Winter Ecology of Piping Plovers at Oregon Inlet, North Carolina

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Abstract.—Humans may modify winter habitat of the imperiled Piping Plover (*Charadrius melodus*), yet published accounts of the species' winter ecology are rare. We studied Piping Plovers at Oregon Inlet, North Carolina from December 2005 to March 2006. Plovers used a 20.1 km^2 area (100% minimum convex polygon home range) containing narrow barrier islands with ocean and sound-side beaches, and small shoals, dredged-material islands, and marsh islands in shallow-water sounds. Plover activity was concentrated in twelve areas totaling 2.2 km^2 (95% fixed kernel home range). When plovers were on ocean beaches, they spent less time foraging (18%) than when on Sound Island beaches (88%) and islands (83%, P = 0.003). Sound island use increased and beach use decreased as the tide dropped (Logistic regression, P < 0.001). Plover use of dredged-material islands implied that habitat managers can create or restore attractive foraging sites where habitat may be declining or limiting. Wintering habitat management should aim to provide foraging opportunities during most of the day and across a range of tide conditions and ensure that foraging habitat is close to roost sites. *Received 19 July 2007, Accepted 20 January 2008.*

Key words.—activity budget, behavior, *Charadrius melodus*, habitat, North Carolina, radio telemetry, Piping Plover, restoration, shorebirds, winter.

Waterbirds 31(3): 472-479, 2008

Factors that affect distribution, abundance and survival of the federally-threatened Piping Plover (*Charadrius melodus*) on the wintering grounds are poorly understood. Protecting non-breeding plovers and their habitat is a priority in the recovery plans for all three North American breeding populations (USFWS 1988, 1996, 2003), which mix on the wintering grounds (Haig *et al.* 2005). Much research has focused on breeding plovers (reviewed in Haig and Elliot-Smith 2004). Dinsmore *et al.* (1998) documented a small population of overwintering Piping Plovers in North Carolina's Outer Banks, but there have been no other studies of winter populations on the Atlantic Coast in 16 years (Nicholls and Baldasarre 1990), during which the Atlantic Coast breeding population more than doubled (USFWS 2004). The Atlantic Coast breeding population decreased slightly, however, from 2002-2005 (USFWS 2004, preliminary unpublished data). Similarly, the Great Plains population declined from 1996-2001 (Haig *et al.* 2005). Information on habitat and survival in winter might help explain these declines and help improve recovery strategies for this species.

Wintering plovers on the Atlantic Coast prefer wide beaches in the vicinity of inlets (Nicholls and Baldassarre 1990; Wilkinson and Spinks 1994). At inlets, foraging plovers are associated with moist substrate features such as intertidal flats, algal flats, and ephemeral pools (Nicholls and Baldassarre 1990; Wilkinson and Spinks 1994; Dinsmore *et al.* 1998). Because tide and weather variation often cause plovers to move among habitat patches, a complex of patches may be important to local wintering populations (Johnson and Baldassarre 1988; Drake *et al.* 2001). Given the affinity of plovers for inlet-associated habitats, artificial closure of storm-created inlets for protection of human property could reduce local plover carrying capacity. Furthermore, inlet stabilization with rock jetties and channel dredging for navigation alter the dynamics of sediment transport and affect the location and movement rate of barrier islands (Camfield and Holmes 1995), which might in turn affect the availability of plover habitat. Coastal engineers, however, sometimes deposit dredged sediment in low wave-energy bays or sounds behind barrier islands (USACE

2006), creating small islands with the potential to attract Piping Plovers (Federal Register 2001).

We studied Piping Plover habitat use and behavior in winter in a human-modified inlet system. There has been little data on the use of different habitat zones in the winter that can be used in habitat conservation planning. Portions of our study area were designated as critical habitat for wintering Piping Plovers (Federal Register 2001) until 2004, when a court decision vacated the designation of this unit and three others in Dare and Hyde Counties, North Carolina (U.S. District Court, District of Columbia Civil Action no. 03-216: Cape Hatteras Access Preservation Alliance vs. U.S. Dept. of the Interior, 344 F. Supp. 2d 108. 2004). The designation was remanded to the U.S. Fish and Wildlife Service (USFWS), which is currently reconsidering it (Federal Register 2006). Data from our study will aid in understanding spatial and temporal patterns of habitat use, and habitat preferences. The results can be used to plan critical habitat protection under the Endangered Species Act, and to provide guidelines for habitat management and creation under programs such as the U.S. Army Corps of Engineers' (USACE) "Beneficial Uses of Dredge Materials" (USACE 2006).

