced many trials and tribulations of heat, cold, wind, insects, storms, grounded boats, dead boat batteries, boats that ran out of gasoline, alligators in the marsh, sinking in the marsh mud up to our knees, getting stranded on Onslow Beach with three Marines in the middle of the night, digging field vehicles out of the sand, sitting in the “Easy-Bake Oven” blind for hours on end trying to conduct observations, belly-crawling through the sand in search of elusive little shorebirds, and so many other “WIPuLar” memories that I can’t possibly list them all! Through it all, I learned so much from each of you, and I hope you have fond memories of our experience together. You all enriched my research and my life. Thank you to Kristina Hudgins and Kevin Rose, the Base’s Red-cockaded Woodpecker experts, who helped me monitor camera stations during the off-season, removed cameras before a storm hit, and came to my aid when my boat ran out of gas. Kevin also photographed a number of Wilson’s Plovers that I have used in scientific presentations over the past several years.

My project was greatly improved by the statistical advice, mentoring, and suggestions from other members of the Fraser and Karpanty lab groups: Jonathan Cohen, Daniel Catlin, and Brian Gerber. I am also grateful for the support and friendship from other graduate students in my lab group (Audrey DeRose-Wilson, J.D. Dwyer, Joy Felio, Matt Hillman, Mary Kotschwar, Zach Farris), and the Department of Fisheries & Wildlife Sciences at Virginia Tech.

I’d like to extend a special note of appreciation to my co-advisors, Jim Fraser and Sarah Karpanty, for giving me the opportunity to pursue my graduate degree at Virginia Tech, and participate in the DCERP project at Camp Lejeune. I have never known two people so dedicated to their work, which contributes greatly to the betterment of this planet. I'm glad I got to be a small part of such a big picture. Thank you, Jim, for your adept ability to speak your mind freely and stand by what you believe in – it has encouraged me to embrace my own beliefs and live by them professionally and personally. Thank you, Sarah, for your tireless mentoring and strength as a woman pursuing her professional and personal passions in life – I'm truly inspired. Much thanks to my committee member, Jeff Walters, whose personality, exemplary reputation as a scientist and manager, and experience and connections at Camp Lejeune have contributed greatly to my positive and successful experience there.

Last, but certainly not least, I'd like to thank my family and friends. Without all of you, I would have never achieved this goal. My mother, Sherri DeRhodes, is an amazing example to me, and her love and reminders of taking it one day at a time were more valuable than she realizes. My sister's (Molly Ray) life successes and loving support provided me the needed fuel to keep going. If I hadn't met N. Danielle Bridgers in this graduate program, I don't think I would have finished. She was my constant rock, and the enormity of her love, support, and friendship contributed greatly to reaching the light at the end of the tunnel. My husband, Jay Ingram, is a pivotal player in my educational and life successes, and his unrelenting example, love, support, and patience has made me the person I've always wanted and could hope to be.

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Chapter One: Introduction

Demography and habitat use of Wilson's Plovers in southeastern North Carolina

Demography

The Wilson's Plover (*Charadrius wilsonia*), is a species of high concern in the southeastern United States, where it breeds and winters (Brown et al. 2000, USFWS 2008). It is listed as Endangered in Maryland and Virginia, a Species of Concern in North Carolina, Threatened in South Carolina, and Rare in Georgia; it is not currently state-listed in Florida. The U.S. Shorebird Conservation Plan (Brown et al. 2000) has nationally and regionally (Southeastern Coastal Plains-Caribbean Region, Hunter 2002) listed the Wilson's Plover as a Species of High Concern (Prioritization Category 4), and the U.S. Fish and Wildlife Service (USFWS, 2008) has designated this species as a Bird of Conservation Concern (BCC). Despite its conservation status, Wilson's Plover population trends are poorly understood (Brown et al. 2000). Only a few studies have attempted to estimate demographic parameters for this species on the U.S. Gulf coast (Bergstrom 1982,1988; Zdravkovic 2005, 2010; Hood 2006) and along the Atlantic coast, in Georgia (Corbat 1990) and Virginia (Boettcher et al. 2007). A third study in North Carolina and Virginia (Bergstrom and Terwillinger 1987) provided data about nest fates, but not other parameters. The U.S. Shorebird Conservation Plan (Brown et al. 2000, Hunter 2002) states that efforts are needed to define essential habitat characteristics for nesting, foraging, and roosting Wilson's Plovers in order to best manage to achieve the goal of doubling the size of the breeding Wilson's Plover population in the southeastern coastal region over the next 50 years. Currently, it is estimated that there are approximately 1500 breeding pairs, and about 5000 individuals, along the U.S. Gulf and Atlantic coasts, and in the Caribbean (Hunter 2002). However, there is low confidence in this estimate (Brown et al. 2000) due to a lack of regionally coordinated, systematic surveys for Wilson's Plovers. The southeastern regional U.S. Shorebird Plan (Hunter 2002) reports that an average 1.5 fledglings per nesting pair over five years is needed to sustain and increase the current Wilson's Plover breeding pair estimate; however, this estimate should be considered speculative as no in-depth population demography studies of Wilson's Plovers have been conducted in this region. There are no peer-reviewed published estimates of Wilson's Plover fledging rates, but state and non-profit conservation partnerships in Virginia (Boettcher et al. 2008) and Louisiana (Zdravkovic *in prep*) have reported 1.00 – 1.82 fledglings per breeding pair.

Habitat

Coastal shorebirds, like the Wilson's Plover, depend on a variety of dynamic and ephemeral habitats for breeding and rearing young (Brown et al. 2000). Intertidal habitats provide foraging resources and resting sites (Brown et al. 2000, Corbat and Bergstrom 2000, Elias et al. 2000, Lowther et al. 2001, Fraser et al. 2005, Cohen et al. 2008). Habitats less susceptible to inundation (e.g. dunes, beach backshore, and interdune sand flats) provide nesting habitat (Corbat 1990, Nol and Humphrey 1994, Douglas 1996, Elliot-Smith and Haig 2004), and foraging opportunities (Corbat 1990, Hubbard and Dugan 2003, Defeo et al. 2009). Widespread coastal development and human recreation have resulted in degradation of such habitats (Burger 1989, Nol and Humphrey 1994, Loegering and Fraser 1995, Corbat and Bergstrom 2000, Page et al. 2009, Cohen et al. 2009). Emerging threats, such as climate change-related sea level rise (IPCC 2007), present additional challenges. Increased sea level may decrease the availability of shorebird foraging resources, as current intertidal zones are converted to sub-tidal habitats and sound side marshes become subject to increased periods of inundation that alter the benthic prey community (Galbraith et al. 2002). Population declines have been linked to the decline and deterioration of both nesting and foraging habitat used by shorebirds (Burger 1994, Corbat and Bergstrom 2000, Brown et al. 2001, Galbraith et al. 2002, Hunter 2002). Understanding the key features that make habitat suitable for breeding shorebirds is an essential precursor to developing effective conservation and management plans.

There have been few studies about the breeding and foraging habitat ecology of Wilson's Plovers; most of the available studies have focused on nesting ecology and life history traits (Tomkins 1944, 1959; Bergstrom 1982, 1988; Bergstrom and Terwillinger 1987; Corbat 1990; Hood 2006; Dikun 2008). Those studies examining nest hatching success (Bergstrom 1982, 1988; Corbat 1990; Hood 2006) found higher success for nests placed in or adjacent to vegetation. These studies also documented the primary causes of nest failure as mammalian predation [bobcat (*Lynx rufus*), coyote (*Canis latrans*), raccoon (*Procyon lotor*)], cattle (Bergstrom 1982, 1988) and feral hog (Corbat 1990) trampling, and heavy rain and tidal flooding (Bergstrom 1982, 1988; Hood 2006). Of all studies, only three (Tomkins 1944, 1959; Bergstrom and Terwillinger 1987; Corbat 1990) were conducted on the Atlantic coast, and Corbat's was the only one to examine habitat characteristics influencing nest site selection and hatching success.

Fiddler crabs (*Uca* spp.) have been identified as a key component of Wilson's Plover diets in both their wintering and breeding seasons (Tomkins 1944, Strauch and Abele 1979, Bergstrom 1982; Morrier and McNeil 1991; Thibault and McNeil 1994, 1995; Corbat and Bergstrom 2000; Leary 2009), suggesting that the presence or density of these prey may play an important role in Wilson's Plover foraging habitat selection. I am unaware of other studies addressing the effect of habitat or prey distribution on selection of brood foraging sites and territory establishment for Wilson's Plovers.

Project Background

I studied the breeding ecology of Wilson's Plovers at Onslow Beach (34°32' N, 77°21'W), Marine Corps Base Camp Lejeune (MCBCL), North Carolina from March–August 2008 and 2009 in order to begin to address some of the demography and habitat information needs as outlined above. My study was funded by the U.S. Department of Defense's (DoD) Strategic Environmental Research and Development Program (SERDP), and was part of the Defense Coastal/Estuarine Research Program (DCERP) administered by Research Triangle Institute (RTI) International. The goal of DCERP (2007a) is to conduct research pertaining to the structure and function of a coastal and estuarine ecosystem in the context of sustaining critical natural resources essential to military training and readiness. This study is a component of the Coastal Barrier module (2007b), one of five total DCERP modules, which together, examine the physical, geological, and biological processes at MCBCL relevant to the long-term integrity of the Base ecosystem and its multiple missions. In particular, the efforts of the Coastal Barrier module seek to support the long-term sustainability of important coastal resources necessary for amphibious training at MCBCL, and the DoD's military mission (DCERP 2007a, 2007b). My study is also relevant to a Memorandum of Understanding (MOU, Federal Register 51580-51585) between MCBCL and the U.S. Fish and Wildlife Service which outlines efforts to protect and promote the conservation of migratory birds on its lands, including breeding shorebirds.

My study examines biotic and abiotic factors influencing Wilson's Plovers productivity on Onslow Beach. I chose Wilson's Plover as the focal species for this study because it is a Species of Concern in this region, and Onslow Beach appeared to be an important breeding location for this species in North Carolina. I found and studied 20 nests of Wilson's Plovers in 2008 and 26 in 2009. The North Carolina Wildlife Resources Commission (NCWRC) considers a coastal habitat containing ≥ 25 Wilson's Plover pairs to be an important breeding location for sustaining and increasing regional and range-wide populations (Susan Cameron, NCWRC, personal communication).

Specific study objectives

I studied breeding Wilson's Plovers and their broods in southeastern North Carolina to estimate demographic parameters and examine habitat characteristics influencing breeding success and foraging site selection. My first objective was to quantify nest survival and failure, chick survival, productivity (i.e. chicks hatched and fledged per breeding pair), and minimum-known-alive adult survival (i.e. second year re-sightings of banded adults). My second objective was to quantify which habitat characteristics affected 1) nest hatching success, 2) brood territory establishment, and 3) foraging site selection. I also explored inter-annual variation in foraging behavior and habitat use by Wilson's Plover broods possibly related to both an anomalous sea-level event in 2009 (Sweet et al. 2009), and considerable natural beach front sand accretion that occurred between years on Onslow Beach.

Chapter introductions

Chapter 2: I report rates of Wilson's Plover nest success and failure by year, and factors affecting nest survival across both years. I report causes of nest failure from physical evidence that remained around nest bowls and photographic data from nest sites monitored with infrared motion-triggered cameras. I provide a second-year return rate for adults banded in 2008 returning in 2009, and productivity estimates (i.e. chicks hatched and fledged per breeding pair) for each year. I explore factors affecting chick survival, in particular nest hatching date and the distance a brood traveled from its nest site to its final foraging territory. I compare my results to similar studies and discuss the differences between two available options for estimating nest survival. Finally, I explore a hypothesis to explain my observation of increasing chick survival for those nests hatching farther away from final brood foraging territories.

Chapter 3: I quantify vegetation characteristics around all nests, and report which habitat characteristics influenced brood foraging territory establishment and foraging site selection within fiddler flats, interdune sand flats, and beach front habitats. I examine inter-annual variation in brood foraging behavior and habitat use which may have been influenced by anomalous water heights in 2009 and the accretion of new beach front foraging habitat between the two breeding seasons. I discuss the management implications of these findings, suggesting a need to manage a matrix of habitats for breeding adults and foraging broods.

Chapter 4: In this thesis conclusion, I summarize the main findings of my study and relate them to MCBCL, regional, and range-wide conservation and management of Wilson's Plovers.

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Chapter 2:

Demography of Wilson's Plovers (*Charadrius wilsonia*) in southeastern North Carolina

Abstract

The Wilson's Plover (*Charadrius wilsonia*) has been identified as a Species of High Concern in the U.S. Shorebird Conservation Plan. Little demographic information is available for this species throughout their range. Our objective was to quantify nest hatching success, productivity, chick survival, and minimum-known-alive adult survival of Wilson's Plovers at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. We located and monitored nest sites until success or failure, and used the Mayfield method to calculate daily and overall nest survival for each year. When possible, causes of nest failures were determined by physical signs or camera monitoring at the nest site. We re-sighted banded individuals (adults and chicks) from both years of the study to calculate in-season chick survival, adult return rates in the second study year, and to assess productivity. We observed little difference in nest survival (≥ 1 egg hatching per nest) between years (45.5% in 2008 and 43.6% in 2009). Virginia opossums (*Didelphis virginiana*) and raccoons (*Procyon lotor*) were responsible for most of the known nest depredations (N = 11 total predation events) over two years. We found 1.56 chicks hatched per pair (N = 39) combining both years of data. Chick survival increased as the distance from the nest to the brood's final foraging territory increased. Hatching date and chick survival were negatively related such that later hatching nests were associated with lower chick survival. The 2-yr mean for fledglings per breeding pair (N = 37) on Onslow Beach was 0.94. Of the 20 adult Wilson's Plovers banded in 2008, 18 returned to Onslow Beach in 2009; only two of 21 chicks banded in the first year returned in the subsequent breeding season. We are unaware of previous published estimates of Wilson's Plover chick survival, and information about fledging rates across this species' range is scarce. Our findings will directly contribute to assessing the status of Wilson's Plover populations in the southeastern U.S.

Key words *Charadrius wilsonia*, nest success, predation, productivity, reproduction, survival, Wilson's Plover

Introduction

The Wilson's Plover (*Charadrius wilsonia*) is a species of high concern in the southeastern United States, where it breeds (Brown et al. 2000, USFWS 2008). It is listed as Endangered in Maryland and Virginia, a Species of Concern in North Carolina, Threatened in South Carolina and Rare in Georgia; it is not currently state-listed in Florida. The U.S. Shorebird Conservation Plan (Brown et al. 2000) has nationally and regionally listed the Wilson's Plover as a Species of High Concern (Prioritization Category 4, Southeastern Coastal Plains-Caribbean Region, Hunter 2002), and the U.S. Fish and Wildlife Service (USFWS, 2008) has designated this species as a Bird of Conservation Concern (BCC). Despite its conservation status, Wilson's Plover population trends are poorly understood (Brown et al. 2000) and few studies have estimated demographic parameters for this species (Bergstrom 1982 and 1988, Corbat 1990, Hood 2006). A study in North Carolina and Virginia (Bergstrom and Terwillinger 1987) provided some data about nest fates, but the primary focus of that study was behavioral ecology. No dedicated studies of Wilson's Plover population demography have been conducted in North Carolina despite its possible importance as a central location of the Wilson's Plover's current Atlantic Coast breeding range.

We studied Wilson's Plover demography on Marine Corps Base Camp Lejeune (MCBCL), North Carolina, from March to August 2008 and 2009. Here we report estimates of Wilson's Plover nest survival, chick survival, chicks hatched and fledged per breeding pair, and minimum-known-alive adult survival.

Study Site

We conducted this study on Onslow Beach (34°32' N, 77°21'W), a 12.9-km barrier island in southeastern North Carolina. It is bounded by New River Inlet and Brown's Inlet (Fig 1).

Human impacts vary across the island. The south end of the island is managed for low impact recreation and wildlife (Wildlife Area), and is closed to recreational vehicles from 1 April to 31 August, annually (Fig 1). The Amphibious Training Zone is designated for military training and the Developed Recreation Area provides recreational opportunities for Marine Corps personnel and their families (Fig 1); surveys in 2008 and 2009 found no Wilson's Plovers nesting in these two areas, so we do not discuss them further. Access to the Military Buffer and Impact zones was restricted and sporadic; we include data from these areas only when they are comparable to the data reported from the more intensely studied Wildlife Area.

Habitats were typical of barrier islands in this region, and included, from the ocean to the marsh: ocean intertidal zone, backshore, primary dunes, interdune sand flats, maritime shrub and forest, and bay-side intertidal flats and marshes. An overwash fan formed during Hurricanes Bertha and Fran in 1996 removed woody vegetation and created an approximately 200 m wide by 1 km long interdune sand flat that included about 400-m of direct interface with marsh and bay-side intertidal flats. Since 1996, sparse low-growing vegetation and clumped grasses have grown in the interdune sand flats (i.e. overwash), including primarily sea rocket (*Cakile harperi*), seashore elder (*Iva imbricate*), seaside pennywort (*Hydrocotyle bonariensis*), dotted horsemint (*Monarda punctata*), saltmeadow cordgrass (*Spartina patens*), sea oats (*Uniola paniculata*), American beach grass (*Ammophila breviligulata*), and smartweed (*Polygonum* spp.).

Methods

We searched for nests in the Wildlife Area, primarily from 06:00-10:00, from the end of March through mid-July in 2008 and 2009. In 2008, we searched for nests by walking daily along the primary dunes and through interdune sand flats. In 2009, we established three transects through the interdune sand flats (0.75 km, 0.77 km, and 1.61 km long, respectively, 45-

190 m apart depending on patches of forest and large dunes) and three through the beach front habitat (0.53 km, 0.83 km, and 0.98 km long, respectively, 35-60 m apart). We searched for nests on these transects 2-3 days per week during the egg-laying period. We used behavioral cues such as territory defense, mock brooding, broken-wing displays, and incubation to locate nesting areas and nest sites.

We used a GPS (Garmin 76, Garmin International, Olathe, KS) to mark nest locations. We checked nests every 1-3 days, standing 2-5 m away to avoid attracting predators. In 2009, we wore rubber boots and sprayed them with Scent-A-Way™ (Hunter's Specialties, Cedar Rapids, IA) to minimize human scent around the nest site. We placed motion-triggered cameras (Reconyx Rapidfire ICR-Color RC55 digital cameras; Reconyx, Inc, Holmen, WI) inside secured wooden boxes to deter theft, at randomly selected nest sites to monitor causes of nest failure. In 2008, we placed cameras 5-8 m from the nest. In 2009, we moved the cameras to within 1.5-2.0 m of the nest (as in Sabine et al. 2005, 2006) to increase the probability of detection and to improve picture clarity. To deter avian predators from perching on the box, we placed a convex chicken-wire perch deterrent on top of each camera box.