STUDY AREA

Plovers at Oregon Inlet (N 35°46.5'W, 75°32.1'), Dare County, in the Outer Banks barrier island chain of North Carolina (Fig. 1) were studied from 5 December 2005 to 23 March 2006, at the northern edge of the species' wintering range (Haig and Eliott-Smith 2004). Monthly mean temperature during the study was 9.2°C. The minimum temperature dropped below freezing in 10 d, approximately 9.4 d less than normal (NOAA 2006a). Total precipitation was 32.8 cm, 35% below normal (NOAA 2006a). Oregon Inlet Channel, a USACE-maintained navigation channel, passed through Oregon Inlet from the Atlantic Ocean in the east to Pamlico

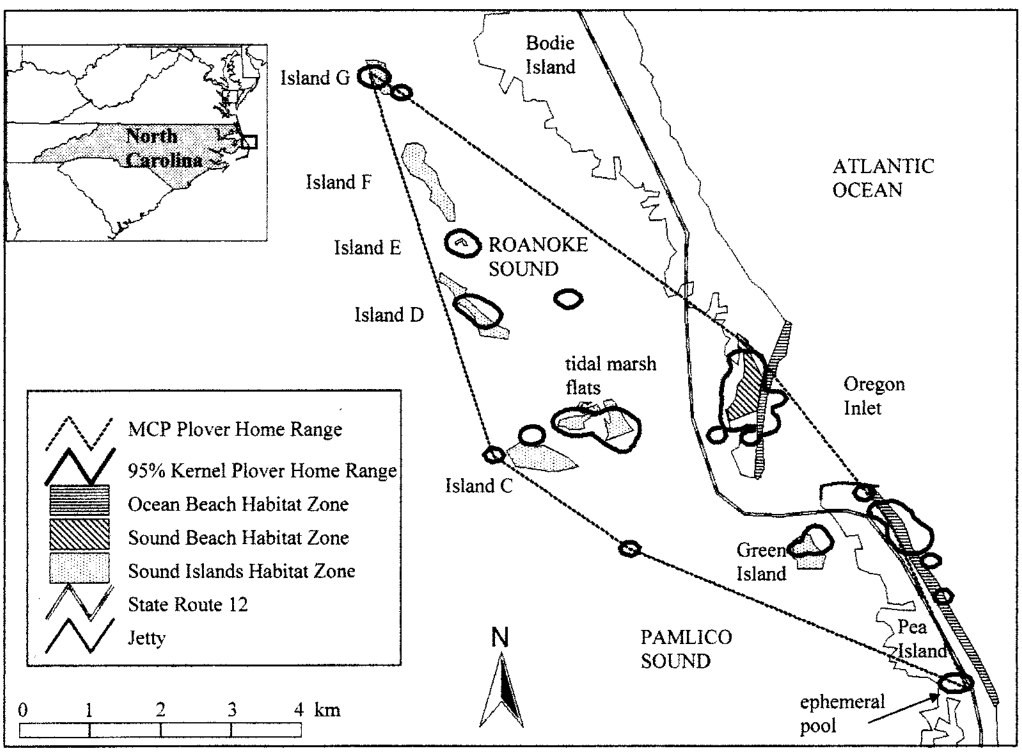

Figure 1. Map of study area for Piping Plover winter ecology research, Oregon Inlet, North Carolina, 2005-2006. Pea Island is the northern tip of Hatteras Island. Piping Plover minimum convex polygon (MCP) and 95% fixed kernel home ranges and the extent of the habitat zones (ocean beach, sound beach, sound islands) recognized in this study are depicted.

Sound (average depth 4.6 m, Paerl *et al.* 2001) and Roanoke Sound (typical depth on nautical charts approximately 0.6 m) in the west. Bodie Island Spit, part of Cape Hatteras National Seashore (CAHA), was a 2-km long peninsula that bounded Oregon Inlet to the north, and ranged from 500-750 m wide. The ocean side of the spit consisted of a sandy beach approximately 150 m wide that was frequented by recreational fisherman in off-road vehicles (ORVs). The Roanoke Sound side of the spit consisted of grassy dunes interspersed with storm-fed ephemeral pools and a 20-ha sand flat, approximately two ha of which was intertidal and the rest of which was algae-covered and overwashed only during extreme high tides. Pea Island National Wildlife Refuge (NWR) on Hatteras Island bounded Oregon Inlet to the south, and was approximately 500 m wide in the study area. The ocean side of the island consisted of a sandy beach approximately 150 m wide and was accessible only by pedestrian traffic. The beach was backed by a grassy dune ridge, behind which Highway 12 ran through the barrier flats. The Pamlico Sound side of the island consisted of salt marsh. The small islands within Pamlico and Roanoke Sounds included Green Island (a flood shoal owned by CAHA) and dredged-material islands C, D, E, F, and G created by the USACE (Fig. 1). Except for Island E, which last received dredged material in 1977 and was wholly intertidal, the Corps deposited dredged material on these islands at least through the mid-1990's (U.S. Army Corps of Engineers, Wilmington District, unpublished data). Dredged-material islands had open or vegetated sand, salt marshes, tidal creeks, and tidal flats. Plovers also used several unnamed tidal marsh flats and mudflat/sandflat islands. The intertidal portions of these named and unnamed islands ranged from <1 ha to 9.6 ha. Due to the shallowness and size of the sounds, tide heights and thus the exposure of sound-side intertidal areas were much affected by wind direction and speed (Pilkey *et al.* 1998). Most tidal flat exposure occurred during strong easterly winds.

METHODS

Field Methods

All accessible Piping Plover habitat were surveyed daily by boat, auto, or foot, scanning by spotting scope and recording the number of Piping Plovers and any band combinations seen. These scans were used to estimate the size of the population, where the winter population was considered to be the set of individuals that used Oregon Inlet from December to March. Capture of plovers was attempted from 4 December 2005 to 8 March 2006 using a combination of noose carpets (Drake *et al.* 2003) and bungee-propelled whoosh nets (SpiderTech, Helsinki, Finland), under federal and state threatened and endangered species and banding permits, and National Park Service and National Wildlife Refuge research permits. All captured birds were uniquely marked with a color band on each tibiotarsus. A 1.4 g radio transmitter (Model BD-2, Holohil Systems Ltd., Ontario, Canada) was attached to the back between the scapulae using cyanoacrylate glue (DURO Quick Gel® Henkel Consumer Adhesives, Inc., Avon, OH). Seven individuals were captured, color-marked, and radio-tagged between 5 December-10 February. Mean radio retention was 17 ± 7 d (range 3-57 d). During the daily surveys, radio-marked birds were tracked with three-element handheld Yagi antennae and an ATS receiver (ATS, Isanti, MN). Attempts were made to locate each marked bird daily between dawn and dusk, and where time allowed twice/d during two different tidal stages. An average of 7.5 h/d (range 1.25-11.33 h/d) was spent surveying the plover population and searching for radio-tagged birds. Short survey days resulted from inclement weather or the need to spend time trapping. The surveys typically began in the morning ($\bar{x}$ = 08.05 h, range 04.00-13.10 h) and ended in mid-afternoon ($\bar{x}$ = 15.32 h, range 08.23-19.00 h). An average of 90% (SE = 3.8, range 33-100%) of the tagged plovers were relocated each day (N = 52 d where tagged birds were available and tracked).

An attempt was made to sample the behavior of all marked birds each day, and if possible twice/d during different tidal stages. When a marked plover was located it was observed through a spotting scope for five min. Foraging attempts (pecks at the substrate) were counted continuously and behavior (foraging, resting/preening/standing alert, intra-specific aggression, flying, other) every 10 s. Behavior of shorebirds is tide-dependant (Burger *et al.* 1977), so it was ensured that different tidal stages within each cover type were sampled to avoid biasing the results.

To estimate foraging habitat availability, the intertidal zone (ITZ, 5-8 contours over a tidal range of 30-50 horizontal m) was contour-mapped in plover foraging habitat, including barrier island ocean beach, barrier island sound beach, and five of the sound islands that contained 68/94 (72%) of the sound island plover sightings, by walking along the water's edge at various tide heights carrying a GPS unit (GeoXT, Trimble, Miami, FL). The contours were differentially-corrected using base station data and Pathfinder software (Trimble, Miami, Florida), then the area exposed at each tidal stage was calcualted in a GIS (ArcGIS 9.1, ESRI, Redlands, CA). Tide tables (NOAA 2005, NOAA 2006c) were used for stations near each of the mapped sites to calculate the predicted tidal height at the time each of the contours was mapped, with the predictions adjusted for the difference between predicted (lunar) height and verified (wind-driven) height available in six-min resolution from the Oregon Inlet Marina NOAA tide station (NOAA 2006b). Simple linear regression was used to model area of ITZ exposed as a function of estimated tide height. The resultant regression equations were used to predict exposed ITZ area in three habitat zones (ocean beach, sound beach, sound islands) at the time of every plover location, considering the sum of the areas at the five sound islands mapped to be an index of ITZ availability for all sound islands.

Data Analysis

Home Range. All radio-tagged Piping Plovers in the Oregon Inlet population were observed in a single flock on 27/38 survey d in which ≥2 tagged plovers were in the population, indicating that the birds tended to move as a flock. All plover locations were therefore pooled and a home range for the flock calculated, disregarding sightings that were closer than one h apart. If two tagged plovers were in the same group at the same time, one of them was randomly chosen for inclusion in the sample. A 100% minimum convex polygon (MCP) home range and a 95% fixed kernel home range were calculated using HRT: Home Range Tools (Rodgers *et al.* 2005) in ArcGIS 9.1 (ESRI, Redlands, California) after eliminating duplicate X,Y coordinates. The smoothing factor (h) was calculated using Least-Squares Cross Validation (Seaman and Powell 1996) and standardized variances for the X and Y coordinates (Silverman 1986).