We considered nests successful if at least one egg hatched. When we discovered a nest during initiation (i.e. < 3 eggs in nest and the male primarily incubating during daylight hours; Bergstrom 1986) we predicted hatch date to be 25 days from clutch completion. We considered clutch completion as a nest typically containing three eggs with the female primarily incubating during daylight hours (Bergstrom 1988, this study). We deemed a nest abandoned if the eggs did not hatch 5 days after the predicted hatch date or if adults were not observed defending a nest containing eggs for ≥ 72 hours. When nests failed, we examined the nest site for signs of the cause; including avian or mammalian tracks, shell fragments, or wrack deposition (due to tidal flooding). We investigated such signs at nest sites with and without cameras.

We trapped adult plovers within 48 hours of nest detection using drop box (Wilcox 1959, Graul 1979) and oblong funnel traps (Lessells 1984, Paton 1994), and banded them with three unique color bands on the left tarsometatarsus. We captured chicks by hand in or near the nest bowl usually 3-8 hrs post-hatch (N = 29), or opportunistically at a later date (N = 7), and banded them using the same scheme as we did for adults. After adults and chicks were banded, we attempted to re-sight them every 1-2 days through the end of the season. We used the same searching techniques for re-sighting that were used for nest searching in 2008 and 2009 (i.e. we searched by walking the dune line and interdune sand flats in 2008 and along established transects in 2009).

In 2009, we used radio-telemetry to assist in locating broods during the first 5-10 days after hatch, when chicks were difficult to detect (Appendix D). We targeted adult males for transmitter attachment since they are the primary incubators approximately 48 hours prior to hatch and attend chicks more frequently than females (Bergstrom 1986, this study); however, females were tagged when males could not be trapped. We used 1.6-g BD-2 transmitters (Holohil Systems Ltd., Ontario, Canada) weighing < 3% of the average adult Wilson's Plover weight (average adult weight = approximately 68 g; this study, Corbat and Bergstrom 2000). We plucked dorsal contour feathers between the bird's scapulae in an approximately 1 cm^2 patch to fit the dimensions (18x10x3.5 mm) of the transmitters. We glued the devices to the exposed skin using cyanocrylate gel (Loctite®, Westlake, Ohio). We used 3-element Yagi antennae and handheld receivers to locate the birds (Communication Specialists, Inc., Orange, California). We searched for radio-tagged Wilson's Plovers and broods every 2-4 days after tag attachment along the same transects established for nest searching and brood re-sighting until the tags were dropped or the birds migrated from the site.

We used Mayfield's method (1961, 1975) to calculate daily (DSR) and overall nest survival (DSR^d; d = incubation days). For survival estimates, we adapted terminology and symbols for our models from Lebreton et al. (1992). We estimated chick survival for 2008 and 2009 using a Cormack-Jolly-Seber recapture model in program MARK (White and Burnham 1999) to generate apparent survival (Φ) and detection probabilities (ρ) based on weekly re-sightings. We estimated weekly survival rates (WSR) using four seven-day encounter periods (chicks fledge in 28 days; this study) with a fifth week accounting for post-fledge survival. We executed all model combinations including the effects of year (i.e. 2008 and 2009 re-sightings), time (i.e. weekly encounter), and additive and multiplicative interactions of year and time on apparent survival (Φ) and detection rate (ρ). We used the resultant top model as a basis for building additional biologically plausible models that included habitat covariates. We included the covariates hatch date, distance (km) from nest site to final brood foraging territory, distance (km) to nearest fiddler crab mud flat, and distance (km) to nearest vegetated edge (vegetation continuously ≥ 1 m tall for at least ≥ 10 m at a habitat type boundary) in the additional modeling efforts. Our chick re-sighting data was not overdispersed ($\hat{c} = 0.99$), therefore no model adjustments were necessary.

We used Akaike's Information Criterion (AIC, Akaike 1973) adjusted for small sample size (AIC_c) to determine the best fitting model for apparent chick survival (Anderson et al. 2001, Burnham and Anderson 2002). We considered models with ΔAIC_c values < 2.0 and model likelihoods ≥ 0.125 as equally competitive in estimating apparent survival (Burnham and

Anderson 2002). Model covariates whose 95% confidence limits did not include zero were considered to be statistically significant in our results.

Since the single best-fit model was based on mean values of each covariate of interest, we executed individual models with user-specified covariate values (i.e. the actual covariate value for each brood) in program MARK to attain a WSR for each brood. Apparent survival for each brood was determined by raising the WSR to the number of weeks (w) to fledging (w = 4, WSR^w). Overall apparent survival for chicks in 2008 and 2009 was determined by averaging the brood WSR estimates and raising the mean to the number of weeks to fledging (i.e. 4 weeks).

Minimum-known-alive adult survival rate was calculated as the proportion of birds banded in 2008 that returned to Onslow Beach in 2009.

Results

We found 20 nests in 2008 and 26 in 2009. These totals included three re-nests in 2008 and four in 2009. We typically observed a clutch size of three eggs (three nests in two years with two eggs) and an incubation period of 25-26 days (Table 1). Raw nest hatching success and Mayfield nest survival estimates were similar between years (Table 1). Predation was the leading cause of nest loss (Table 2). We were able to confirm more depredations in 2009 due to improved camera placement at nests; however, we continued to examine physical signs at the nest site as we did in 2008 (Table 2). For both years, predators included Virginia opossums (*Didelphis virginiana*, seven nests), raccoons (*Procyon lotor,* three nests), ghost crab (*Ocypode quadrate,* one nest), and unidentified rodents (Rodentia, two nests). In two cases, opossums were the first of two sequential nest predators; consuming two eggs before a raccoon consumed the last one the next day, and eating two eggs from another nest prior to a ghost crab taking the last one two days later.

Mean chicks hatched per pair and fledged per pair were 1.56 and 0.94, respectively, for both years combined (Table 1). Ninety percent (18 out of 20) of adult Wilson's Plovers banded in 2008 were observed on the study area in 2009, but only 9.5% (two out of 21) of the 2008-banded chicks were observed in 2009.

Only hatch date and distance from nest site to final brood territory (km) were used in building biologically plausible models, and both appeared in the resultant single top model (Table 3). We excluded the other two covariates because often times the fiddler crab mud flat was the brood's final foraging territory, and vegetated edges (as previously defined) were almost always next to sound-side mud flats (i.e. fiddler crab mud flats). The top model including covariates estimated the maximum possible chick survival based on mean values ($\bar{x}$ distance to final foraging territory = 0.54 km; $\bar{x}$ hatch date = 20th day of the breeding season – approximately 5 Jun at MCBCL) used in our analyses. Wilson's Plover chick survival was best predicted by a model including the distance a brood traveled from its nest site to its final foraging territory (km), and the date the brood hatched (Table 3). We identified a positive relationship between chick survival and distance to final foraging territory, while hatch date was negatively related to chick survival (i.e. confidence limits do not encompass zero, Table 3, Fig. 2).

Weekly survival rate and overall apparent survival from our top model, which predicted chick survival based on average apparent survival estimates from the user-specified covariate models for all broods, was 93% and 75% respectively (Appendix A, Table 1). In 2009, we observed 20 of 30 chicks (0.67 ± 0.08) at age 28 days or older, and 15 of 25 chicks (0.60 ± 0.13) fledged in 2008. Detection probabilities of chicks (ρ) differed by week within each year (2008 = 0.21 – 1.00, 2009 = 0.59 – 0.77).

Discussion

Clutch sizes and incubation periods in this study were similar to those observed in Georgia and Texas (2.90–2.92 eggs, 25–27 days; Bergstrom 1988, Corbat 1990; Appendix A, Table 2). However, nest survival at Camp Lejeune was higher than what was documented in those studies (means of 23% and 27% respectively; Bergstrom 1988, Corbat 1990; Appendix A, Table 2), but similar to Hood's (2006) findings in south Texas (58%, Appendix A, Table 2). Nest predators identified in those studies included raccoons, coyotes (*Canis latrans*), bobcats (*Lynx rufus*), feral hogs, unidentified rodents, and unidentified birds. In addition, some nests in Texas were trampled by cattle. We identified raccoons and opossums as the primary nest predators in our North Carolina study. Bobcats were present at Camp Lejeune, but we found no evidence that they depredated Wilson's Plover nests. In 2009, one motion-triggered camera recorded a bobcat walking within 1 – 2 m of a nest at night; this nest hatched successfully.

We identified the cause of failure for a higher percentage of nests in 2009 than in 2008, likely because we put cameras closer to nests in 2009. In 2008, some nests were lost, but the predators did not trigger the cameras and we could not easily confirm the suspected cause of failure from physical signs (tracks and egg shell fragments) alone. We moved our cameras closer (i.e. within 1.5 – 2.0 m) to nest sites in 2009, and increased confirmed depredation events by approximately 15%, subsequently reducing unknown nest fates from 30% to 15% in 2008. In our study and others (Bergstrom 1988, Corbat 1990), nests with unknown fates had no physical signs of depredation or wash out (e.g. flooding, high tides), and there were no adults or pairs defending the nest as if the eggs hatched and the chicks were nearby. It is likely that nests with unknown fates were depredated; however, blowing sand may have concealed indicative signs and some predators, such as birds, may not leave tracks (Bergstrom 1988, Corbat 1990).

We found few cases of nest abandonment related to direct human disturbance, similar to studies in Texas (Bergstrom 1988) and Georgia (Corbat 1990). We observed only one nest abandonment each year; both cases occurred over Memorial Day weekend when an influx of boats and people were observed picnicking and walking near nest sites that were not located within protected areas marked with symbolic fencing and signs. Roche (2010) found that the disappearance of an attending adult was the primary reason behind nest abandonment in the Great Lakes Piping Plover population. It is plausible this happened in 2008 on Onslow Beach, as we never observed the male with the female or incubating the nest. We did not observe any abandonment due to camera placement or regular monitoring of nest sites (i.e. nest checks every 2-3 days). Similarly, Sabine et al. (2005, 2006) did not find that the close proximity of their cameras (1.5-2.0 m) to American Oystercatcher (*Haematopus palliatus*) nests caused nest abandonment.

Nest failure due to flooding or high tides was also minimal during our study (only one nest in 2008) despite anomalous sea level heights (+ 0.20 m residual (observed –predicted) water height) reported by the National Oceanic and Atmospheric Administration (NOAA) for June and July 2009 (Sweet et al. 2009). Most of the Wilson's Plover nests in this study were located in interdunal habitat (i.e. overwash) or immediately adjacent to it along primary dunes. The mean elevation of the overwash in the southern end of the island was 1.52 m above mean sea level (A. Rodriguez, University of North Carolina at Chapel Hill Institute of Marine Sciences, personal communication), and no major storm events (i.e. Nor'easters, tropical storms, or hurricanes) occurred during the breeding seasons of this study.

Hood's (2006) overall nest survival estimate (58%) as calculated from a recently developed generalized linear modeling approach (Dinsmore et al. 2002, Rotella et al. 2004) was higher than our nest survival estimates (46%, 44% in 2008, 2009) and those of Bergstrom (1988) and Corbat (1990), all of which used Mayfield's method for calculating nest success (1961, 1975). The Mayfield method assumes that nest survival is constant throughout the incubation period, while the generalized linear modeling approach (i.e. a likelihood-based model) is more flexible and able to account for spatial- and temporal-specific covariates influencing variation in daily nest survival (Rotella et al. 2004). Nest survival estimates using Mayfield's method may result in underestimated survival rates since day-to-day variation is not accounted for, and nests are not commonly monitored from the onset of incubation (Mayfield 1975), as was the case in this study. Hood (2006) did not find evidence that seasonal or annual variation or nest age influenced Wilson's Plover nest survival, but rather discovered that an assumption of constant survival best fit the data. Given her findings (and our raw calculations), it is plausible that we attained a reasonably precise overall nest survival estimate using Mayfield's method.

We are unaware of previous published estimates of Wilson's Plover chick survival. In this study, chick survival was negatively related to hatch date such that later hatching nests had lower chick survival, similar to findings for other shorebirds (Nisbet et al. 1978, Moreno 1998, Arnold et al. 2004, Arnold et al. 2006, Catlin 2009). As in previous studies, we hypothesize that this negative relationship between hatch date and chick survival is due to fact that experienced breeders arrive to breeding grounds first (Møller 2001, Møller et al. 2004) and establish higher quality nesting and foraging territories (Aebischer et al. 1996). This mechanism remains to be tested for Wilson's Plovers. Those broods hatching later in the breeding season may also experience reduced survival due to heat stress associated with higher temperatures (Burger 1982, Safina and Burger 1983), an influx in juvenile avian and mammalian predators at this time of year, or a reduction in food availability (Loegering and Fraser 1995, Elias et al. 2000).

We included distance from the nest to the final foraging area in our candidate models expecting that greater distances traveled to reach foraging sites would increase the chances of chick predation. In contrast to our expectation, we found a positive relationship between survival and the distance to the final foraging territory. This may be explained by the foraging patterns in the first days after hatching. In 2008, the final foraging territory was always a fiddler crab (*Uca* spp.) mud flat. In 2009, birds often established two-fold foraging territories encompassing fiddler crab mud flats and another habitat type (e.g. interdune sand flat or beach front containing ephemeral pools). When nests hatched on Onslow Beach, broods foraged near the nest site on insects among sparse clumps of vegetation on interdune sand flats or along dune toes. Chicks easily camouflaged themselves during foraging by remaining motionless in vegetation (Bergstrom and Corbat 2000) and using litter and debris as protective cover (e.g. driftwood, shells, dead vegetation, peat deposits). After ≤ 10 days, broods typically moved toward sound-side mud flats where final foraging territories were established, and where chicks fed primarily on fiddler crabs until fledging. Of the nine flats in the study area, six were surrounded by vegetation ≥ 1 m tall in ≥ 10 m increments which might offer cover and concealment for mammalian predators (Dijack and Thompson 2000, Erwin et al. 2001, Mazzocchi and Forys 2005), such as raccoons and opossums observed on Onslow Beach during both years of the study. We hypothesize that the farther the nest site (i.e. the initial foraging territory) was from the densely vegetated edges (≥ 1 m tall) of sound-side mud flats, the higher the probability that chicks escaped potential predators in their first days of life when their motor skills were relatively undeveloped (i.e. hiding versus running). Kotliar and Burger (1986) suggested that dense vegetation may inhibit maneuverability of Least Tern (*Sterna antillarum*) chicks evading predators. As Wilson's Plover chicks progress in development (≥ 7 days observed in this study), their motor skills improved, and they began to run as a mechanism to escape perceived threats, less often sitting motionlessly under clumped vegetation to evade potential danger. Increased chick mobility and independence may allow adults and broods begin to establish final foraging territories on fiddler crab mud flats (that may or may not be obstructed by vegetation ≥ 1 m tall) at this stage of chick growth.

My research contributes valuable information towards evaluating the validity of the population goals for Wilson's Plovers as identified in the U.S. Shorebird Plan for the southeastern coastal plains region (Hunter 2002). The plan set a regional goal to double the Wilson's Plover population over the next 50 years (Hunter 2002), and suggested a 5-yr mean productivity of 1.5 fledglings per breeding pair based on estimates from Piping Plovers (*Charadirus melodus*; Haig 1992, USFWS 1996) and Snowy Plovers (*Charadrius alexandrinus*, Page et al. 1995). I observed a mean fledging rate over a 2-yr period of only 0.94 fledglings per pair. It may be plausible that 1.5 fledglings per breeding Wilson's Plover pair are unnecessary to maintain a viable population. An increased understanding of Wilson's Plover population demography in this region is needed before setting target productivity values necessary to sustain or increase this population. For instance, target productivity rates for sustaining the Threatened Atlantic coast Piping Plover population were determined by analyzing 10 years of pooled demographic data collected from areas that accounted for 90% of the breeding coastal population (USFWS 1996); thus, at this stage in our knowledge of Wilson's Plover demography, it is premature to estimate sustainable productivity levels.

Peer reviewed research efforts pertaining to all life history aspects of the Wilson's Plover to date are modest. Considering the 1) dynamic nature of coastal barrier ecosystems that Wilson's Plovers depend on for breeding, 2) documented anthropogenic impacts that have reduced the quality, quantity, and availability of shorebird nesting and foraging habitat over the past 50 years on barrier islands (Brown et al. 2001, Peterson and Bishop 2005, Peterson et al. 2006, Schlacher et al. 2008, Defeo et al. 2009), and 3) current predictions of sea level rise which may reduce the availability of breeding habitat (Galbraith et al. 2002, IPCC 2007, Defeo et al. 2009), ongoing demographic research and monitoring of this species is critical in sustaining and growing regional populations while simultaneously conserving Wilson's Plovers across their entire range.

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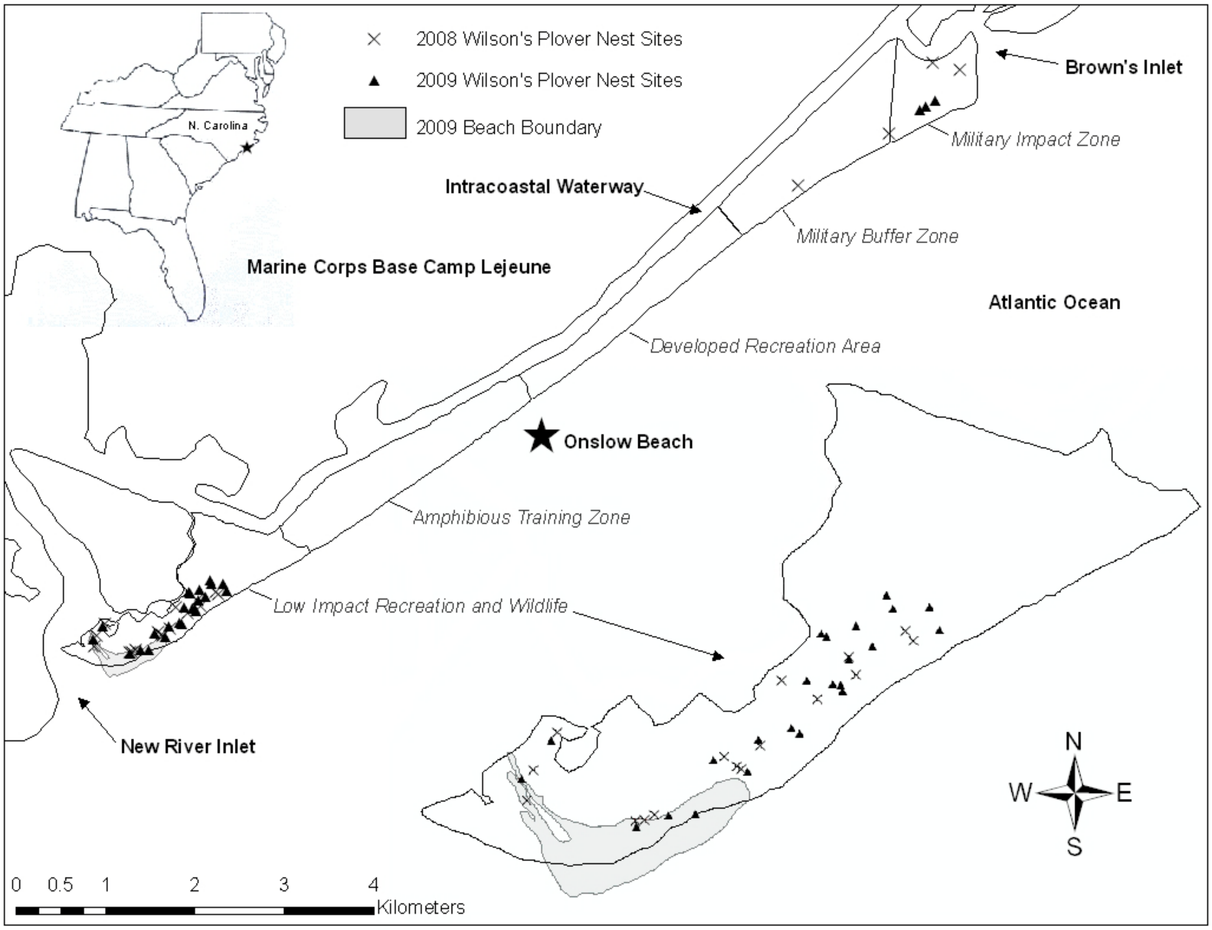

Fig 1**.** Study area at Onslow Beach on Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. The low impact recreation and wildlife area is enlarged to clearly depict Wilson's Plover (*Charadrius wilsonia*) nest site locations, and changes in the beach boundary between years.