Habitat Use and Availability. All plover habitats used fell into one of three habitat zones: ocean beach (barrier islands), sound beach (barrier islands), and sound island (dredged material, shoal, and other marsh and mudflat/sandflat islands, Fig. 1). Discrete-choice (multinomial) logistic regression (McFadden 1974) was used to model habitat zone use (the probability of the flock occupying a particular zone) as a function of the index of sound island ITZ exposed. Use was categorized as 1 = ocean beach, 2 = sound beach, 3 = sound islands each time a radio-tagged bird was located. Since this analysis was performed for the flock rather than for individual birds, one tagged bird was randomly chosen for the analysis if two or more birds were observed together, using only observations that were at least one h apart. To check the validity of pooling the birds, an individual bird effect was tested using a repeated measures logistic regression model, which found that it did not fit better than the model with individuals pooled (AIC_c for repeated measures model = 380.2, for pooled model = 381.1, where a difference <2 indicates neither model is better than the other, Burnham and Anderson 2002). By using radio-telemetry to locate the flocks, the need to consider detection bias that can affect inferences about presence (Nichols *et al.* 2000) was minimized. The fit of the model was assessed by examining the deviance/degrees of freedom (df) and the Pearson χ^2/df (Hosmer and Lemeshow 1989). Values close to 1.0 indicated good fit. If either measure was >1.0, the larger was used as a scale factor for the covariance matrix, to reduce bias in our standard error estimates.

Behavior. Foraging rates among the three habitat zones were compared using repeated measures ANOVA with first-order temporal autocorrelation (Proc Mixed, SAS Institute, Cary, NC), where the birds were the subjects. Mean % time in different behaviors for each bird within each habitat zone was calculated. The median of these mean activity budgets was compared among habitat zones using multi-response permutation procedure for blocked data (MRBP) in Blossom (Cade and Richards 2001), where the blocks were individual birds. The MEDQ procedure in Blossom was used to produce the multivariate median coordinate (MMC) of the activity budgets within each habitat zone. The MMC is a measure of location that takes into account the non-independence of the response variables (Cade and Richards 2001), which were % time in behavioral categories in this case. If the overall test of a difference among habitat zones was significant, the MRBP analysis was performed on each pair of habitat zones (α = 0.05/3 habitat zones categories = 0.016). MRBP was then used on each behavioral category separately to determine which ones differed among habitat zones (α = 0.05/5 behavior categories = 0.01).

RESULTS

Population Size and Survival

A minimum total population size of eleven birds was estimated in the region of Oregon Inlet. This was the maximum counted in one flock, was the maximum observed on daily counts from 1 January-23 March, and was the count in 11/82 daily surveys. All marked plovers were known to be alive on 4 March. Three were observed on 23 March, the final survey day.

Home Range. The MCP home range size for the population was 20.1 km^2 (Fig. 1). The 95% fixed kernel home range size was 2.2 km^2 (Fig. 1) and included twelve islands and beaches.

Habitat Use and Availability. The Pearson χ^2/df for the discrete choice logistic model was 1.3, indicating some overdispersion, so $\sqrt{1.3}$ was used as a scale factor for the covariance matrix. Probability of the flock being present on the sound islands increased and probability of use of sound and ocean beaches decreased with increasing exposure of the intertidal area of the sound islands (Fig. 2). Piping Plovers were more likely to use sound islands than the ocean beach (Wald's χ^2_1 = 12.7, P< 0.001) and the sound beach (Wald's χ^2_1 = 16.7, P < 0.001), as the Sound Islands became exposed, but were equally likely to use the sound and ocean beaches (Wald's c^2_1 = 1.9, P = 0.164). In the early stages of the falling tide, the sound and ocean beach ITZ emerged while the sound island ITZ remained mostly submerged; as the tide dropped further the sound island ITZ emerged rapidly (Fig. 3).

Behavior. Mean foraging rate was higher in the sound islands than the ocean beach,

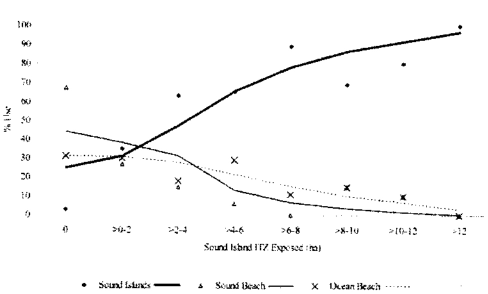

Figure 2. Piping Plover % use (points) and predicted % use from a discrete-choice logistic regression model (lines) of sound islands, sound beach, and ocean beach as a function of estimated area of sound island intertidal zone (ITZ) exposed. Global significance test for model fit: Wald's χ^2_2 = 24.0, P< 0.001, N = 197 observations of tagged birds.