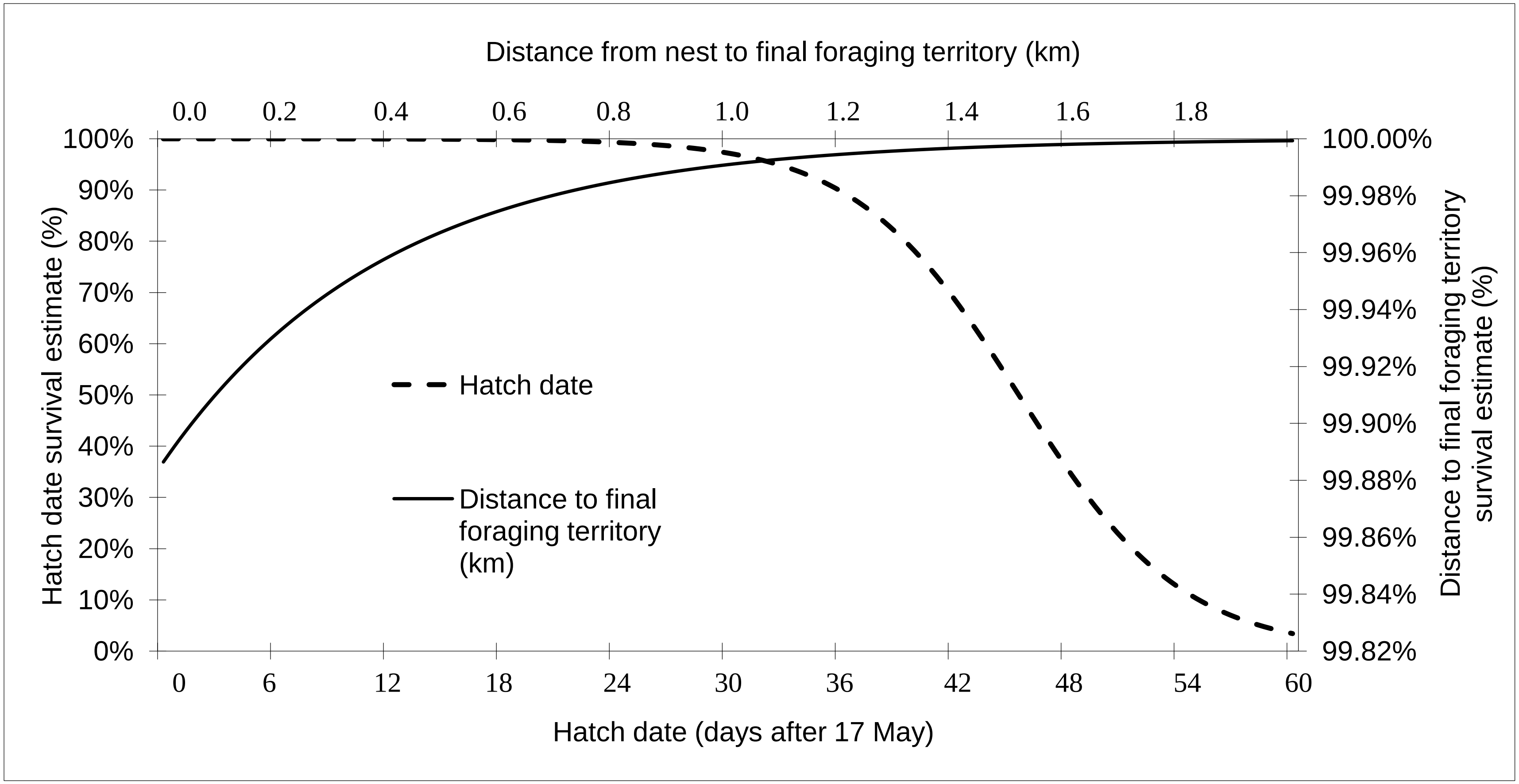

Fig 2. Predicted survival of Wilson's Plover chicks based on the top-ranked model containing actual covariate values predicting survival as a function of hatch date and distance (km) from nest to final foraging territory at Marine Corps Base Camp Lejeune, North Carolina, 2008-2009.

Table 1. Demographic estimates (±SE) for Wilson's Plovers (*Charadrius wilsonia*) on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. Sample size of nests/pairs/broods used in calculating each estimate is in parentheses after value.

Year	Mean clutch size	Incubation days	Hatching success (≥ 1 egg)	Mayfield nest survival	Chicks hatched per pair	Chicks fledged per pair	Days to fledging
2008	2.80 ± 0.12 (20)	25 (9)	45% (17)	46% (17)	1.47 ± 0.36 (17)	0.88 ± 0.26 (17)	28 (9)
2009	2.96 ± 0.04 (26)	25-26 (11)	50% (22)	44% (20)	1.64 ± 0.31 (22)	1.00 ± 0.25 (20)	28-29 (11)

Table 2. Causes of failure for Wilson's Plover (*Charadrius wilsonia*) nests on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. Confirmed depredations via physical signs, camera confirmation, or both techniques are reported.

	Depredated N^a (%)	Abandoned N (%)	Washed out N (%)	Unknown N (%)	Physical signs	Camera confirmation	Both
2008	3 (15)	1 (5)	1 (5)	6 (30)	3	0	0
2009	8 (31)	1 (4)	0 (0)	4 (15)	3	6	3
Total	11 (24)	2 (4)	1 (2)	10 (22)	6	6	4

[a]*N* = number of nests failed by given cause; total nests observed were 20 (2008) and 26 (2009)

Table 3. Model-selected parameter estimates (β_x), standard errors (± SE), and 95% lower and upper confidence limits (LCL, UCL) for the best-fitting model [a] (AIC_c < 2.00 or model likelihood ≥ 0.125) predicting Wilson's Plover (*Charadrius wilsonia*) chick survival (*N* = 20 broods) on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009.

Model Covariates	β_x	± SE	95% LCL	95% UCL
Hatch Date	-0.23	0.10	-0.44	-0.03
Distance to Final Foraging Territory (km)	2.73	1.16	0.46	4.99

[a] {Φ(HatchDate DistFTerr) ρ(year×week)}was the best-fitting model predicting chick survival (Φ) as a function of hatch date (HatchDate), and the distance (km) a brood traveled from its nest site to its final foraging territory (DistFTerr), AIC_c = 222.25, ΔAIC_c (difference between candidate model's score and the top model score) = 0.00, *K* (number of model parameters) = 11, w_i (weight of each model as compared to all candidate models) = 0.87, model likelihood = 1.00.

Chapter 3:

Habitat characteristics affecting nest hatching success, brood territory establishment, and foraging site selection of Wilson's Plovers (*Charadrius wilsonia*) in southeastern North Carolina

Abstract

Little information is available on Wilson's Plover (*Charadrius wilsonia*) habitat ecology to guide management actions for this species of concern in the southeastern United States. We examined habitat characteristics affecting Wilson's Plover nest hatching success, brood territory establishment, and foraging site selection at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. We measured substrate and vegetation characteristics at the nest site to determine features influencing nest success. Fiddler crabs (*Uca* spp.) are a primary component of Wilson's Plover diets so we sampled prey abundance, vegetation attributes, and area of fiddler crab mudflats to assess which, if any, variables influenced foraging territory establishment on fiddler flats. We sampled these same habitat characteristics at focal bird foraging locations in all habitats in which foraging birds were observed (e.g. fiddler flats, interdune sand flats, beach front) and compared these data to paired, non-used sites within the same habitat type. Finally, we compared foraging behaviors of adults and chicks across habitat types between years. A higher proportion of nests placed among clumped grasses and mixed vegetation were successful than those placed on bare ground or in low-growing sparse vegetation. Area of a given fiddler flat was the most important factor influencing brood territory establishment. Close proximity to water and vegetative cover were important factors in where broods chose to forage in all habitats ≥ 7 days. In 2009, beach front sand accumulation created new foraging habitat, and anomalous water heights restricted accessibility to fiddler flats. Wilson's Plovers responded to these habitat changes by foraging more frequently on the beach front and interdune sand flats and pecking more for insects in this second year. Chick survival was similar in the two years. These findings suggest that Wilson's Plovers have flexible foraging strategies which are likely adapted to the dynamic coastal environment they inhabit. Managers should strive to maintain a complex of sparsely vegetated interdune sand flats for nesting birds with adjacent accessible beach front and large fiddler flats (>1250 m^2) for Wilson's Plovers broods.

Key words: beach accretion, Charadrius wilsonia, *fiddler crab, foraging territory, hatching success, sea level anomaly, Wilson's Plover*

Introduction

The Wilson's Plover (*Charadrius wilsonia*) is a species of concern throughout the southeastern United States and a high priority species in the U.S. Shorebird Conservation Plan for the Southeastern Coastal Plains-Caribbean Region (Brown et al. 2001, Hunter 2002). Nevertheless, there have been few studies of Wilson's Plover. To date, studies have focused on nesting ecology and life history traits (Tomkins 1944, Bergstrom 1982, 1988; Corbat 1990; Hood 2006, Dikun 2008). Studies examining nest survival (Bergstrom 1982, Corbat 1990, Hood 2006, this study) found higher hatching success for nests placed in or adjacent to vegetation. We are unaware of studies addressing the effect of habitat or prey distribution on selection of brood foraging sites. Studies of other shorebird species have shown that habitat quality and availability are important factors in defining brood foraging territories that successfully produce fledglings (Loegering and Fraser 1995, Elias et al. 2000, Vickery et al. 2001, Schekkerman et al. 2009). Fiddler crabs (*Uca* spp.) are a key component of Wilson's Plover diets in both wintering and breeding seasons (Tomkins 1944, Strauch and Abele 1979, Bergstrom 1982; Morrier and McNeil 1991; Thibault and McNeil 1994, 1995; Corbat and Bergstrom 2000; Leary 2009), and thus the presence or density of these invertebrates may play an important role in Wilson's Plover habitat selection.

We studied habitat characteristics affecting nest site selection and hatching success, brood territory establishment, and foraging site selection of Wilson's Plovers. We examined inter-annual variation in the use of inter-tidal mud flats colonized by fiddler crabs, and brood foraging behavior across three habitat types, as the habitat was altered due to an anomalous rise in sea level in 2009 (Sweet et al. 2009), and natural beach front sand accretion that occurred between years on Onslow Beach.

Methods

Study Site

We studied breeding Wilson's Plovers at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina from March–August 2008 and 2009. Onslow Beach (77°20'9.751"W 34°31'52.911"N) is a 12.9-km coastal barrier island bounded by the New River Inlet and Brown's Inlet (Fig. 1). The south end of the island (Wildlife Area) is designated and managed for Low Impact Recreation and Wildlife and is closed to recreational vehicles from 1 April–31 August, annually. The Amphibious Training Zone is designated for military training and the Developed Recreation Area provides recreational opportunities for Marine Corps personnel and their families; no nesting Wilson's Plovers were found in these two areas, so we do not discuss them further. Access to the Military Buffer and Impact zones was restricted and sporadic; we include data from these areas only when they are comparable to the data reported from the more intensely studied Wildlife Area (Fig. 1).

For purposes of this study, we described three habitat types found in both the Wildlife Area and Military Buffer and Impact zones: 1) sound-side intertidal mud flats colonized by fiddler crabs (fiddler flats); 2) sparsely vegetated sand flats behind the primary dunes, and adjacent to sound-side mud flats (interdune sand flats), and 3) ocean beach front consisting of the ocean intertidal zone, the backshore (open sand between the intertidal zone and foredune), and primary dunes (beach front). Vegetation on the fiddler flats included smooth cordgrass (*Spartina alternaflora*) and glasswort (*Salicornia* spp.). An overwash fan formed in the interdune sand flats of the Wildlife Area when Hurricanes Fran and Bertha in 1996 removed woody vegetation and created an approximately 200 m wide by 1 km long interdune sand flat that included about 400 m of direct interface with marsh and bay-side intertidal flats. Since 1996, sparse low-growing vegetation, such as sea rocket (*Cakile harperi*), seashore-elder (*Iva imbricate*), seaside pennywort (*Hydrocotyle bonariensis*), and dotted horsemint (*Monarda punctata*); and clumped grasses and forbs including saltmeadow cordgrass (*Spartina patens*), sea oats (*Uniola paniculata*), American beach grass (*Ammophila breviligulata*), and smartweed (*Polygonum* spp.) have grown in these interdune sand flats. Beach front habitat included those plants adapted to the coastal dynamics of tidal fluctuations, wind, and sand movement; specifically, clumped grasses growing on primary dunes (e.g. sea rocket, new growth seashore-elder, dune spurge (*Euphorbia polygonifolia*), sea oats, and American beach grass). While the Military Buffer and Impact zones also contained these habitat types, they both also had a complex dune system unlike the rest of the island. Primary and secondary dune heights in the Military Impact and Buffer zones were more than double the height (~3-5 m) of the dunes in the Wildlife Area (~0-2 m). Further, the interdune sand flats in the Military Impact and Buffer Zones were more commonly adjacent to maritime forest than those in the Wildlife Area, which were adjacent to sound-side inter-tidal flats.

Typical of barrier islands, Onslow Beach differed in size and shape during the two years of the study. In 2009, Onslow Beach experienced unusually high water levels from 18 – 26 June 2009 (Sweet et al. 2009), which covered most fiddler flats across all tidal states. Further, there was substantial sand accretion at the south end of the island between 2008 and 2009 that resulted in the addition of approximately 15 ha of beach front in 2009 (Fig. 1). The newly accreted area was largely vegetation-free and contained several ephemeral pools.

Nest searching and habitat measurements

In 2008, we walked the study area to search for Wilson’s Plover nests and used behavioral cues (e.g. territorial defense, broken-wing displays, incubation posture) to locate nest sites. In 2009, we established two paths through fiddler flats (0.78 km and 1.36 km, respectively; 1.1 km apart separated by maritime forest), and three paths each on beach front (0.53 km, 0.83 km, and 0.98 km, respectively; 35-60 m apart separated by dunes), and interdune sand flats (0.75 km, 0.77 km, and 1.61 km, respectively; 45-190 m apart separated by dunes and woody shrubs) in the Wildlife Area. We walked these paths 2-3 times weekly in 2009 searching for nests. We monitored located nests in the Wildlife Area every 1-3 days in both years and nests in the Military Impact and Buffer zones opportunistically. We considered nests successful if ≥ 1 egg(s) hatched.

We sampled substrate at the nest site within 3 days after hatching or failure using a 1 m^2 PVC pipe quadrat containing 5 x 5 cm cells made of plastic string (Cook and Bonham 1977). We centered the quadrat over the nest and performed ocular estimates of the percent composition of pebbles (2-64 mm), cobble (> 64 mm), small shells (< 2 mm), medium shells (2-64 mm), and large shells (> 64 mm). We determined percent composition by counting the number of cells containing the substrate variable and dividing by the total cells in the quadrat.

We recorded vegetation characteristics at the nest site that included 1) an ocular estimate of percent composition of vegetation cover within a 1 m^2 quadrat, 2) height of tallest vegetation (i.e. vegetation ≥ 1 m tall) within a 5-m radius of the nest bowl, and 3) vegetation growth form within 15 cm of the nest bowl. We defined vegetation growth form as either 1) bare ground and low-growing sparse vegetation (e.g. sea rocket, seaside pennywort, new-growth seashore-elder, and dune spurge) or 2) clumped grasses (e.g. sea oats, American beach grass, saltmeadow cordgrass, smartweed), or any combination of clumped vegetation and low-growing sparse vegetation. Finally, we recorded distance (m) to nearest nest (any species), and distance (m) to fiddler flat from each nest site.

We sampled the same characteristics at a paired, randomly-selected point 1-18 m from the nest within the same habitat type to examine differences between used and non-used sites within the same locale. We chose the upper sampling limit (18 m) as half of the shortest inter-nest distance documented for Wilson's Plovers in Bergstrom's (1982) Texas study.

Brood identification and territory establishment

We trapped adult plovers on nests within 48 hours of nest detection using drop box (Wilcox 1959, Graul 1979) and oblong funnel traps (Paton 1994, Lessells 1984), and banded them with three unique color bands on the left tarsometatarsus. We captured chicks by hand in or near the nest bowl usually 3-8 hrs post-hatch (n = 29), or opportunistically at a later date (n = 7), and banded them using the same scheme as we did for adults. We attempted to capture and band all adults and chicks from each nest. We searched for banded, foraging adults and chicks in the same manner as we searched for nests in 2008 and 2009. We recorded locations of banded individuals observed in all habitat types using a handheld Garmin 76 GPS (Garmin International, Olathe, KS).

We sampled all known fiddler flats in the study area to determine which habitat features influenced flat selection in establishing a brood foraging territory. We sampled each fiddler flat within 2 hours of low tide (to ensure flats were not inundated) once in each of three periods in 2009 (21 May–25 May, 5 June–9 June, and 30 June– 6 July).