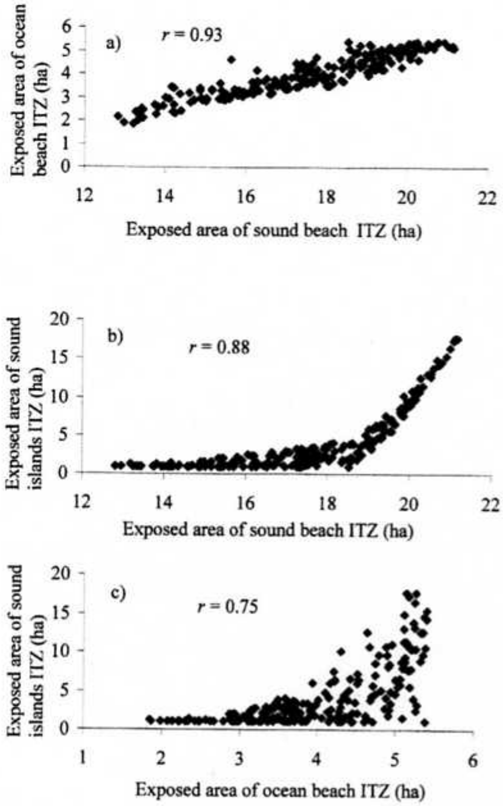

Fig. 3. Correlations (*r*) between predicted exposed area a) sound and ocean beach ITZ, b) sound island and sound beach ITZ, and c) sound island and ocean beach ITZ. Data derived from National Oceanic and Atmospheric Administration tide stations and our tide line contour maps. In the bottom two figures, untransformed data is depicted but the data were log-transformed before correlation calculation, to linearize the relationships.

while foraging rate in the sound beach was similar to that of both of the other habitat zones (Table 1). Plovers spent more time standing (resting/preening/alert) and less time foraging when on ocean beaches than when on the sound beach and the sound islands (Table 2). When on the ocean beach, the flock was more often found on Pea Island south of the inlet (44/46 locations, 96%) than on Bodie Island north of the inlet (2/46 locations, 4%, $\chi^2_1 = 38.3$, $P < 0.001$). The southern roosting area was 1.8 km from the sound beach foraging site and 3.8 km from the most often used sound island, while the northern roosting area was 0.4 km from the sound beach foraging site and 1.8 km from the most often used sound island.

Discussion

Piping Plover habitat use at Oregon Inlet was strongly influenced by tidal stage. When water levels were low, exposing the intertidal areas of the sound islands, plovers preferred sound islands over both the ocean and sound sides of the barrier islands. Piping Plovers in Alabama also preferred sand flat islands at low water levels (Zivojnivich and Baldassarre 1987). Other studies have shown that where wintering shorebird habitat availability depends on the tide, habitat selection is a function of safety at roost sites (Rogers *et al.* 2006), foraging habitat quality (Burger *et al.* 1977; Smith and Nol 2000; van Gils *et al.* 2006), and the distances between roosts and foraging areas (Dias *et al.* 2006; van Gils *et al.* 2006). Although our results are in accord with and extend other findings, replication of our study with more flocks in different parts of the winter range would lend greater support to our inferences.

Wintering birds with small home ranges containing safe roosts and abundant prey should experience low commuting costs, and would be expected to have high survival, as was demonstrated for Piping Plovers wintering in Texas which had 100% survival (mean home range size 12.6 ± 3.3 km^2, Drake *et al.* 2001). Although the home range of Piping Plovers in our study area was only 1.6 times greater than was observed in Texas, and we likewise observed no mortality, the population size in our study area, as estimated by maximum count, was very small. This was despite the fact that foraging rates in our study area were similar to those observed in Texas (range of means within different cover types 7.0-16.2 attempts/min, Zonick 2000) where population sizes are much larger. The low population size at Oregon Inlet may have been a function of our study area being at the edge of the species' range (Dougall *et al.* 2005; Voisin *et al.* 2005). However, anthropogenic factors such as human disturbance that might diminish carrying capacity (Goss-Custard *et al.* 1996) need to be assessed before

Table 1. Foraging rates (attempts/min) of Piping Plovers in the vicinity of Oregon Inlet, North Carolina, December 2005-March 2006.