We characterized vegetation along a path of least obstruction from the interdune sand flat (where most Wilson's Plovers nested in this study) to each fiddler flat (where most broods established final foraging territories) during each sampling period to determine if dense vegetation prevented use of certain flats. Starting points on the interdune sand flats and sampling paths were established using a combination of criteria. First, the interdune sand flat edge at the start of each transect was identified as the point where vegetation cover was ≤ 30% within a 0.5 m^2 plot. Second, sampling paths between the interdune sand flat and fiddler flat were selected after having met one or both of the following criteria: 1) a continuous path approximately 0.5 m wide where >50% bare ground was visible between the sand flat and fiddler flat (e.g. a predator trail or path with less vegetation compared to its immediate surroundings), and/or 2) the shortest distance between the sand and fiddler flats. Lastly, we defined the fiddler flat edge when a plot contained ≤ 50% *Spartina* spp. or glasswort cover, and its location was ≤ 5 m from the bare exposed flat. We recorded path locations using a handheld GPS and collected data along the same path in each of the sampling periods.

We used a modified vegetation density board (Higgins et al. 2005) to obtain an index of vegetation obstruction along each path. The density board contained three rows (11.3 cm high) and 11 columns (8.3 cm wide) with each grid row containing the numbers 3 (top row), 2 (middle row), or 1 (ground row). We performed density board readings every 10 m along the path until the edge of the fiddler flat was reached. Observers placed their heads as close to the ground as possible 5 m from the density board and summed the numbered squares obstructed by ≥ 70% by vegetation. We used the average of the density board readings taken along the path to calculate the obstruction index for each fiddler flat during each sampling period. We recorded a boundary along the defined edge of each fiddler flat with a GPS, and uploaded the track into ArcMap 9.3 (ESRI, Redlands, CA) as a polygon shape file to calculate flat area (m^2). Finally, we measured the shortest distance (m) from the fiddler flat to water, and categorized the flat as 1) frequently subject to tidal inundation or 2) infrequently subject to tidal inundation.

For each fiddler flat in each period, we used Hawth's Tools in ArcMap 9.3 to generate 1) five random points within a 5-m buffer extending inward from the vegetated fiddler flat edge, and 2) five points in the area extending from the 5-m buffer towards the bare or nearly-bare center of the flat. We counted fiddler crab burrows and individual crabs (males, females/juveniles, or unknown) within a 1 m^2 quadrat centered on each point. Depending on vegetation density and line of sight distance, we stood 1–3 m from the plot to count crabs for 5 min using 8 x 40 binoculars. We counted all individuals 3–4 times throughout the 5-min observation and recorded the greatest count in each age class as a single value for the sample. At the end of the observation, we approached the quadrat and counted the burrows (Macia et al. 2001). We calculated separate averages for fiddler crab and burrow counts on each flat. For each 1-m^2 plot, we recorded an ocular estimate of the percentage of bare ground, smooth cordgrass, and glasswort.

Foraging site selection and behavioral observations

We gathered information about Wilson's Plover foraging site selection and behavior by conducting focal observations of banded adults and chicks across all tidal stages on fiddler flats, interdune sand flats, and beach front habitat. We concealed ourselves 10-80 m away from the brood in blinds or behind natural barriers, such as vegetated dunes, for each observation. We continuously recorded 5-min focal samples of foraging attempts that included pecks, which are indicative of insect consumption, and "run and grabs," which is a behavior used by Wilson's Plovers to hunt fiddler crabs (Altmann 1974, Lehner 1979, Tyler 1979). Each focal observation included a single chick or adult. After we obtained one focal observation for each visible chick in a brood, we sampled the adult male or female (or both, if present). We repeated observations of individuals when possible. Our sampling took 30 min – 2 hrs per brood, during which 1-8 focal bird samples were collected. We included samples in analyses if the bird was visible for $\geq$ 2.5 min. We calculated foraging rates (attempts min^{-1}) for adults and chicks and categorized them by habitat type (Elias et al. 2000, Fraser et al. 2005). Mean foraging rates were calculated for adults and chicks within each brood.

After the observation period ended, we conducted prey sampling within 5 m of each location most used by each focal bird. At each focal bird foraging location, we sampled insects using wooden paint stirrers covered in Tree Tanglefoot® Insect Barrier (The Tanglefoot Company, Grand Rapids, Michigan; Loegering and Fraser 1995, Elias et al. 2000). Sticks were positioned with one inserted vertically into the substrate and the other placed horizontally on the ground. We exposed "sticky sticks" for approximately 40 min, leaving an observer nearby (≥ 40 m) to prevent plovers from coming into contact with the sticks. Insects were counted and identified to order at the end of the sampling period. We accounted for exposure time by dividing our prey counts by the number of minutes each set of sticks was collecting insects, and report the results as insects collected min^{-1}. We measured vegetation characteristics at each focal bird sampling location (within a 1-m^2 plot) by visually estimating 1) percent cover of vegetation and species composition, 2) distance (m) to vegetative cover beyond the plot, and 3) distance (m) to water from the center of the sampling plot.

We sampled prey abundance (insects, fiddler crabs, and fiddler crab burrows) and vegetation in the same manner described above at paired, randomly-selected non-use points within the same habitat ≤ 40 m from the used, focal bird sampling points. The upper limit (40 m) between used and non-used points was selected as it is the mean of the lengths and widths of all fiddler flats in the Wildlife Area. Distance and direction from the used point to the paired non-use point was selected randomly. If the habitat edge was reached before the selected distance was reached, the researcher would reverse direction and continue until the selected distance was traversed.

Inter-annual variation in fiddler flat use and foraging behavior

We compared inter-annual observations of broods, and analyzed differences in foraging behavior potentially related to anomalous water heights (Sweet et al. 2009) in 2009 and beach front sand accretion that occurred between the 2008 and 2009 breeding seasons on Onslow Beach. We plotted the daily proportion of Wilson's Plover broods observed using fiddler flats in both years during the time frame corresponding with near-complete fiddler flat inundation in 2009 against the daily mean residual water height (m, observed height – predicted height) within 2 hours of the lowest tide (i.e. daily average based on five hourly water heights) to determine if a higher proportion of broods used this habitat at low tide in 2008 than in 2009. We used predicted and observed water heights reported at the National Oceanic and Atmospheric Administration (NOAA) tidal station in Beaufort, North Carolina (the closest tidal station to Onslow Beach) to calculate daily mean residual water heights. We compared mean adult and chick foraging rates for each brood by year and habitat type.

Statistical analyses

We used SAS 9.2 (SAS Institute Inc., Cary, NC) for all analyses. We used logistic regressions to assess which habitat features distinguished 1) nest sites from paired, unused locations, 2) successfully hatched nests from failed nests, 3) fiddler flats containing brood foraging territories from those that did not, and 4) foraging sites from paired, non-used areas. To identify candidate variables used in modeling efforts, we computed Pearson correlation coefficients (r) for all habitat variables collected. We considered variables with $r \geq 0.60$ highly correlated, and chose the variable best representing the habitat characteristic of interest or combined correlated variables into one composite variable. We executed biologically plausible single- and multi-variable logistic regressions, and ascertained model fit using Hosmer and

Lemeshow's (2000) goodness-of-fit test. We used Akaike's Information Criterion (Akaike 1973) adjusted for small sample size (AIC_c) to rank the logistic models (Burnham and Anderson 2002, Anderson et al. 2001). We considered models with ΔAIC_c values ≤ 2.0 as top models, but also reported models with likelihoods ≥ 0.125 (Burnham and Anderson 2002) as being competitive. When our analyses resulted in ≥ 1 competitive model(s), we used model-averaging to estimate model parameters and confidence limits to determine the relative importance (R_i) of each covariate from all model results (Burnham and Anderson 2002). Relative importance (R_i) was calculated by summing the AIC_c weight of each variable for all model results (Burnham and Anderson 2002). Post-hoc, we used Pearson's chi-squared analyses (χ^2_{df}) to compare the proportions of successful and failed nests placed in each of the two vegetation growth form categories examined in logistic regressions.

We used Wilcoxon signed-rank tests to examine 1) differences in prey abundance between used foraging sites and paired, non-used sampling points, and 2) inter-annual variation in the proportion of habitat use and mean adult and chick foraging rates across all habitat types. We report means ± SE, medians, and 25-75% inter-quartile ranges (Q1-Q3) in the results; we consider $P \leq 0.05$ to be significant.

Results

Correlates of nest site selection and hatching success

We found 20 Wilson's Plover nests in 2008 and 26 in 2009. Accounting for both years, most nests were in the interdunal area, 19 on sand in vegetation and 12 on dunes in clumped grasses. Eleven nests were on the beach front berm (150–200 m wide); nine of these were in sparsely distributed clumped grasses, and two were placed in vegetation-free areas.

Shells 2 to $\geq$ 64 mm, appeared in both top models differentiating used nest sites from paired unused locations (Table 1); this variable had a high relative importance (R_i = 0.87), but its confidence limits encompassed zero, and thus its effect on nest site selection was unclear (Table 2). While distance to the nearest nest of any species and tall vegetation within 5 m were in the top models, the relative importance values of these variables were low and their coefficients were not different than zero (Table 2).

Vegetation growth form (Table 3) within 15 cm of the nest bowl was in all top models explaining the success or failure of a Wilson's Plover's nest (Table 4). Despite its high importance (R_i = 0.75), the confidence interval for vegetation growth form overlapped zero (Table 4). Sixteen of 20 (80%) nests placed in clumped grasses or mixed vegetation were successful, compared to 9 of 22 (41%) nests in low-growing sparse vegetation or open sand (χ^2_1 = 6.66, P = 0.01, n = 42). Mean percent vegetation cover at nest sites was 15.33 ± 2.33 for both years (Appendix B, Table 1); successfully hatched nests had an average 18.85 ± 3.57% vegetation cover within 1 m^2 of the nest bowl.

Brood territory establishment

Wilson's Plovers selected the largest fiddler flats to rear their broods and only one brood occupied a flat at any given time, with the exception of one long flat divided by *Spartina* spp. exceeding 1 m tall. Fiddler flat area was in all top models predicting whether or not Wilson's Plover broods used a given fiddler flat (Table 5). The probability of a brood establishing a territory on a fiddler flat increased with the area of the flat, and area was the most important variable in predicting establishment of a brood foraging territory on a fiddler flat (R_i = 0.97, Table 6). Burrow count had slightly more predictive power than crab count in our initial AIC_c analyses, and neither variable was significant in model averaging results. A subsequent analysis omitting crab count did not demonstrate marked differences from our initial analyses. All other habitat variables appeared in at least one of the top selected models, but the relative importances of each of these other variables were low ($R_i < 0.30$; Tables 5-6).

Fiddler flats ranged in size from approximately 44–14 029 m^2 (Appendix B Table 2). In both years, ≥ 1 brood established foraging territories concurrently or sequentially on three of the largest fiddler flats (> 1250 m^2), two of which had no vegetation obstruction around their borders (Appendix B Table 2). Fiddler flats ≥ 1250 m^2 had less cover (mean cover based on 1 m^2 quadrats) per flat (9.43–35.15% for 3 flats) compared to those ≤ 1250 m^2 (36.03–55.83% for 6 flats). Most flats were within 10 m of water; however, not all were subject to regular tidal inundation (Appendix B Table 2).

Foraging site selection

Wilson's Plovers foraged closer to water and vegetation cover than expected at random. Distance to water and to vegetative cover from the foraging bird's location were in all top models distinguishing used from unused points at foraging sites on fiddler flats, interdune sand flats, beach front, and all habitat types combined (Table 7). Within each habitat type, the probability of foraging site selection by Wilson's Plovers increased as distance to water decreased, although the confidence interval overlapped zero, except when all habitats were combined (Table 8). Mean percent vegetation cover at focal bird foraging locations in all habitat types ranged from 12.50 ± 4.17 to 14.44 ± 3.47. On average, Wilson's Plover broods foraged closer to water on fiddler flats than in beach front habitat or on interdune sand flats (Appendix B, Table 3).

When on fiddler flats, Wilson's Plovers foraged in areas with the highest individual crab densities. The number of crab burrows and individual crabs in sampling plots were similar between years (Table 9). For both years of the study (i.e. 2-yr mean), burrow counts were higher at used ($\bar{x}$ = 53.64 ± 3.60, median = 45, Q1-Q3 = 35-78) than unused sites (42.40 ± 4.04, n = 81, median = 36, Q1-Q3 = ¯9-48, z = 601, P = 0.004). Likewise, crab counts were higher at used ($\bar{x}$ = 25.55 ± 2.34, median = 25.5, Q1-Q3 = 3-42) than unused points over the 2-yr study period (12.17 ± 1.38, n = 82, median = 9, Q1-Q3 = 1-19, z = 1131, P = <0.0001).

We exposed “sticky sticks” for an average of 41 min to collect insects in 2008 and 2009. The average number of insects caught in sticky traps on the beach front increased between 2008 and 2009 (Table 10). For both years combined (i.e. 2-yr mean), we collected more insects at beach front focal bird foraging locations (n = 84; $\bar{x}$ = 0.08 ± 0.01 insects min^{-1}, median = 0.03, Q1-Q3 = 0.00–0.09) than at random non-use sites ($\bar{x}$ = 0.06 ± 0.02 insects min^{-1}, median = 0.02, Q1-Q3 = 0.00–0.06; z = 387, P = 0.01). We found no differences in 2-yr mean insect counts at used and paired non-use sampling points on fiddler and interdune sand flats.

Inter-annual variation of fiddler flat use and foraging behavior

From 20-25 June 2009, tidal heights were > 20 cm higher than predicted, and many fiddler flats were continually inundated, even during low tide (Fig. 2). From 20–26 June 2009, we observed only one of nine (11%) known Wilson’s Plover broods using fiddler flats, on one day only, 23 June. For the same time period in 2008, we re-sighted 12.5–25% of known broods using fiddler flats on 3 different days (22, 24, and 26 June). We did not conduct surveys of fiddler flats 19-20 June 2008, but we did conduct brood surveys on all other days in 2008 and 2009.

Chick pecking rates on interdune sand flats were higher in 2009 than in 2008 (Table 11); however, there were no differences in Wilson’s Plover adult (n = 10 pairs) and chick (n = 10 broods) foraging behavior between years (Tables 11-12) in other habitats.

Discussion

Wilson's Plovers have been observed placing their nests at the toe of dunes, in overwash areas, or in newly accreted beach where vegetation is sparse (Corbat and Bergstrom 2000, Dikun 2008). In this study, we observed most Wilson's Plovers placing nests on interdune sand flats and dunes adjacent to or within vegetation. In our study, a greater proportion of nests placed in clumped grasses and mixed vegetation were successful than those placed on bare ground or in low-growing sparse vegetation. Our findings are similar to those of Corbat (1990) who found higher hatching success rates for nests placed within 0.5 m^2 of vegetation on Georgia barrier islands, and Bergstrom (1982) who observed 83% of known nests (n = 29) located adjacent to clumped vegetation in Texas. Dikun (2008) found an average 12.9 ± 1.9% vegetation cover within 1 m^2 of nest sites in her South Carolina study examining habitat features influencing nest placement, which is similar to our findings of 15.33 ± 2.33% vegetation cover within 1 m^2 of successful nests. In contrast, Hood (2006) identified a decrease in nest survival for those nests placed within 0.5 m^2 of dense clumps of vegetation compared to nest bowls located in sparse, diffuse vegetation in south Texas. The average density of vegetation surrounding our nest sites was higher than the density in Hood's (2006) study (7.9% within 0.5 m^2). These differences may be attributable to the fact that Onslow Beach has not experienced a significant overwash event since Hurricanes Fran and Bertha in 1996 (Foxgrover 2008), while lower elevation nesting habitat in Hood's (2006) study included coastal bays and sound-side sand flats on barrier islands prone to frequent inundation. Accordingly, Hood commonly observed washouts as a cause of nest failure, while we identified only 2 losses in 2 years attributed to tidal fluctuations or storm-increased water levels. In the absence of overwash, the sand flats on Onslow Beach have become increasingly vegetated, but are suitable for Wilson's Plover nesting success.

Area of a fiddler flat was the most important factor in Wilson's Plover brood territory establishment. Similarly, wintering Ruddy Turnstone (*Arenaria interpress*) and Sooty Oystercatcher (*Haematopus fuliginosus*) densities in northwest Tasmania were higher in larger habitat patches, but in that study increased prey densities and the absence of a non-preferred food resource were equally important to area in foraging site selection (Spruzen et al. 2008). We did not find evidence that prey abundance (e.g. crab burrows or individual crabs) was an influential factor in Wilson's Plover brood territory establishment on fiddler flats. However, within used flats, Wilson's Plovers foraged in areas with higher prey abundance than found at random on the same flat. Thus, broods may select a fiddler flat based on its size, and then select a specific foraging location on that flat according to prey abundance, as would be consistent with other studies showing that shorebirds select foraging sites based on the availability, distribution, and abundance of food resources (Thibault and McNeil 1995, Backwell et al. 1998, Elias et al. 2000, Placyk and Harrington 2004, Ribeiro et al. 2004, Karpanty et al. 2006, Spruzen et al. 2008). Spatial distribution of conspecifics in an area (e.g. on a selected fiddler flat) may also be influenced by competition with other species (Folmer et al. 2010), but we did not address interspecific resource competition in this study.

In our study, three of the largest mud flats ($> 1250\ m^2$) also lacked dense vegetation around their borders, making these foraging locations both the most accessible and large enough for ≥ 1 brood to establish concurrent or sequential territories. While we hypothesized that accessibility of fiddler flats might be an important characteristic influencing Wilson's Plover brood territory establishment, we did not find that any of our metrics of accessibility (i.e. vegetation density measures) were important in predicting territory establishment. These large flats had lower mean percentages of vegetation cover per $1\ m^2$ than the smaller flats, likely because the large flats were adjacent to or within 10 m of a fluctuating body of water (i.e. tidal creek or ponds fed by creeks) and therefore experienced more inundation than other flats.

Foraging broods were closer to vegetation and water on fiddler flats (and in all habitats combined) than at paired random sampling locations within a foraging site. Vegetation likely provided chicks the necessary cover to evade predators, rest, and regulate their body temperature while proximity to water may have increased foraging success rates if fiddler crab or insect densities increase with close proximity to water or inundation frequencies (Elias et al. 2000, Cohen et al. 2009); however, this remains to be tested. Wilson Plover chicks in Texas similarly fed in low-lying wet areas where young could conceal themselves in vegetation (Bergstrom1982). These findings suggest that an ideal fiddler flat for Wilson's Plover brood territory establishment at Onslow Beach, and possibly other areas, would be one that is ≥ 1250 m^2, within 10 m of water, subject to regular tidal inundation, and within approximately 4 m of vegetation adapted to water fluctuations (i.e. glasswort).

Wilson's Plovers have also been observed foraging along the beach front intertidal zone, above the high tide line on the beach backshore, and along the toes of primary dunes (Corbat 1990, Leary 2009, this study). We found that an increased density of vegetation and number of insects around beach front foraging sites were important characteristics for Wilson's Plovers foraging in this habitat. Our results suggest an optimal range of 11–18% vegetation cover per 1 m^2 of beach front habitat for foraging broods at Onslow Beach. There is likely a vegetation cover threshold at which foraging site selection on beach front habitat will begin to decline. Habitat containing coverage < 11% may be unattractive to Wilson's Plover chicks which require some vegetation cover to thermoregulate and avoid predation, especially by avian-predators as has been shown to be important for Least Terns (Burger 1989).