Habitat Area	Least-square			Lower	Upper
	N[a]	$\bar{x}$	SE	95% CL	95% CL
Ocean beach	5	8.14 B[b]	1.70	4.29	11.99
Sound beach	6	12.45 AB	0.95	10.30	14.61
Sound islands	7	15.57 A	0.66	14.08	17.60
Roadside pool[c]	1	12.37	—	—	—

[a]N = number of birds. Foraging rate of each bird was subsampled several times (range = 1-11 for ocean beach, 1-34 for sound beach, 13-36 for sound islands).

[b]Means with the same capital letter are not significantly different (Repeated measures ANOVA, $F_{2,9}$ = 10.21, P = 0.005, pairwise comparisons calculated with Tukey's test on least-squares means).

[c]One marked bird was observed seven times foraging at an ephemeral pool beside Highway 12 within Pea Island NWR. Not included in ANOVA.

conclusions about ecological correlates of population size at Oregon Inlet can be drawn.

Intense human disturbance in shorebird winter habitat can be functionally equivalent to habitat loss if the disturbance prevents birds from using an area (Goss-Custard *et al.* 1996), and can lead to roost abandonment and local population decline (Burton *et al.* 1996). In our study Piping Plovers commonly roosted on the ocean beach south of Oregon Inlet and rarely roosted on the ocean beach north of the inlet, despite the fact that the southern beach was 2.1 and 4.5 times farther than the two most frequently-used foraging sites. The northern beach was used by ORVs while the southern beach had only limited pedestrian traffic. Controlled management experiments could determine if recreational disturbance drives roost site selection at Oregon Inlet, and if control of disturbance might lead to increased use of the northern beach as a roost area.

The temporal lag in ITZ exposure among sites at Oregon Inlet meant that plovers had foraging opportunities during most of the tidal cycle. Without the sound islands, good foraging habitat might have become scarce at low water levels on some days, because the sound beach ITZ dried out at low tide when the wind was easterly, and dry intertidal zone may not be profitable (Burger *et al.* 1977). The ability of plovers to find food during much of the day can be important for survival of the energetically-demand-

Table 2. Multivariate median activity budgets of Piping Plovers in the vicinity of Oregon Inlet, North Carolina, December 2005-March 2006.

Behavior	Median Proportion of Time Spent[a]			STS[b]	P
	Ocean beach	Sound beach	Sound islands		
Foraging	0.11	0.88	0.82	-7.23	<0.001
Resting/Preening/Alert	0.82	0.07	0.10	-7.40	<0.001
Intraspecific aggression	0.01	0.00	0.00	0.94	0.863
Flying	0.01	0.01	0.02	-0.21	0.340
Other	0.03	0.02	0.05	0.76	0.763
All				-5.24[c]	<0.001

[a]Multivariate median coordinates (MMC) from the MRBP, N = 6 mean activity budgets (one bird was not observed on the sound beach and had to be dropped from MRBP); number of observations from which means were calculated = 158 on sound islands, 74 on sound beach, 64 on ocean beach).

[b]STS = Standardized test statistic (Pearson Type III) of the MRBP analysis.

[c]STS for the overall test of similarity of activity budgets among habitat zones. The MRBP analysis was conducted for each pair of habitat zones (α = 0.016). The sound beach and sound islands did not differ (STS = 1.61. P = 0.942), and the ocean beach was different than both the sound beach (STS = -2.61, P = 0.016) and the sound islands (STS = -3.18, P = 0.009).

ing winter period (Pienkowski 1982). Most of the sound islands used by plovers were artificially created by the USACE, suggesting that constructed sand flats can successfully mitigate habitat loss due to other beach and inlet management activities or recreational disturbance, and may be useful in habitat restoration projects in general. Plovers used engineered islands in which the most recent sand deposition ranged from 28 years to < ten years, suggesting that restoration efforts could have short- and long-term benefits. The roost-foraging site distances we observed suggest that foraging habitat created as far as 6.5 km from a roost could benefit Piping Plovers. The USACE's "Beneficial Uses of Dredged Material" program provides one avenue for creation of wildlife habitat using sediment dredged during navigation projects (Yozzo *et al.* 2004; USACE 2006). In addition, recent collaboration between the Corps and the bird conservation community has significantly raised awareness of the importance for the Corps to consider bird habitat needs during coastal engineering projects (Guilfoyle *et al.* 2006, 2007).

ACKNOWLEDGMENTS

We thank the U.S. Army Engineer Research and Development Center, Environmental Laboratory, Dredging Operations and Environmental Research Program for funding this study. We thank Cape Hatteras National Seashore and S. Maddock of Audubon North Carolina for logistical support. The U.S. Army Corps of Engineers Wilmington District provided aerial photographs and historical information. J. Bercume and P. Doherty performed the field work.