We did not find nesting Wilson's Plovers in the Developed Recreation Area or the Amphibious Training Zone. This may be partly attributed to topographical differences between these use areas and the Wildlife Area. Sound-side intertidal flats colonized by fiddler crabs do not exist in the Developed Recreation Area, and while present in the Amphibious Training Zone, were not accessible to broods. The road behind the primary dunes in the Amphibious Training Zone, combined with dense vegetation (primarily *Phragmites* spp.) surrounding any present mud flats, present a barrier to Wilson's Plover broods. In both of these use zones, the landward side of the island is adjacent to Intracoastal Waterway (ICW), where boats frequently travel. In the Wildlife Area and the Military Buffer and Impact Zones, marsh and inter-tidal mud flats act as a buffer between the island and the ICW, providing habitat and shelter for Wilson's Plover broods.

We observed a lower proportion of Wilson's Plover broods using fiddler flats from 18 – 26 June 2009 (i.e. the time period we observed near complete inundation of fiddler flats regardless of tidal state on Onslow Beach) compared to the same time frame in 2008. NOAA reported (Sweet et al. 2009) an average 0.2 m residual water level height (i.e. observed – predicted water height) extending along the Atlantic coast from North Carolina to New Jersey during this time period in 2009 only. By establishing a systematic survey scheme in 2009, we increased our visits to fiddler flats in 2009 compared to 2008. As a result, we expected to observe more brood use of fiddler flats during the second year of the study, but we actually identified fewer broods than in the first year. The decrease in broods observed using fiddler flats from 18-26 June 2009 in comparison to this same time period in 2008 may be related to two environmental changes: 1) the sea level anomaly that began mid-June 2009, and 2) beach front sand accretion that occurred on the southwestern end of Onslow Beach from 2008 to 2009 which created habitat that was not available in 2008. Tidal height fluctuations and sand accumulation influence the area, availability, and micro-fauna abundance on beach fronts (Hubbard and Dugan 2003) and can create important foraging habitat for shorebirds (Burger et al. 1977, Connors et al. 1981, Warnock and Takekawa 1995, Long and Ralph 2001). The atypically high water heights in 2009 may have reduced the availability of fiddler flats on Onslow Beach, but also contributed to the formation of ephemeral pools on newly accreted beach front sand that served as important foraging habitat for Wilson's Plover broods. In 2009, we observed six brood foraging territories encompassing > 1 habitat type (e.g. fiddler flat and beach front or interdune sand flat). Two of these multi-habitat final brood foraging territories did not include fiddler flats, but rather a combination of beach front ephemeral pools and sparsely vegetated interdune sand flats. In 2008, we observed Wilson's Plover broods establishing final foraging territories only on fiddler flats.

Our inter-annual findings related to foraging behavior do not indicate strong differences in feeding strategies from one year to the next despite these habitat changes; however, chick pecking was higher across all habitats in 2009 than in 2008, and adult and chick behavior associated with hunting fiddler crabs decreased in 2009, suggesting an opportunistic response to decreased accessibility to preferred habitat (i.e. fiddler flats) and prey items (i.e. fiddler crabs). In Florida, Leary (2009) observed a Wilson's Plover chick capture and consume a small finfish, which is an uncommon prey item, trapped in a shallow beach front tidal slough; he attributed this unusual behavior to the presence of an ephemeral pool in the beach front habitat. In 2009, we occasionally watched adults and young probe for and consume benthic worms and unidentifiable aquatic invertebrates on inter-tidal mud flats and around the edges of ephemeral pools in beach front and sound-side habitats, an observation analogous to Leary's (2009). We did not observe

Wilson's Plovers consuming benthic invertebrates in 2008; however, we observed one female eating *Donax* spp. in the inter-tidal zone.

Management and conservation implications

The U.S. Shorebird Conservation Plan (Brown et al. 2001, Hunter 2002) states that efforts are needed to determine key habitat characteristics supporting nesting, foraging, and roosting Wilson's Plovers to support the goal to double the breeding Wilson's Plover population in the southeastern coastal plains-Caribbean region over the next 50 years. Currently, it is estimated that there are approximately 1500 breeding pairs along the Gulf and Atlantic coasts (Hunter 2002), but there is low confidence in this estimate due to a lack of regionally coordinated, systematic surveys for this species (Brown et al. 2001). Protection and maintenance of sparsely vegetated interdune sand flats may be an important contributor in maintaining and increasing Wilson's Plover nest numbers. Our work, combined with other studies in the southeastern U.S. and Gulf Coasts, suggest that there may be a threshold density of sparse vegetation after which a site becomes unsuitable for nesting Wilson's Plovers, but that threshold may vary by region and/or preferred nesting habitat within a region. Protecting the integrity of, and access to, large fiddler flats (< 1250 m^2) is crucial for foraging Wilson's Plover broods; specifically, broods in our study preferred to forage in habitat with close proximity (≤ 10 m) to water and sparse vegetation (≤ 4 m), which is presumably used as protective cover from predators, and provides opportunity for body temperature regulation. We found no evidence of differences in chick survival between years (Ray et al. unpublished data), and our data suggest that Wilson's Plovers exhibit some behavioral plasticity and are able to successfully fledge broods that forage not only on fiddler flats, but also on interdune sand flats, beach front, or a combination of multiple habitats.

Management that focuses on providing a matrix of potential foraging sites from the beach front to sound-side fiddler flats will provide multiple opportunities for foraging Wilson's Plover broods that may be prevented from accessing a certain habitat type due to stochastic environmental factors (e.g. storms that result in beach erosion), variations in land management, or longer-term changes such as sea-level rise that may alter intertidal areas or render them inaccessible.

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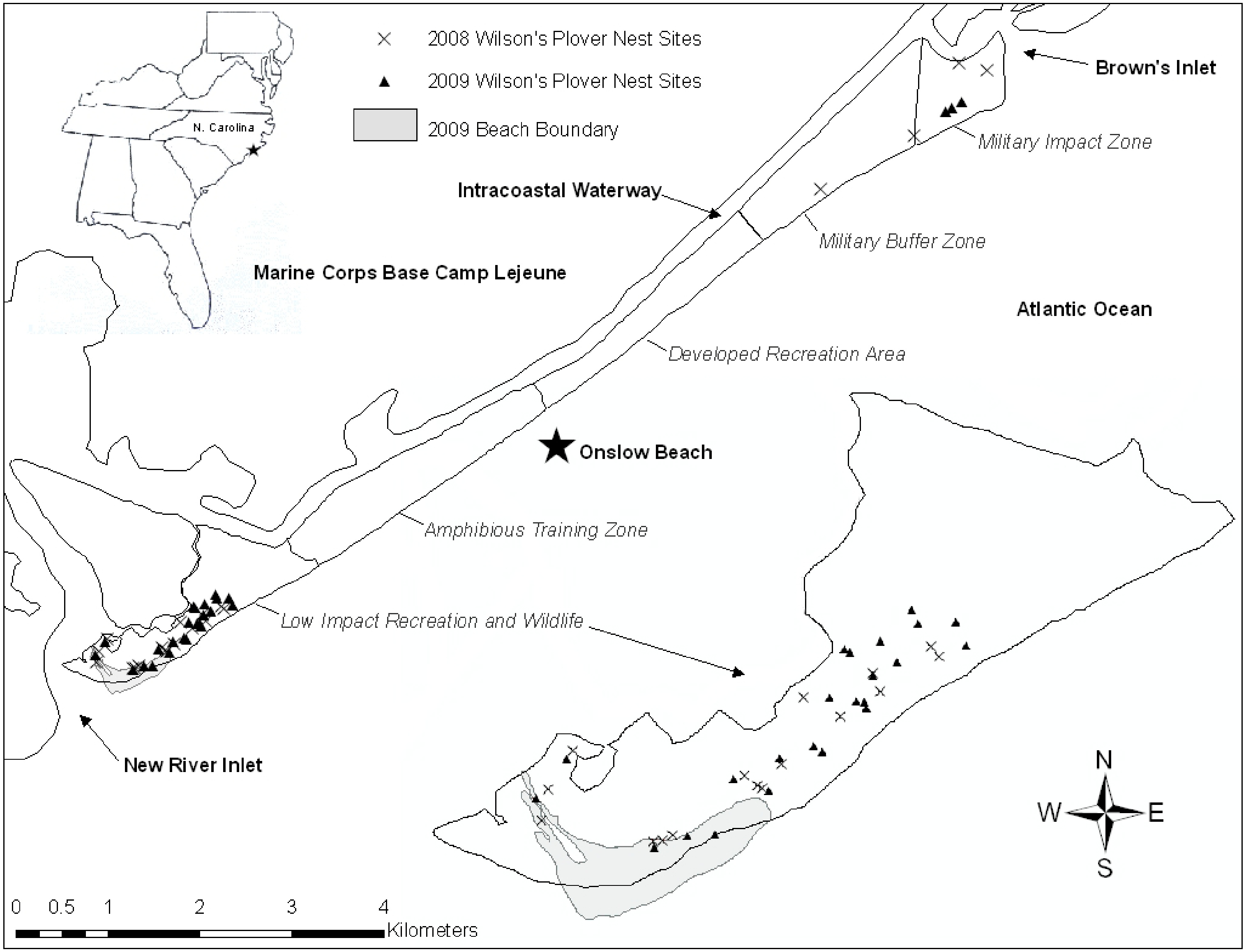
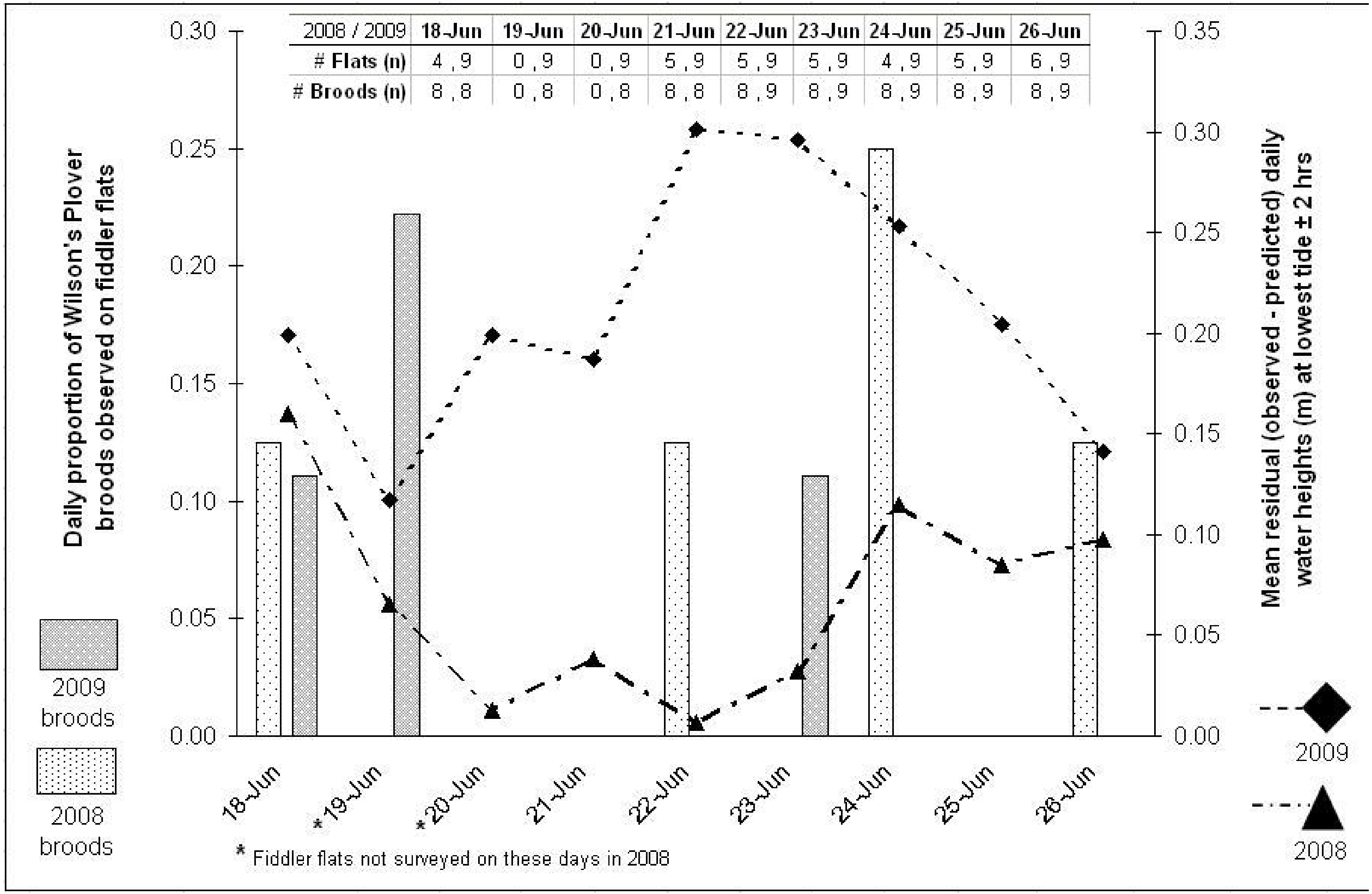

2008 Wilson's Plover Nest Sites
2009 Wilson's Plover Nest Sites
2009 Beach Boundary
N. Carolina
Brown's Inlet
Military Impact Zone
Intracoastal Waterway
Military Buffer Zone
Marine Corps Base Camp Lejeune
Atlantic Ocean
Developed Recreation Area
Onslow Beach
Amphibious Training Zone
Low Impact Recreation and Wildlife
New River Inlet
N
W
E
S
0 0.5 1 2 3 4
Kilometers

Fig. 1. Study area at Onslow Beach on Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. The Low Impact Recreation and Wildlife Area is enlarged to clearly depict Wilson's Plover (*Charadrius wilsonia*) nest site locations, and changes in the beach boundary between years.



2008 / 2009 | 18-Jun | 19-Jun | 20-Jun | 21-Jun | 22-Jun | 23-Jun | 24-Jun | 25-Jun | 26-Jun
Flats (n) | 4 , 9 | 0 , 9 | 0 , 9 | 5 , 9 | 5 , 9 | 5 , 9 | 4 , 9 | 5 , 9 | 6 , 9
Broods (n) | 8 , 8 | 0 , 8 | 0 , 8 | 8 , 8 | 8 , 9 | 8 , 9 | 8 , 9 | 8 , 9 | 8 , 9
Daily proportion of Wilson's Plover broods observed on fiddler flats
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Mean residual (observed - predicted) daily water heights (m) at lowest tide ± 2 hrs
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
18-Jun
*19-Jun
*20-Jun
21-Jun
22-Jun
23-Jun
24-Jun
25-Jun
26-Jun
* Fiddler flats not surveyed on these days in 2008
2009 broods
2008 broods
2009
2008

Fig. 2. Daily proportion of known Wilson's Plover (*Charadrius wilsonia*) broods observed on fiddler crab (*Uca* spp.) mud flats in 2008 and 2009 at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, during the date range in 2009 (19 – 26 June) when near-complete inundation of flats were observed on Onslow Beach. The number of fiddler crab mud flats surveyed (out of nine) and broods followed each day in 2008 and 2009 appear at the top of the figure. Mean residual water heights (m, observed - predicted height) ± 2 hrs of the lowest daily tide are based on tidal station data collected by National Oceanic and Atmospheric Administration in Beaufort, North Carolina.

Table 1. Top-ranked models ($\Delta AIC_c \leq 2.00$ or model likelihood ≥ 0.125) from 36 single- and multi-variable logistic regressions of habitat characteristics at Wilson's Plover (*Chardrius wilsonia*) nest sites and paired non-used locations (n = 42 nests) at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008–2009.

Variables in Model[a]		K[b]	Prob > χ^2 [c]	AIC_c[d]	ΔAIC_c[e]	w_i[f]	Model Likelihood
MLShell	TallVeg5	3	0.64	46.81	0.00	0.35	1.00
MLShell	DistNrNest	3	0.53	48.79	1.97	0.13	0.37

[a] TallVeg5 = height of tall vegetation (≥ 1.0 m) within a 5-m radius of sample sites; MLShell = percent cover of medium (2-64 mm) and large (> 64 mm) shells within 1-m^2 plot; DistNrNest = distance to nearest nest site (m) of any species.

[b] K = No. of model parameters.

[c] Prob > χ^2 = Hosmer and Lemeshow goodness-of-fit test for binary logistic regression models.

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

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

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

Table 2. Model-averaged parameter estimates, unconditional standard errors (SE) and confidence limits (CL), and relative importance (R_i) from 36 single- and multi-variable logistic regression models of habitat characteristics at Wilson's Plover (*Chardrius wilsonia*) nest sites and paired non-used locations (*n* = 42 nests) on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008–2009.

Variable[a]	Parameter Estimate	SE	Lower 95% CL	Upper 95% CL	R_i[b]
Intercept	0.00	0.00	0.00	0.00	---
MLShell	-0.08	0.05	-0.17	0.02	0.87
TallVeg5	0.38	0.51	-0.62	1.38	0.44
DistNrNest	0.01	0.01	-0.02	0.03	0.15

[a] MLShell = percent cover of medium (2-64 mm) and large (> 64 mm) shells within 1-m^2 plot; TallVeg5 = height of tall vegetation (≥ 1.0 m) within a 5-m radius of sample site; DistNrNest = distance (m) to nearest nest site of any species.

[b] R_i = sum of AIC_c weights for each variable included in all model results.

Table 3. Top-ranked models ($\Delta AIC_c \leq 2.00$ or model likelihood ≥ 0.125) from 37 single- and multi-variable logistic regressions of habitat characteristics influencing nest ($n = 42$ nests) hatching success of Wilson's Plovers (*Chardrius wilsonia*) at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008–2009.

Variable(s) in Model[a]		K[b]	Prob > χ^2 [c]	AIC_c[d]	ΔAIC_c[e]	w_i[f]	Model Likelihood
VegForm	---	2	.	53.07	0.00	0.14	1.00
VegForm	MLShell	3	0.16	53.08	0.01	0.14	1.00
VegForm	VegCover	3	0.83	53.53	0.46	0.11	0.79
VegForm	TallVeg5	3	0.09	53.86	0.79	0.10	0.68
VegForm	Sshell	3	0.10	53.96	0.89	0.09	0.64
VegForm	DistFidd	3	0.46	54.02	0.96	0.09	0.62
VegForm	DistNrNest	3	0.59	54.03	0.96	0.09	0.62

[a] VegForm = vegetation growth form within 15 cm of the nest site defined as (1) bare ground or low-growing sparse vegetation or (2) clumped grasses or a combination of clumped grasses and low-growing sparse vegetation; MLShell = percent cover of medium (2-64 mm) and large (> 64 mm) shells within a 1-m^2 quadrat placed over the nest site; VegCover = percent cover of dead and live vegetation within a 1-m^2 quadrat placed over the nest site; TallVeg5 = height of tall vegetation (≥ 1.0 m) within a 5 m radius of the nest site; Sshell = percent coverage of small (< 2 mm) shells within a 1-m^2 quadrat placed over the nest site; DistFidd = distance to nearest fiddler crab (*Uca* spp.) flat from the nest site; DistNrNest = distance to nearest nest site (m, any species) from the nest site.

[b] K = No. of model parameters.

[c] Prob > χ^2 = Hosmer and Lemeshow goodness-of-fit test for binary logistic regression models.

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

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

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

Table 4. Model-averaged parameter estimates, unconditional standard errors (SE) and confidence limits (CL), and relative importance (R_i) from 37 single- and multi-variable logistic regression models of habitat characteristics influencing nest hatching success (*n* = 42 nests) of Wilson's Plovers (*Chardrius wilsonia*) on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008–2009.

Variable[a]	Parameter Estimate	SE	Lower 95% CL	Upper 95% CL	R_i[b]
Intercept	-2.42	1.74	-5.82	0.98	---
VegForm	1.29	0.99	-0.66	3.24	0.75
MLShell	0.004	0.01	-0.01	0.02	0.21
VegCover	0.003	0.01	-0.01	0.01	0.21
TallVeg5	0.03	0.08	-0.13	0.20	0.17
DistFidd	-1.13	0.76	-2.62	0.36	0.15
Sshell	0.000	0.002	-0.003	0.003	0.14
DistNrNest	0.000	0.001	-0.001	0.001	0.13

[a] VegForm = vegetation growth form within 15 cm of the nest site defined as (1) bare ground or low-growing sparse vegetation, or (2) clumped grasses or a combination of clumped grasses and low-growing sparse vegetation; MLShell = percent cover of medium (2-64 mm) and large (> 64 mm) shells within a 1-m^2 quadrat placed over the nest site; VegCover = percent cover of dead and live vegetation within a 1-m^2 quadrat placed over the nest site; TallVeg5 = height of tall vegetation (≥ 1.0 m) within a 5-m radius of the nest site; DistFidd = distance to nearest fiddler crab (*Uca* spp.) mud flat from the nest site; Sshell = percent coverage of small (< 2 mm) shells

within a 1-m^2 quadrat placed over the nest site. DistNrNest = distance to nearest nest site (m) of any species from the nest site.

[b] R_i = sum of AIC_c weights for each variable included in all model results.

Table 5. Top-ranked models ($\Delta AIC_c \leq 2.00$ or Model Likelihood ≥ 0.125 out of 16 models) predicting Wilson's Plover (*Charadrius wilsonia*) brood foraging territory establishment on fiddler crab (*Uca* spp.) mud flats ($n = 9$) at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2009.

Variable(s) in Model[a]		K[b]	Prob > χ^2[c]	AIC_c[d]	ΔAIC_c[e]	w_i[f]	Model Likelihood
Area	---	2	0.11	27.86	0.00	0.26	1.00
Area	BurrCount	3	0.23	28.14	0.28	0.22	0.87
Area	VegTrnDist	3	0.11	28.78	0.92	0.16	0.63
Area	VegVO	3	0.13	28.79	0.93	0.16	0.63
Area	VegCover	3	0.11	28.79	0.93	0.16	0.63

[a] Area = area of fiddler crab mud flat (m^2); BurrCount = mean burrow count in 1-m^2 sampling quadrat; VegTrnDist = length (m) of vegetated path from interdune sand flat to fiddler crab mud flat; VegVO = index depicting visual obstruction (density) of vegetation around the fiddler crab mud flat; VegCover = mean percent of vegetation cover in 1-m^2 sampling quadrat.

[b] K = No. of model parameters.

[c] Prob > χ^2 = Hosmer and Lemeshow goodness-of-fit test for binary logistic regression models.

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

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

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

Table 6. Model-averaged parameter estimates, unconditional standard errors (SE) and confidence limits (CL), and relative importance (R_i) from multi-variable logistic regression models predicting Wilson's Plover (*Charadrius wilsonia*) brood foraging territory establishment on fiddler crab (*Uca* spp.) mud flats (n = 9) on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2009.

Variable[a]	Parameter Estimate	SE	Lower 95% CL	Upper 95% CL	R_i[b]
Intercept	-1.07	1.52	-4.06	1.92	---
Area	0.002	0.001	0.000	0.003	0.97
BurrCount	-0.007	0.02	-0.04	0.02	0.23
VegCover	-0.002	0.008	-0.02	0.01	0.18
VegTrnDist	0.001	0.005	-0.01	0.01	0.18
VegVO	-0.002	0.009	-0.02	0.02	0.18

[a] Area = area of fiddler crab mud flat (m^2); BurrCount = mean burrow count in 1-m^2 sampling quadrat; VegTrnDist = length (m) of vegetated path from interdune sand flat to fiddler crab mud flat; VegVO = index depicting visual obstruction (density) of vegetation around the fiddler crab mud flat; VegCover = mean percent of vegetation cover in 1-m^2 sampling quadrat.

[b] R_i = sum of AIC_c weights for each variable included in all model results.

Table 7. Top single- and multi-variable logistic regression models ($\Delta AIC_c \leq 2.00$ or model likelihood ≥ 0.125, 28 models) of habitat characteristics at foraging sites used by Wilson's Plover (*Chardrius wilsonia*) broods and random non-use sampling points on fiddler crab (*Uca* spp.) mud flats (n = 25 paired samples), beach front (n = 25 paired samples), interdune sand flats (n = 10 paired samples), and all habitats (n = 60 paired samples) combined at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina in 2009.

Habitat Type	Variables in Model		K^a	AIC_c^b	ΔAIC_c^c	w_i^d	Model Likelihood
All Habitats:	Distance to Water (m)	Distance to Vegetative Cover (m)	3	89.45	0.00	0.595	1.000
Fiddler Crab Mud Flats:	Distance to Water (m)	Distance to Vegetative Cover (m)	3	31.14	0.00	0.348	1.000
	Distance to Water (m)	---	2	31.24	0.10	0.332	0.953
	Distance to Water (m)	Mean Percent Vegetation Cover (1 m^2)	3	32.22	1.08	0.203	0.582
Beach Front:	Distance to Water (m)	Distance to Vegetative Cover (m)	3	31.14	0.00	0.348	1.000

Habitat Type	Variables in Model		K^a	AIC_c^b	ΔAIC_c^c	w_i^d	Model Likelihood
	Distance to Water (m)	---	2	31.24	0.10	0.332	0.953
	Distance to Water (m)	Mean Percent Vegetation Cover (1 m^2)	3	32.22	1.08	0.203	0.582
Interdune Sand Flats:	Distance to Water (m)	Distance to Vegetative Cover (m)	3	7.02	0.00	0.614	1.000

[a] K = No. of model parameters.

[b] Prob > χ^2 = Hosmer and Lemeshow goodness-of-fit test for binary logistic regression models.

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

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

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

Table 8. Model-averaged parameter estimates, unconditional standard errors (SE) and confidence limits (CL), and relative importance (R_i) from single- and multi-variable logistic regression models examining habitat characteristics at foraging sites used by Wilson's Plover (*Chardrius wilsonia*) broods and random non-use sampling points on fiddler crab (*Uca* spp.) mud flats (*n* = 25 paired samples), beach front (*n* = 25 paired samples), interdune sand flats (*n* = 10 paired samples), and all habitats (*n* = 60 paired samples) combined on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina in 2009.

Habitat Type	Variables by Habitat	Parameter Estimate	SE	Lower 95% CL	Upper 95% CL	R_i[a]
All Habitats:	Distance to Water (m)[b]	-0.02	0.01	-0.05	-0.001	0.79
	Distance to Vegetative Cover beyond 1 m^2 (m)[b]	-0.05	0.02	-0.10	-0.001	0.77
Fiddler Crab Mud Flats:	Distance to Water (m)	-0.06	0.04	-0.15	0.02	0.88
	Distance to Vegetative Cover beyond 1 m^2 (m)[b]	-0.07	0.02	-0.11	-0.02	0.43
	Mean Percent Vegetation Cover (1 m^2)	0.001	0.01	-0.01	0.01	0.27
Beach Front:	Distance to Water (m)	-0.001	0.003	-0.01	0.01	0.22
	Distance to	-0.003	0.02	-0.04	0.03	0.55

	Vegetative Cover beyond 1 m^2 (m)					
	Mean Percent Vegetation Cover (1 m^2)[a]	0.04	0.02	-0.01	0.08	0.89
Interdune Sand Flats:	Distance to Water (m)	-0.16	0.11	-0.37	0.06	0.87
	Distance to					
	Vegetative Cover beyond 1 m^2 (m)	-0.67	0.44	-1.53	0.18	0.69

[a] R_i = sum of AIC_c weights for each variable included in all model results.

[b] Significant variable (confidence limits do not include zero)

Table 9. Fiddler crab (*Uca* spp.) burrow counts and individual counts at focal Wilson's Plover (*Charadrius wilsonia*) foraging locations (i.e. use sites) and paired, non-use samples on fiddler flats at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. Wilcoxon signed-rank test ($P \geq z$) results comparing yearly means ($\bar{x}$) and standard errors (SE), medians, and 25-75% (Q1-Q3) inter-quartile ranges for fiddler crab (*Uca* spp.) counts.

Prey Item	2008						2009					
(Use/non-use)	*n*	$\bar{x}$ (± SE)	Median	Q1-Q3	*Z*	$P \geq z$	*n*	$\bar{x}$ (± SE)	Median	Q1-Q3	*Z*	$P \geq z$
Burrows (use)	66[a]	53.09 (4.09)	44	37-78	379.5	0.01	15	56.07 (7.63)	53	31-81	29.5	0.10
Burrows (non-use)	67[a]	44.27 (4.61)	44	13-98			15	34.07 (7.93)	30	7-54		
Crabs (use)	69[b]	24.45 (2.66)	17	2-45	694	<0.001	15	30.60 (4.62)	33	15-38	52.5	0.001
Crabs (non-use)	68[b]	12.47 (1.56)	9	2-20			15	10.80 (2.92)	10	0-17		

[a] sample size (*n*) for Wilcoxon results = 66 paired samples

[b] sample size (*n*) for Wilcoxon results = 67 paired samples

Table 10. Total mean insect counts (insects collected per min^{-1}) at focal Wilson's Plover (*Charadrius wilsonia*) foraging locations (i.e. use sites) and paired, non-use samples at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. Wilcoxon signed-rank test ($P \geq z$) results comparing yearly means ($\bar{x}$) and standard errors (SE), medians, and 25-75% (Q1-Q3) inter-quartile ranges for beach front insect counts.

Prey Item	2008						2009					
(Use/non-use)	*n*	$\bar{x}$ (± SE)	Median	Q1-Q3	*z*	$P \geq z$	*n*	$\bar{x}$ (± SE)	Median	Q1-Q3	*Z*	$P \geq z$
Total Insects (use)	6	0.02 (0.01)	0.02	0.00-0.05	-10.5	0.03	78	0.09 (0.02)	0.03	0.00-0.10	367.5	0.003
Total Insects (non-use)	6	0.04 (0.01)	0.04	0.02-0.07			78	0.07 (0.02)	0.02	0.00-0.04		

Table 11. Wilson's Plover (*Chardrius wilsonia*) chick (n = 10 broods) pecking rates (pecks per min^{-1}) on fiddler crab (*Uca* spp.) mud flats, beach front, and interdune sand flats at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. Wilcoxon signed-rank test ($P \geq z$) results comparing yearly means ($\bar{x}$) and standard errors (SE), medians, and 25-75% (Q1-Q3) inter-quartile ranges for chick pecking rates.

	2008			2009			Results	
Habitat	$\bar{x}$ (± SE)	Median	Q1-Q3	$\bar{x}$ (± SE)	Median	Q1-Q3	z	$P \geq z$
Fiddler flat	2.41 (0.63)	2.13	1.23-2.99	3.53 (0.87)	2.97	1.48-5.57	6.5	0.56
Beach front	0.43 (0.42)	0.00	0.00-0.03	2.66 (1.23)	0.70	0.00-4.01	9	0.23
Interdune sand flat	0.73 (0.23)	0.00	0.00-0.00	2.50 (1.04)	1.16	0.00-3.63	10.5	0.03

Table 12. Wilson's Plover (*Chardrius wilsonia*) adult (n = 10 pairs) and chick (n = 10 broods) "run and grab" rates (run and grab per min^{-1}) on fiddler crab (*Uca* spp.) mud flats at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. Wilcoxon signed-rank ($P \geq z$) test results comparing yearly means ($\bar{x}$) and standard errors (SE), medians, and 25-75% (Q1-Q3) inter-quartile ranges for "run and grab" rates.

	2008			2009			Results	
Age	$\bar{x}$ (± SE)	Median	Q1-Q3	$\bar{x}$ (± SE)	Median	Q1-Q3	z	$P \geq z$
Adults	0.15 (0.08)	0.04	0.00-0.14	0.11 (0.04)	0.09	0.00-0.12	1	0.95
Chicks	0.12 (0.04)	0.08	0.04-0.18	0.06 (0.03)	0.00	0.00-0.11	-16	0.06

Chapter 4: Conservation Implications and Conclusion

To date, peer reviewed research on Wilson's Plovers has been limited. However, studies addressing population declines in other shorebird species suggest that human impacts and coastal development have been primary contributors to pervasive degradation of nesting and foraging habitat necessary to support viable populations (Brown et al. 2000, Hunter 2002, Peterson and Bishop 2005, Peterson et al. 2006, Schlacher et al. 2008, Cohen et al. 2009, Defeo et al. 2009). More recently, climate change-related sea level rise (Galbraith et al. 2002, IPCC 2007, Defeo et al. 2009) has arisen as a factor that may alter the availability of foraging resources by modifying prey communities in intertidal feeding areas or resulting in the permanent loss of important habitat (Galbraith et al. 2002). Developing an increased understanding of how shorebirds respond to short- and long-term changes in habitat availability, quantity, and quality is necessary to most effectively develop conservation and management plans. In this chapter, I summarize the main findings of my work and their relevance to conservation and management of Wilson's Plovers.

Demography of Wilson's Plovers:

Summary of findings:

1. In both years, Wilson's Plover's nests at Onslow Beach were depredated most commonly by Virginia opossums and raccoons. We confirmed 15% of nests were lost to predators in 2008 and 31% in 2009 using only physical signs around the nest bowl in 2008, and camera data combined with physical signs in 2009. There were minimal differences between yearly overall nest survival calculated using Mayfield's (1961, 1975) method (46% nest survival in 2008 and 44% in 2009) and my actual

observations of successfully hatched nests (45% nest success in 2008 and 50% in 2009).

2. Mean chicks hatched per pair and fledged per pair were 1.56 and 0.94, respectively, for both years combined.

3. Chick survival was higher for those nests hatching earlier in the breeding season and higher for those nests that were farther from the brood's final foraging territory. Chick survival from a Cormack-Jolly-Seber recapture model was 75% for both years combined in this study based on weekly re-sightings throughout each season. I actually observed 64% of hatched chicks in 2008 and 2009 fledge.

4. Adults banded in 2008 had a high second-year return rate (90%) to Onslow Beach in 2009; however only 9.5% of chicks banded in 2008 returned in 2009.

Conservation and Management Implications

My research contributes valuable information towards evaluating the validity of the population goals for Wilson's Plovers as identified in the U.S. Shorebird Plan for the southeastern coastal plains region (Hunter 2002). The plan set a regional goal to double the Wilson's Plover population over the next 50 years (Hunter 2002), and suggested a 5-yr mean productivity of 1.5 fledglings per breeding pair based on estimates from Piping Plovers (*Charadrius melodus*; Haig 1992, USFWS 1996) and Snowy Plovers (*Charadrius alexandrinus*, Page et al. 1995). I observed a mean fledging rate over a 2-yr period of only 0.94 fledglings per pair. It may be plausible that 1.5 fledglings per breeding Wilson's Plover pair are unnecessary to maintain a viable population. An increased understanding of Wilson's Plover population demography in this region is needed before setting target productivity values necessary to sustain or increase this population. For instance, target productivity rates for sustaining the Threatened

Atlantic Coast Piping Plover population were determined by analyzing 10 years of pooled demographic data collected from areas that accounted for 90% of the breeding coastal population (USFWS 1996); thus, at this stage in our knowledge of Wilson's Plover demography, it is premature to estimate sustainable productivity levels.

Another research priority outlined in the southeastern regional shorebird conservation plan was to assess the impacts of nest depredation on successful reproduction (Hunter 2002). In my study, I identified common mammalian nest predators as the primary cause of nest failures on Onslow Beach using physical signs and camera data at the nest site. Similarly, Corbat (1990) identified raccoons as a common nest predator in her study. I provided this information to MCBCL Land and Wildlife in the Environmental Management Division during both years of my study to assist them in targeting and locating raccoons and opossums, thus increasing the efficiency of their seasonal trapping strategies and efforts. It is important to consider that predation is a natural process, and determining appropriate or effective levels of removal (if necessary at all) will depend on the region, predator community, prey community, presence or absence of human activity (i.e. human-attracted predators), and temporal stochastic environmental variables (i.e. storms, temperature, drought). At this point, we cannot definitively say whether predators are the most important factor limiting Wilson's Plover population numbers at Onslow Beach; further study of factors limiting Wilson's Plovers at Onslow Beach are needed to fully justify predator removal activities. For example, data should be collected on Wilson's Plover population numbers before and after well-controlled predator removal activities, holding habitat availability constant, to truly assess the efficacy of predator management at this site.

Wilson's Plover nesting and foraging habitat use:

Summary of findings:

1. Sixteen of 20 (80%) nests placed in clumped grasses or mixed vegetation were successful, compared to 9 of 22 (41%) nests in low-growing sparse vegetation or open sand ($\chi^2_1 = 6.66$, $P = 0.01$, n = 42).
2. Area of a fiddler crab mud flat was the most important habitat feature influencing whether or not a Wilson's Plover brood established a territory on it.
3. Close proximity to water and vegetative cover were important factors in where broods chose to forage on a given fiddler crab mud flat and in all habitats (fiddler flats, interdune sand flats, beach front) combined $\geq$ 7 days post-hatch.
4. Wilson's Plover broods appeared to peck more and 'run and grab' less in 2009 compared to 2008. This change in foraging behavior may have been a response to changing environmental conditions in 2009. Similarly, broods established final foraging territories in all available foraging habitat (i.e. fiddler flats, interdune sand flats, and beach front) in 2009, but only used fiddler flats in 2008. In 2009, Wilson's Plover access to fiddler crab mud flats was limited due to a coast-wide sea level anomaly; however, sand accretion occurring between the two study seasons increased the beach front foraging opportunities during this same time period. I found no evidence of decreased chick survival between years despite this observed habitat shift by foraging adults and broods.