LITERATURE CITED

Burger, J., M. A. Howe, D. C. Hahn and J. Chase. 1977. Effects of tide cycles on habitat partitioning by migrating shorebirds. Auk 94: 743-758.

Burnham, K. P. and D. R. Anderson. 2002. Model Selection and Multimodel Inference: A Practical Information-theoretic Approach, 2nd ed. Springer-Verlag, New York.

Burton, N. H. K., P. R. Evans and M. A. Robinson. 1996. Effects on shorebird numbers of disturbance, the loss of a roost site and its replacement by an artificial island at Hartlepool, Cleveland. Biological Conservation 77: 193-201.

Cade, B. S. and J. D. Richards. 2001. Blossom Statistical Software. U.S. Geological Survey, Midcontinent Ecological Science Center, Fort Collins, CO.

Camfield, F. E. and C. M. Holmes. 1995. Monitoring completed coastal projects. Journal of Performance of Constructed Facilities 9: 169-171.

Defos du Rau, P., C. Barbraud and J. Mondain-Monval. 2005. Incorporating uncertainty into analyses of red-crested pochard habitat selection. Biological Conservation 355-367.

Dias, M. P., J. P. Granadiero, M. Lecoq, C. D. Santos and J. M. Palmierim. 2006. Distance to high-tide roosts constrains the use of foraging areas by dunlins: implications for the management of estuarine wetlands. Biological Conservation 131: 446-452.

Dougall, T. W., P. K. Holland, A. Mee and D. W. Yalden. 2005. Comparative population dynamics of common sandpipers *Actitis hypoleucos*: living at the edge. Bird Study 52: 80-87.

Drake, K. R., J. E. Thompson and K. L. Drake. 2001. Movement, habitat use, and survival of nonbreeding Piping Plovers. Condor 103: 259-267.

Federal Register. 2001. Endangered and threatened wildlife and plants; final determinations of critical habitat for wintering Piping Plovers; final rule. 66: 36038-36143.

Federal Register. 2006. Endangered and threatened wildlife and plants; amended designation of critical habitat for the wintering population of the Piping Plover; proposed rule. Federal Register 71: 33703-33721.

Goss-Custard, J. D., R. T. Clarke, S. E. A. Le V. Dit Durell, R. W. G. Caldow and B. J. Ens. 1996 Population consequences of winter habitat loss in a migratory shorebird. II. Model predictions. Journal of Applied Ecology 32: 337-351.

Guilfoyle, M. P., R. A. Fischer, D. N. Pashley and C. A. Lott (Eds.). 2006. Summary of first regional workshop on dredging, beach nourishment, and birds on the south Atlantic Coast. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. ERDC-EL-TR-06-10.

Guilfoyle, M. P., R. A. Fischer, D. N. Pashley and C. A. Lott (Eds.). 2007. Summary of second regional workshop on dredging, beach nourishment, and birds on the North Atlantic Coast. U.S. Army Engineer Research and Development Center, Vicksburg, Mississippi. In Press.

Haig, S. M. and E. Elliott-Smith. 2004. Piping Plover (*Charadrius melodus*). *in* A. Poole (editor) The Birds of North America Online, Cornell Laboratory of Ornithology, Ithaca, New York, USA http://bna.birds.cornell.edu/BNA/account/Piping_Plover/, accessed 1 September 2006.

Haig, S. M., C. L. Ferland, F. J. Cuthbert, J. Dingledine, J. P. Goossen, A. Hecht and N. Mcphillips. 2005. A complete census and evidence for regional declines in Piping Plovers. Journal of Wildlife Management 69: 60-173.

Hosmer, D. and S. Lemeshow. 1989. Applied Logistic Regression. John Wiley and Sons, New York.

Johnson, C. M. and G. A. Baldassarre. 1988. Aspects of the wintering ecology of Piping Plovers in coastal Alabama. Wilson Bulletin 100: 214-233.

McFadden, D. 1974. Conditional logit analysis of qualitative choice behaviour. Pages 105-142 *in* Frontiers in Econometrics (P. Zarembka, Ed.). Academic Press, New York.

National Oceanographic and Atmospheric Administration [NOAA]. 2005. Tide Tables 2005: East Coast of North and South America. International Marine, Camden, ME.

National Oceanographic and Atmospheric Administration [NOAA]. 2006a. NCDC: Locate weather observation station record. http://lwf.ncdc.noaa.gov/oa/

climate/stationlocator.html, accessed 8 September 2006.

National Oceanographic and Atmospheric Administration [NOAA]. 2006b. Data Retrieval: Oregon Inlet Marina. http://tidesandcurrents.noaa.gov/data_menu.shtml?stn=8652587%20Oregon%20Inlet%20Marina,%20NC&type=Historic%20Tide%20, accessed 14 September 2006.

National Oceanographic and Atmospheric Administration [NOAA]. 2006c. Tide Tables 2006: East Coast of North and South America. International Marine, Camden, ME.

Nicholls, J. L. and G. A. Baldassarre. 1990. Habitat selection and interspecific associations of Piping Plovers along the Atlantic and Gulf Coasts of the United States. Wilson Bulletin 102: 581-590.

Paerl, H. W., J. D. Bales, L. W. Ausley, C. P. Buzzelli, L. B. Crowder, L. A. Elby, J. M. Fear, M. Go, B. L. Peierls, T. L. Richardson and J. S. Ramus. 2001. Ecosystem impacts of three sequential hurricanes (Dennis, Floyd, and Irene) on the United States' Largest Lagoonal Estuary, Pamlico Sound, NC. Proceedings of the National Academy of Sciences of the United States of America 98: 5655-5660.

Pienkowski, M. W. 1982. Diet and energy intake of Grey and Ringer Plovers in the non-breeding season. Journal of Zoology, London 197: 511-549.

Pilkey, O. H., W. J. Neal, S. R. Riggs, C. A. Webb, D. M. Bush, D. F. Pilkey, J. Bullock and B. A. Cowan. 1998. The North Carolina Shore and its Barrier Islands: Restless Ribbons of Sand. Duke University Press, Durham, NC.

Rodgers, A. R., A. P. Carr, L. Smith and J. G. Kie. 2005. HRT: Home Range Tools for ArcGIS. Ontario Ministry of Natural Resources, Centre for Northern Forest Ecosystem Research, Thunder Bay, Ontario.

Rogers, D. I., P. F. Battley, T. Piersma, J. A. Van Gils and K. G. Rogers. 2006 High-tide habitat choice: insights from modelling roost selection by shorebirds around a tropical bay. Animal Behaviour 72: 563-575.

SAS Institute, Inc. 2003. Proc Genmod Details: general linear models theory. SAS Online Documentation. http://support.sas.com/onlinedoc/913/docMainpage.jsp, accessed 9 October 2006.

Seaman, D. E. and R. A. Powell. 1996. An evaluation of the accuracy of kernel density estimators for home range analysis. Ecology 77: 2075-2085.

Silverman, B. W. 1986. Density Estimation for Statistics and Data Analysis. Chapman and Hall, London.

Smith A. C. and E.Nol. 2000. Winter foraging behavior and prey selection of the semipalmated plover in coastal Venezuala. Wilson Bulletin 112: 467-472.

U.S. Army Corps of Engineers [USACE]. 2006. Beneficial uses of dredged material: fish and wildlife habitats. http://el.erdc.usace.army.mil/dots/budm/factsheets.cfm?Topic=Fish%20and%20Wildlife%20Habitats&Id=0, accessed 11 September 2006.

U.S. Fish and Wildlife Service [USFWS]. 1988. Great Lakes and northern Great Plains piping plover recovery plan, Bismarck, ND.

U.S. Fish and Wildlife Service [USFWS]. 1996. Piping Plover *(Charadrius melodus)*, Atlantic Coast Population, Revised Recovery Plan. Hadley, MA.

U.S. Fish and Wildlife Service [USFWS]. 2003. Recovery plan for the Great Lakes Piping Plover (*Charadrius melodus*), Ft. Snelling, Minnesota.

U.S. Fish and Wildlife Service [USFWS]. 2004. 2002-2003 status update: U.S. Atlantic Coast Piping Plover population. Sudbury, MA.

van Gils, J. A., B. Spaans, A. Dekinga and T. Piersma. 2006. Foraging in a tidally structured environment by red knots (*Calidris canutus*): ideal, but not free. Ecology 87: 1189-1202

Voisin, C., J. Godin and A. Fleury. 2005. Status and behaviour of Little Egrets wintering in western France. British Birds 98: 468-475.

Wilkinson, P. M. and M. Spinks. 1994. Winter distribution and habitat utilization of Piping Plovers in South Carolina. Chat 58: 33-37.

Yozzo, D. J., P. Wilber and R. J. Will. 2004. Beneficial uses of dredged material for habitat creation, enhancement, and restoration in New York-New Jersey Harbor. Journal of Environmental Management 73: 39-52.

Zivojnovich, M. J. and G. Baldassarre. 1987. Habitat selection, movements, and numbers of Piping Plovers wintering in coastal Alabama. Project number W-44-12, study number II-A and II-B. Alabama Department of Conservation and Natural Resources, Montgomery, AL.

Zonick, C. A. 2000. The winter ecology of Piping Plovers (*Charadrius melodus*) along the Texas Gulf Coast. Ph.D. Dissertation. University of Missouri, Columbia, MO.