Conservation and Management Implications:

Management should aim to provide a matrix of potential nesting and foraging sites from the beach front to sound-side mud flats to allow flexible habitat use by breeding Wilson's

Plovers and foraging broods. I outline specific management suggestions here to support the habitat objectives outlined in the U.S. Shorebird Conservation Plan.

1. This study and previous research suggests that Wilson's Plover hatching success is positively related to the presence of a certain vegetation density around the nest site (i.e. successful nests have 7.9% - 22.4 % vegetated cover within 0.5 - 1 m^2 of nest bowl) and a gradient of vegetation growth form (i.e. low-growing sparse vegetation and clumped grasses) beginning at the nest bowl and extending up to 1 m^2.
2. According to this study, an ideal fiddler mud flat for Wilson's Plover brood territory establishment would be one that is ≥ 1250 m^2, within10 m of water, subject to regular tidal inundation, and within approximately 4 m of vegetation cover.
3. My results suggest an optimal range of 11–18% vegetation cover per 1 m^2 of beach front habitat as favorable for foraging broods. This goal can be achieved by protecting newly formed overwash and beach front sand accumulation that results in habitat relatively free of vegetation, except for sparse low-growing plants adapted to the coastal dynamics of tidal fluctuations, wind, and sand movement (i.e. sea rocket (*Cakile edentula*), new growth seashore-elder (*Iva imbricate*), seaside pennywort (*Hydrocotyle bonariensis*)).

Environmental personnel at MCBCL post symbolic signs and fencing to protect shorebird nesting areas, and I worked with them during my study to identify and safeguard unknown and new nesting habitat. In addition to the specific habitat recommendations outlined, I suggest increased efforts to protect ephemeral and inter-tidal foraging areas beach front and sound-side in the southern portion of Onslow Beach. Flexible management as such will not only provide a matrix of habitats for Wilson's Plovers to use, but also provide resources for other breeding shorebirds like the Atlantic Coast Threatened Piping Plover.

While the Base has met with public objections about restricting access to this area of island during shorebird breeding season, alternative measures to signs and fencing, such as posting interns or technicians during high use periods to conduct educational outreach and monitor critical foraging areas might be a less confrontational, more effective approach to habitat management and conservation.

Future challenges for shorebird conservation at MCBCL

A challenge currently on the horizon for MCBCL land management will be its response to the planned relocation of the New River Inlet, located at the southern end of Onslow Beach. The inlet relocation is part of a stabilization effort to protect North Topsail Beach (across the inlet) communities and its tourism-based economy from ongoing beach erosion. North Topsail Island hosts year-round and vacation residences that have been negatively impacted by beach erosion related to tropical storms and hurricanes over the past 20 years (Federal Register 2010-1810). In 2007, the Town of North Topsail Beach requested that the U.S. Army Corps of Engineers (USACE) submit an Environmental Impact Statement (EIS) to the Environmental Protection Agency (EPA) to facilitate immediate and ongoing beach nourishment, and to relocate the New River Inlet. These efforts will minimize erosion on North Topsail Beach, but will likely increase erosion on Onslow Beach. The EPA (Region 4) issued a letter of concern to the USACE expressing concerns about the impacts of increased erosion on the southwestern end of Onslow Beach due to the inlet relocation, in particular potentially adverse effects on shorebird habitat. Originally, relocation of the New River inlet was planned to begin in Fall 2010 (Federal Register 2010-1820), however; this has extended at least into 2011. While the permit process is complete, insufficient funds have delayed the project. MCBCL has been involved in the EIS process and is aware of the potential adverse effects of short- and long-term beach loss (Mueller 2010). The potentially adverse effects of inlet relocation on the southwest portion of Onslow Beach may accelerate the erosion process and threaten to diminish existing and newly formed habitat important for breeding and foraging shorebirds (Hubbard and Dugan 2003).

On Onslow Beach, Foxgrover (2009) reported a trend of shoreline erosion over the past 80 years, emphasizing the limited sediment volume from nearshore and fluvial sources necessary naturally to mitigate this loss. While erosion on Onslow Beach is primarily attributed to natural barrier island movement, habitat loss has already occurred and will likely continue even in the absence of inlet relocation (Morton and Miller 2005, Foxgrover 2009). In the face of historical and ongoing large-scale coastal habitat loss and alteration, conserving what remains at a regional scale is of crucial importance. MCBCL should prepare to mitigate for the probability of increased short-term erosion rates as a result of proximate beach stabilization efforts at North Topsail Beach.

It is likely that the newly accreted beach front sand accumulation on the southwestern end of the island will diminish, with or without the inlet relocation (Morton and Miller 2005), as this area is actively undergoing barrier-island rollover (Foxgrover 2009). However, the speed at which this newly accreted habitat is lost may accelerate if the inlet is moved (Griggs 2005, Cooper and McKenna 2008, Defeo et al. 2009). Given Onslow Beach's long term beach erosion trend (Foxgrover 2009) and predictions for ongoing natural habitat loss (Morton and Miller 2005), we suggest that regulators consider recommending North Topsail Beach fund a mitigation effort that would create new shorebird habitat on Onslow Beach and protect the existing sand accretion on the southwestern end of Onslow Beach. Past studies have demonstrated that stabilization structures and efforts can result in erosion on adjacent beach front shorelines (Hall and Pilkey 1991, Griggs 2005).

One possible mitigation effort would be to increase shorebird (specifically Wilson's Plovers as related to this study's findings) monitoring efforts in the Military Buffer and Impact Zones where these birds do already nest, and both monitoring and management efforts in the Amphibious Training Zone, where we did not find nests during this study. Since access is restricted and enforced in these areas of the island, management approaches such as posting symbolic fencing would not be as necessary; however, collecting presence/absence, habitat, and reproductive data would be beneficial in ongoing demographic monitoring and contribute to long-term population recovery goals. If monitoring activities determined that habitat in these Zones could be improved for Wilson's Plovers by simple activities such as vegetation thinning or creation of pathways to foraging fiddler flats, the Base could then weigh the costs and benefits of increasing Wilson's Plovers in these areas if the population decreases in the Wildlife Area due to beach erosion. For example, one option would be to create a path from the Amphibious Training Zone beach front to the sound-side intertidal mud flats in the middle of the island. The path could be located between Egresses 10 and 11 where there is already a break in the access roads at this point. Vegetation removal and thinning would most likely be necessary for broods to gain access to the flats since there has been a lack of overwash in the middle of the island. Similarly, vegetation thinning or removal just north of the overwash in the Wildlife Area would be beneficial is making fiddler flats more accessible to foraging Wilson's Plover broods.

Less aggressive, but still invaluable, mitigation would be to re-focus land management efforts to other important existing and ephemeral foraging habitats and nesting areas in the Wildlife Area. In particular, I recommend increased management (i.e. symbolic fencing, patrols, on-site educators) of the fiddler flats and surrounding nesting habitats at the sound-side southwestern end of Onslow Beach (Fig 1). The largest (> 14 000 m^2) and most used (by Wilson's Plover broods) fiddler crab mud flat is located in this area sound-side, and is bordered by the New River Inlet and marsh habitat. Additional inter-tidal mud flats (not colonized by fiddler crabs) surround this flat, and provide benthic and terrestrial arthropod prey resources for Wilson's Plovers, and other breeding, migratory, and resident foraging shorebirds, such as Piping Plovers (Federally Threatened), Semi-palmated Plovers (*Charadrius semipalmatus*), Black-bellied Plovers (*Pluvialis squatarola*), Sanderlings (*Calidris alba*), and Ruddy Turnstones (*Arenaria interpres*; Ray, unpublished data). My behavioral observations of Wilson's Plover broods using this area coupled with regular shorebird surveys (Ray, unpublished data) indicate that these intertidal mudflats at the southwestern end of the island are important habitat for breeding, migrating, wintering, foraging, resting, and roosting shorebirds. This would also be an ideal area for North Topsail Beach to work with Base personnel in creating, stabilizing, and protecting critical shorebird habitat that may be lost on the beach front as a result of inlet relocation and island stabilization efforts.

The sound-side habitat on the southwestern end of Onslow Beach is a challenging area to protect as it is easily accessible by recreational boaters and fisherman. During this 2-yr study, recreational users often used the bayside inter-tidal zone within 5-10 m from posted shorebird areas surrounding the fiddler flat to anchor their boats, picnic, and walk. While the inter-tidal zone is a public property, it is apparent that symbolic fencing and signs are not entirely effective in protecting Wilson's Plover nesting pairs and foraging broods using the higher-elevation dry sand (i.e. posted sand flat) and adjacent fiddler crab mud flat. All five nests found in this area of the island over the 2-yr period failed; we confirmed three nest depredations by mammalian predators, but two (one in each year) were abandoned shortly after the Memorial Day holiday when ≥ 100 people and up to 20 boats were counted in this area. Studies have shown that human disturbance can lead to nest abandonment and increased depredation from human-attracted predators (MacIvor et al. 1990, USFWS 1996, Lord et al. 2001, Cohen et al. 2009). Nest abandonment caused by human disturbance (i.e. physical presence of humans) has been observed in Wilson's Plover studies (Bergstrom 1988, Corbat and Bergstrom 2000, this study), but to a small extent relative to other causes of nest failure.

Considering the predominantly natural, long-term erosion on Onslow Beach (Foxgrover 2009) and planned relocation of the New River Inlet, increasing and improving shorebird habitat and the monitoring and protection of existing nesting and foraging areas may help to mitigate the likely habitat loss beach front, and provide supplemental resources to sustain and increase Wilson's Plover productivity. Regardless of ever-present natural-caused or imminent human-induced changes to the southwestern end of Onslow Beach, it will be important for the Base's Environmental Management Division to apply flexible management practices to protect newly formed and ephemeral habitats (e.g. overwash, sand accretion, ephemeral tidal pools) supporting Wilson's Plover nesting pairs and broods, and other breeding shorebirds with similar habitat requirements that nest and raise young on Onslow Beach (e.g. Piping Plovers, American Oystercatchers (*Haematopus palliates*), Least Terns (*Sterna antillarum*), and Willets (*Catoptrophorus semipalmatus*); Ray, unpublished data).

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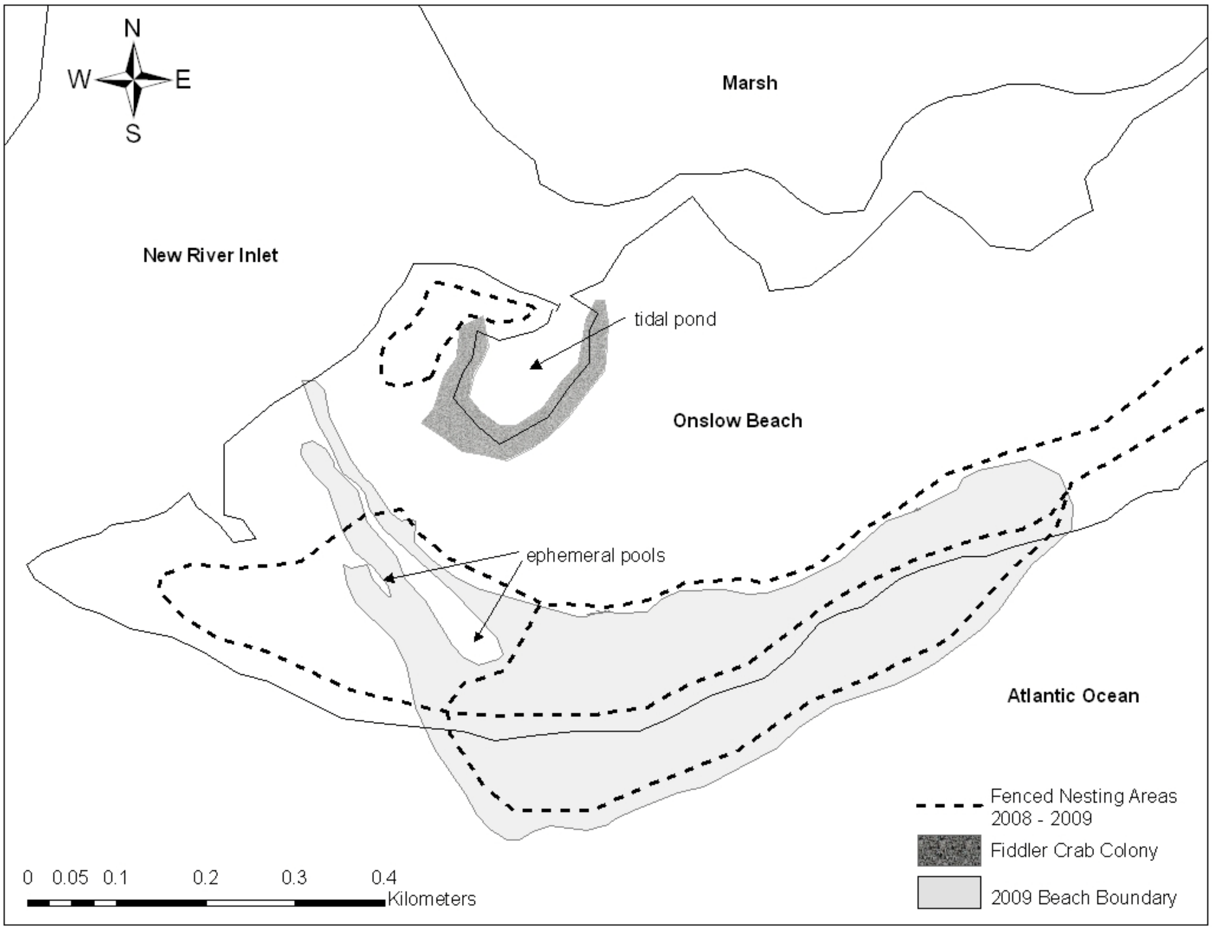

Fig. 1. Map depicting fenced Wilson's Plover (*Charadrius wilsonia*) nesting areas adjacent to unprotected foraging habitat (i.e. ephemeral pools, tidal pond, and fiddler crab (*Uca* spp.) mud flat) on the southwestern end of Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008–2009.

Appendix A. Wilson's Plover (*Charadrius wilsonia*) supplemental demographic information to Chapter 2

Table 1. Wilson's Plover (*Charadrius wilsonia*) brood-specific (*N*=20, Brood ID) covariate values (hatch date and the distance a brood traveled from its nest site to its final foraging territory (km, DistFTerr), weekly survival rates (WSR ± standard error (SE)), overall apparent survival (Φ), and averaged estimates of WSR and overall apparent survival based on the top-ranked model predicting chick survival at Marine Corps Base Camp Lejeune, North Carolina, 2008-2009.

Brood ID	Hatch date	DistFTerr (km)	WSR	± SE	WSR 95% LCL	WSR 95% UCL
10	9	0.17	0.9999	0.0007	0.8425	1.0000
12	43	0.98	0.9391	0.0471	0.7542	0.9873
18	37	0.18	0.8760	0.0823	0.6156	0.9689
1	0	1.82	1.0000	0.0000	0.9658	1.0000
20	59	1.82	0.7842	0.1683	0.3409	0.9623
3	7	0.67	0.9999	0.0001	0.9015	1.0000
4	9	0.31	0.9999	0.0005	0.8603	1.0000
6	9	0.21	0.9998	0.0007	0.8478	1.0000
16	7	0.14	0.9999	0.0005	0.8465	1.0000
38	25	0.145	0.9906	0.0168	0.7521	0.9997
42	41	0.031	0.6489	0.1462	0.3446	0.8667
27	0	0.138	0.9999	0.0001	0.8717	1.0000
31	5	0.152	0.9999	0.0003	0.8557	1.0000
33	14	0.932	0.9999	0.0003	0.9031	1.0000

Brood ID	Hatch date	DistFTerr (km)	WSR	± SE	WSR 95% LCL	WSR 95% UCL
34	19	0.169	0.9978	0.0053	0.7949	1.0000
35	9	0.082	0.9997	0.0009	0.8298	1.0000
36	15	0.074	0.9989	0.0031	0.7994	1.0000
37	13	0.825	0.9999	0.0003	0.8977	1.0000
45	32	1.355	0.9982	0.0040	0.8767	1.0000
46	46	0.053	0.3791	0.2008	0.1029	0.7647
	Average WSR:		0.9306	Overall apparent Φ[b]		0.7499

[a]{Φ(HatchDate DistFTerr) ρ(year×week)}= best-fitting model predicting chick survival (Φ) as a function of hatching date (Hatch date), and the distance a brood traveled from its nest site to its final foraging territory (km, DistFTerr), AIC_c = 222.25, ΔAIC_c (difference between candidate model's score and the top model score) = 0.00, K (number of model parameters) = 11, w_i (weight of each model as compared to all candidate models) = 0.87, model likelihood (probability of observed values being a function of unknown values in the model) = 1.00.

[b]Overall apparent survival per brood = Average WSR raised to the number of weeks (w) to fledging (w=4, WSR^4).

Table 2. Demographic comparisons of breeding Wilson's Plovers (*Charadrius wilsonia*) in the United States, 1944-2009.

Years Region	Mean clutch size (± SE)	Incubation period (days)	Hatching success (≥ 1 egg)	Overall nest survival	Chicks hatched/pair (± SE)	Chicks fledged/pair (SE not reported)	Days to fledging
2006 – 2008 Louisiana[a]	---	---	66% (2007)	---	---	1.00 (2006-2007)	31-35 (2006-2008)
2005 – 2006 Virginia[b]	---	---	---	---	---	1.63, 1.82	---
2003 – 2004 Texas[c]	---	---	66%, 63% (TX)	---	---	---	---
2003 – 2004 Texas[d]	---	25	---	**58.0%	---	---	---
1986 –1987 Georgia[e]	2.90 ± 0.09	25	2.5%, 11.8%	*10.8%, 55.2% ($\bar{x}$ =27.3%)	---	---	---
1979 –1980 Texas[f]	2.92 ± 0.05	23-27	25.0%, 53.8%	*12.0%, 34.0% ($\bar{x}$ =23.0%)	≥ 1	---	---

Years Region	Mean clutch size (± SE)	Incubation period (days)	Hatching success (≥ 1 egg)	Overall nest survival	Chicks hatched/pair (± SE)	Chicks fledged/pair (SE not reported)	Days to fledging
1944 and 1965 Georgia[g]	---	25 (1965)	---	---	---	---	≥ 21 (1944)

*Mayfield method estimate / **generalized linear modeling approach/likelihood-based model estimate.

[a] Coastal Louisiana (Zdravkovic *in prep*, 2010).

[b] 2 northern barrier islands, VA (Boettcher et al. 2008).

[c] Lower Laguna Madre region of south coastal Texas and Padre Island National Seashore, Texas (Zdravkovic 2005).

[d] Lower Laguna Madre region of south coastal Texas (Hood 2006).

[e] Ossabaw, Sapelo, and Little St. Simons Islands, GA (Corbat 1990).

[f] Laguna Atascosa National Wildlife Refuge and Matagorda Island, Aransas National Wildlife Refuge, Texas (Bergstrom 1988).

[g] Barrier islands along the Savannah River and bordering Callibogue Sound and the Atlantic Ocean in northern coastal Georgia (Tomkins, 1944 and 1965).

Appendix B. Wilson's Plover (*Charadrius wilsonia*) supplemental habitat use information to Chapter 3

Table 1. Mean comparisons of habitat variables collected at Wilson's Plover (*Charadrius wilsonia*) nest sites and random, paired non-used locations at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina 2008-2009.

Variables[a]:	MLshell	TallVeg5	DistNrNest	PebbCobb	DistDune	VegCover	DistFidd
Nest Site (1)							
Mean	12.71	1.14	89.24	13.82	19.57	15.33	227.19
SE	2.60	0.20	12.84	3.07	4.86	2.33	46.20
Non-nest Site (0)							
Mean	19.28	0.71	86.96	19.25	18.58	14.29	226.41
SE	3.22	0.13	12.65	3.55	4.51	3.13	46.50

[a] MLShell = percent cover of medium (2-64 mm) and large (> 64 mm) shells within a 1-m^2 quadrat placed over paired sample sites; TallVeg5 = height of tall vegetation (≥ 1.0 m) within a 5-m radius of paired sample sites; DistNrNest = distance to nearest nest site (m) of any species from paired sample sites; PebbCobb = percent cover of pebbles (2-64 mm) and cobble (> 64 mm) within a 1-m^2 quadrat placed over paired sample sites; DistDune = distance (m) to nearest dune; VegCover = percent vegetation cover within a 1-m^2 quadrat placed over paired sample sites; DistFidd = distance (m) to nearest fiddler crab (*Uca* spp.) mud flat.

Table 2. Habitat measurements on and around fiddler crab (*Uca* spp.) mud flats at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2009. The number of Wilson's Plover (*Charadrius wilsonia*) broods (Obs) that established foraging territories on each flat are also indicated.

Flat ID	# Broods	Area (m^2)	Path Dist[a] (m)	Density Index[b]	% Veg Cvr on Path[c]	% Veg Cvr on Flat[d]	Burrows[e]	Crabs[f]	H2ODist[g] (m)	T/NT[h]
A	2	2405.94	0.00	0.00	0.00	20.83 ± 2.10	67.50 ± 2.33	46.98 ± 1.63	0.00	T
B-D	0	1358.25	26.41	32.28 ± 0.28	65.56 ± 7.57	35.15 ± 2.99	60.09 ± 0.81	41.60 ± 0.53	0.00	T
C-M	2	1252.25	26.41	32.78 ± 0.15	65.56 ± 7.57	32.44 ± 2.72	65.05 ± 1.41	35.96 ± 0.26	9.52	T
E	0	197.20	47.08	30.21 ± 0.42	85.17 ± 3.21	40.90 ± 1.04	51.03 ± 2.82	40.88 ± 3.67	7.50	NT
G	0	473.29	13.63	25.33 ± 2.00	60.00 ± 12.54	36.03 ± 2.10	72.28 ± 1.35	47.74 ± 0.63	0.00	T
I-J-F	1	239.12	67.55	31.00 ± 0.13	58.90 ± 1.22	55.83 ± 1.22	55.65 ± 2.87	32.69 ± 1.67	9.68	T
K-L	1	552.18	48.04	32.92 ± 0.04	77.50 ± 3.15	46.30 ± 1.19	56.33 ± 3.27	33.86 ± 2.08	13.05	NT
N	2	14028.68	0.00	0.00	0.00	9.43 ± 0.41	45.90 ± 0.81	31.90 ± 1.09	0.00	T
Y-Z	1	44.37	0.00	0.00	0.00	46.17 ± 0.64	42.35 ± 2.58	25.68 ± 1.61	0.00	NT

[a] Path Dist = length (m) of vegetated path from inter-dune sand flat to fiddler crab mud flat.

[b] Density Index = index depicting visual obstruction of vegetation along sampling path.

[c] % Veg Cover on Path = mean of percent of vegetation cover in 0.5-m^2 plots taken every 10 m along sampling path.

[d] % Veg Cover on Flat = mean percent of vegetation cover in 1-m^2 plot around foraging site on fiddler crab mud flat.

[e] Burrows = mean crab burrow count in 1-m^2 plot.

[f] Crabs = mean fiddler crab count in 1-m^2 plot.

[g] H2ODist = distance to water (m).

[h] T/NT = subject to frequent Tidal inundation or Not subject to frequent Tidal inundation.

Table 3. Wilcoxon signed-rank test (P ≥ *z*) results examining mean ($\bar{x}$ ± standard error) differences in habitat variables (distance to water (m), distance to vegetation cover (m) beyond the 1-m^2 plot, and percent vegetation cover within 1-m^2 plot) at Wilson's Plover (*Charadrius wilsonia*) foraging locations (use) and random, paired non-use sampling points by habitat type at Marine Corps Base Camp Lejeune, North Carolina, 2009.

Habitat Type	Use $\bar{x}$ ± SE	Use Q1–Q3[a]	Non-use $\bar{x}$ ± SE	Non-use Q1–Q3[a]	All Q1–Q3[a]	z	Prob ≥ *z*
Fiddler Crab Mud Flat (*n* = 26)							
Distance to Water	16.00 ± 3.81	1.50–19.50	21.75 ± 3.89	7.50–33.00	4.13–30.75	-81	0.04
Distance to Vegetative Cover	4.06 ± 1.88	0.00–2.25	6.57 ± 2.75	0.00–3.75	0.00–3.00	-16.5	0.46
Percent Vegetation Cover	13.72 ± 3.56	0.00–20.00	11.64 ± 3.79	0.00–20.00	0.00 – 20.00	17	0.54
Beach Front (*n* = 36)							
Distance to Water	47.88 ± 7.13	13.50–75.00	51.09 ± 7.11	9.00–84.75	13.5–80.5	-38	0.47
Distance to Vegetative Cover	9.93 ± 2.19	0.00–20.25	13.69 ± 3.06	2.25–17.25	0.50–17.25	-59	0.30
Percent Vegetation Cover	14.44 ± 3.47	0.00–20.00	4.73 ± 2.32	0.00–0.00	0.00–15.00	54	0.02
Interdune Sand Flat (*n* = 10)							
Distance to Water	38.78 ± 8.99	19.25 – 55.00	61.60 ± 13.89	28.50–88.50	22.13–84.88	-20.5	0.04

Habitat Type	Use	Use	Non-use	Non-use	All	z	Prob ≥ *z*
	$\bar{x}$ ± SE	Q1–Q3[a]	$\bar{x}$ ± SE	Q1–Q3[a]	Q1–Q3[a]		
Distance to Vegetative Cover	0.55 ± 0.24	0.00–0.50	1.36 ± 1.06	0.00–0.10	0.00–0.50	0.00	1.00
Percent Vegetation Cover	12.5 ± 4.17	5.00 – 20.00	23.2 ± 5.92	0.00–40.00	5.00–31.00	-14.5	0.15

[a] 25% (Q1) – 75% (Q3) inter-quartile ranges for use, non-use, and all sampling plots.

Appendix C. Mean morphological measurements of Wilson's Plover (*Charadrius wilsonia*) adults and chicks on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2008-2009.

Sex/Age	*N*[a]	Weight (g) (± SE)	Right wing chord (mm) (± SE)	Culmen (mm) (± SE)	Body (cm) (± SE)	Right tarsus (mm) (± SE)
Males	18	63.78 (0.77)	128.28 (1.84)	18.80 (0.65)	13.50 (0.27)	26.69 (1.08)
Females	22	71.32 (1.23)	115.45 (1.03)	19.67 (0.71)	13.64 (0.21)	22.92 (0.91)
Chicks (1 day)	29	9.13 (0.14)	14.21 (0.61)	6.81 (0.42)	4.20 (0.17)	---
Chicks (2-6 days)	5	9.00 (0.63)	14.80 (1.59)	8.57 (0.47)	3.64 (0.24)	---
Chicks (21 days)	2	21.00 (2.00)	31.50 (6.50)	11.30 (0.81)	6.40 (2.10)	---

[a] sample size

Appendix D. Results from Wilson's Plover (*Charadrius wilsonia*) radio telemetry pilot study on Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina, 2009.

Introduction

The Wilson's Plover (*Charadrius wilsonia*) is a species of high concern in the southeastern United States, where it breeds (Brown et al. 2000, USFWS 2008). It is listed as Endangered in Maryland and Virginia, a Species of Concern in North Carolina, Threatened in South Carolina and Rare in Georgia; it is not currently state-listed in Florida. The U.S. Shorebird Conservation Plan (Brown et al. 2000) has nationally and regionally (Southeastern Coastal Plains-Caribbean Region, Hunter 2002) listed the Wilson's Plover as a Species of High Concern (Prioritization Category 4), and the U.S. Fish and Wildlife Service (USFWS, 2008) has designated this species as a Bird of Conservation Concern (BCC). Despite its conservation status, Wilson's Plover population trends are poorly understood (Brown et al. 2000) and few studies have estimated demographic parameters for this species (Bergstrom 1982 and 1988, Corbat 1990, Hood 2006).

Previous studies have documented the difficulty of locating and observing this secretive and cryptic coastal avian species during its reproductive life stage (Bergstrom 1982, Corbat 1990, Bergstrom and Corbat 2000). We implemented radio telemetry as part of a demographic study (not discussed here) to assist in locating broods during the first 5-10 days after hatch, when broods are most difficult to detect and observe in order to estimate adult productivity (i.e. number of young per breeding pair) and chick survival.

Study Site

We studied breeding Wilson's Plovers at Onslow Beach, Marine Corps Base Camp Lejeune, North Carolina from March–August 2009. Onslow Beach (77°20'9.751"W

34°31'52.911"N) is a 12.9-km coastal barrier island bounded by the New River Inlet and Brown's Inlet along the Atlantic Ocean (Fig 1). The south end of the island is designated and managed for Low Impact Recreation and Wildlife (Wildlife Area) and is closed to recreational vehicles from 1 April–31 August, annually. Breeding Wilson's Plovers occurring on Onslow Beach were most commonly found in this area of the island; however, we found nesting pairs on the northern portion of the island where access is restricted due to its being a military training buffer and impact area.

Methods

We searched for incubating adults only in the Wildlife Area of the island, primarily from 06:00-10:00, from the end of March through mid-July in 2009. We established three nest searching transects through inter dune sand flats (0.75 km, 0.77 km, and 1.61 km long, respectively, 45-190 m apart depending on patches of forest and large dunes) and three through the beach front habitat (0.53 km, 0.83 km, and 0.98 km long, respectively, 35-60 m apart). We searched for incubating adults on these transects 2-3 days per week and used behavioral cues such as territory defense, mock brooding, broken-wing displays, and incubation to locate nesting areas and nest sites.

We trapped adult plovers within 48 hours of nest detection using a drop box (Wilcox 1959, Graul 1979) and oblong funnel traps (Paton 1994, Lessells 1984), and targeted adult males for transmitter attachment since they are the primary incubators approximately 48 hours prior to hatch, and attend chicks more frequently than females (Bergstrom 1986, this study). However, females were tagged when males could not be trapped. We used 1.6-g BD-2 transmitters (Holohil Systems Ltd., Ontario, Canada) weighing < 3% of the average adult Wilson's Plover weight (average adult weight = approximately 68 g; this study, Corbat and Bergstrom 2000). We plucked dorsal contour feathers between the bird's scapulae in an approximately 1 cm^2 patch to fit the dimensions (18x10x3.5 mm) of the transmitters. We glued the devices to the exposed skin using cyanocrylate gel (Loctite®, Westlake, Ohio), and implemented a 10-min maximum bird handling time. We modeled our method after Cohen et al. (2008, 2009), who successfully employed this method of affixing transmitters on piping plovers (*Charadrius melodus*) and red knots (*Calidris canudus*) in radio telemetry studies conducted in Oregon Inlet, North Carolina, Delaware Bay, and Virginia. We used 3-element Yagi antennae and handheld receivers to locate the birds (Communication Specialists, Inc., Orange, California). We searched for radio-tagged Wilson's Plovers and broods every 2-4 days after tag attachment along the established transects until the tags were dropped or the birds migrated from the study site. We recorded the geographic location of the re-sighted individuals and their associated broods with a handheld Garmin 76 GPS unit (± 10-20 m).

Results

We located all tagged adults (N = 10) and their associated broods using radio telemetry between 21 May and 29 Jun. During this time period, we also detected 22 un-tagged adults and three broods using binoculars, scopes, and the naked eye. We observed an average retention time for radio transmitters of 8.9 ± 1.94 days. Four tags were retained ≤ 5 days, three receivers remained on birds 15-18 days, and three tags were intact for 6-9 days.

Discussion

Implementing radio telemetry did not increase our chances of locating adults and their associated broods. However, in two cases we were able to confirm that nests hatched and were not depredated by locating the adult, and subsequently, the associated brood. In one case, we were able to capture two chicks to take morphological measurements and place color bands on them. In these few instances, radio telemetry was advantageous in finding and banding chicks, confirming nest fates, and locating the final foraging territory of adults and their broods. We experienced trap-shy responses from Wilson's Plovers we attempted to trap multiple times so as to adhere radio transmitters. Many of the birds were previously trapped, measured, and banded or were at or near the nest site when their mate was captured. Each subsequent trapping attempt of the same individual was increasingly difficult, and often we were forced to use alternate trapping methods (e.g. oblong funnel trap or a visual variation of the drop box). We recommend two trapping attempts per individual using an alternate method in the subsequent effort to minimize trapping difficulty and prevent harassment of the birds. We limited all of our trapping efforts to ≤ 20 minutes in the cooler morning hours. We do not recommend the use of glued radio transmitters on Wilson's Plovers as retention time of transmitters was low compared to other studies using the same method of adherence where average retention was 17 days (Cohen et al. 2008, 2009). We observed tagged birds excessively preening around transmitters, and four were dropped within 1-5 days of adherence. Long term monitoring and research efforts conducted by the Coastal Bird Conservation Program (Zdravkovic 2010) on the Louisiana Gulf coast implemented radio tagging of Wilson's Plovers in 2008. As in our study, researchers experienced low transmitter retention times (i.e. dropping transmitters within the first week) and excessive preening after gluing the devices on the bird. In cases where dropped transmitters were located, they were bent and twisted as if wrapped around a bill and pulled from the skin. With time, diligence, patience, and proper field training, detection of Wilson's Plover broods will increase, as we observed in this study.

Acknowledgements

The radio telemetry portion of our study was funded in part by the E. Alexander Bergstrom Memorial Research Fund administered by Association of Field Ornithologists, Inc. We received additional funding from the Strategic Environmental Research and Development Program (SERDP), administered by the Research Triangle Institute (RTI). This project was part of the Defense Coastal/Estuarine Research Program (DCERP) at Marine Corps Base Camp Lejeune (MCBCL), North Carolina, USA.

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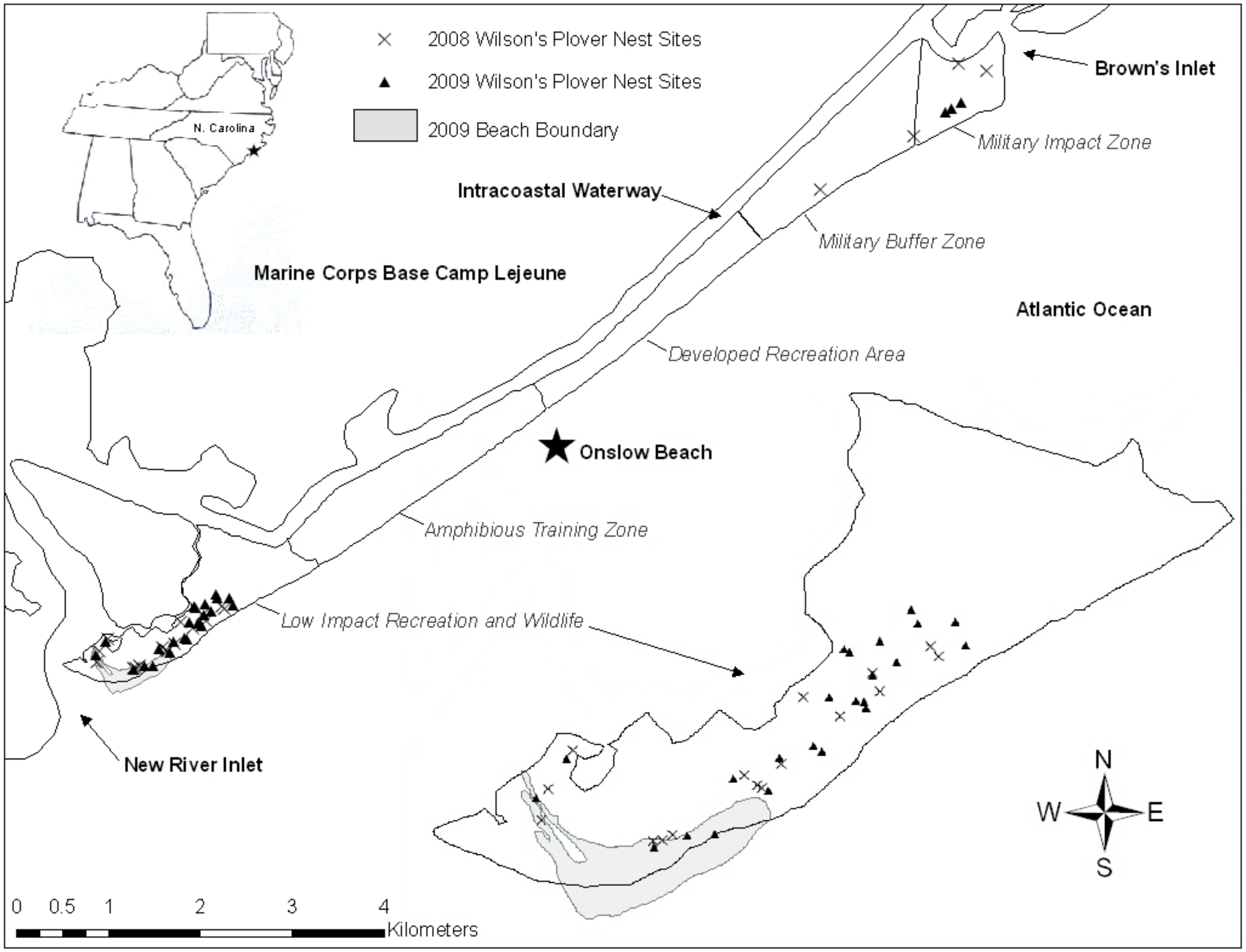

Fig. 1. Study area at Onslow Beach on Marine Corps Base Camp Lejeune, North Carolina, 2008-2009. The Low Impact Recreation and Wildlife area is enlarged to clearly depict Wilson's Plover (*Charadrius wilsonia*) nest site locations.